Development of Health-Related Waist Circumference Thresholds Within BMI Categories

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Abstract

ARDERN, CHRIS I., IAN JANSSEN, ROBERT ROSS, AND PETER T. KATZMARZYK. Development of health-related waist circumference thresholds within BMI categories. *Obes Res.* 2004;12:1094–1103.

Objective: To develop and cross-validate waist circumference (WC) thresholds within BMI categories. The utility of the derived values was compared with the single WC thresholds (women, 88 cm; men, 102 cm) recommended by NIH and Health Canada.

Research Methods and Procedures: The sample included adults classified as normal weight (BMI = 18.5 to 24.9), overweight (BMI = 25 to 29.9), obese I (BMI = 30 to 34.9), and obese II+ (BMI ≥ 35) from the Third U.S. National Health and Nutrition Examination Survey (NHANES III; n = 11,968) and the Canadian Heart Health Surveys (CHHS; n = 6286). Receiver operating characteristic curves were used to determine the optimal WC thresholds that predicted high risk of coronary events (top quintile of Framingham scores) within BMI categories using the NHANES III. The BMI-specific WC thresholds were cross-validated using the CHHS.

Results: The optimal WC thresholds increased across BMI categories from 87 to 124 cm in men and from 79 to 115 cm in women. The validation study indicated improved sensitivity and specificity with the BMI-specific WC thresholds compared with the single thresholds.

Discussion: Compared with the recommended WC thresholds, the BMI-specific values improved the identification of health risk. In normal weight, overweight, obese I, and obese II+ patients, WC cut-offs of 90, 100, 110, and 125 cm in men and 80, 90, 105, and 115 cm in women, respectively, can be used to identify those at increased risk.

Key words: anthropometry, Framingham, receiver operating characteristic, U.S. National Health and Nutrition Examination Survey

Introduction

Evidence supporting the use of BMI and waist circumference (WC)[1] measurements in the primary prevention of chronic diseases is mounting. The use of BMI and WC in predicting health risk has been recognized by the U.S. National Heart, Lung, and Blood Institute of the NIH (1) and Health Canada (2). The NIH and Health Canada clinical guidelines for identifying and managing obesity indicate that health risk increases in a graded fashion when moving from normal weight to obese BMI categories and that *within* each BMI category, individuals with high WC values are at a greater health risk than those with normal WC values (1,2). The current guidelines recommend that a single WC threshold (men, 102 cm; women, 88 cm) be used to denote a high WC, regardless of BMI category. These gender-specific thresholds were originally developed in a large sample of white men and women in which a WC of 102 cm in men and 88 cm in women corresponded to a BMI of 30.0 kg/m^2 (3). Thus, these thresholds were not developed based on the relationship between WC and health risk; rather, they were designed to be used in place of BMI as an alternative way to identify those in need of weight management.

Received for review November 24, 2003.
Accepted in final form May 7, 2004.
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[1] Nonstandard abbreviations: WC, waist circumference; NHANES III, Third U.S. National Health and Nutrition Examination Survey; TC, total cholesterol; HDL-C, high-density lipoprotein-cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; CHHS, Canadian Heart Health Surveys; CHDRI, coronary heart disease risk index; ROC, receiver operating characteristic; AUC, area under the curve.

Despite these limitations, it has recently been confirmed that the NIH and Health Canada WC thresholds predict increased health risk within normal weight, overweight, and obese class I BMI categories (4,5). However, at present, there is no evidence to suggest that the current WC thresholds are the *optimal* cut-offs within a given BMI category, particularly given the potential redundancy between the WC and BMI thresholds. Indeed, these cut-offs may not adequately provide further discrimination of health risk, because few normal weight individuals have WC values above the NIH and Health Canada cut-offs, whereas almost all obese individuals have WC values exceeding these thresholds (4,5).

Given that the WC thresholds currently recommended by the NIH and Health Canada were developed based on their relationship with BMI and not health risk and that these cut-offs were not designed to be used in combination with BMI categories, a critical re-evaluation of the utility of using WC cut-offs within BMI categories is warranted. The objectives of this study were to 1) identify the optimal WC threshold *within* each BMI category for predicting those at a high risk of future coronary events and 2) test the use of these thresholds compared with the original thresholds (men, 102 cm; women, 88 cm) advocated by the NIH and Health Canada in a validation sample.

Research Methods and Procedures

Third U.S. National Heath and Nutrition Examination Survey

The Third U.S. National Heath and Nutrition Examination Survey (NHANES III; 1988 to 1994) is a nationally representative cross-sectional survey comprised of a questionnaire and a mobile clinic visit, in which trained personnel collected demographic, health practice, and risk factor information (6). During the clinic visit, body weight was measured to the nearest 0.1 kg using a Toledo self-zeroing electronic digital scale (Mettler-Toledo, Inc., Worthington, OH), and height was measured to the nearest 0.1 cm while the subject stood against a stadiometer. WC was measured at minimal respiration and reported to the nearest 0.1 cm by positioning a flexible anthropometric tape parallel to the floor and immediately above the iliac crest.

Approximately 90 mL of blood was drawn from the antecubital vein after a ≥6-hour fast for the measurement of blood glucose and lipid/lipoprotein values. After centrifuging, the resulting serum was used to enzymatically measure total cholesterol (TC) through a series of peroxidase-coupled reactions. After the precipitation of other lipoproteins, high-density lipoprotein-cholesterol (HDL-C) was assayed in a separate run with a Boehringer Mannheim/Hitachi 714 microcomputer (Indianapolis, IN).

Three blood pressure measurements were obtained and averaged using the first and fifth Korotkoff sounds for systolic (SBP) and diastolic (DBP) blood pressures, respectively. Smoking status (0 = nonsmokers; 1 = regular cigarette, cigar, or pipe smokers) was self-reported in the questionnaire portion of the survey. The presence of diabetes was based on self-reported physician-diagnosed diabetes (other than gestational diabetes) and from fasting blood glucose levels obtained during the clinic visit. The study protocol was approved by the National Center for Health Statistics, and all participants provided written informed consent before participation. The response rate for the clinical examination portion of the survey was 78% of those screened for NHANES III (6).

Canadian Heart Health Surveys

The Canadian Heart Health Surveys (CHHS) database is a compilation of cross-sectional surveys that were conducted within each of the 10 provinces between 1986 and 1992. Participants were identified through provincial medical insurance registries and selected based on a stratified random sampling design, according to six age-by-sex groups. The survey included a home interview and clinical component in which cardiovascular risk factors were assessed.

At the clinic visit, anthropometric variables were measured with subjects barefoot and wearing normal indoor clothing. Weight (in kilograms) was measured using standardized beam balance scales (Continental Scale Works, Chicago, IL), and height (in centimeters) was measured against a walled tape measure while subjects stood on a hard surface. In the case of pregnancy at the clinic visit, self-reported weight from the home interview was used in the calculation of BMI. After a normal expiration, WC was measured at the noticeable narrowing of the waist or midway between the 12th rib and the iliac crest, when the narrowest waist could not be determined (7).

The average of four blood pressure readings was reported, using the first and fifth Korotkoff sounds to identify SBP and DBP, respectively. Eight-hour fasting venous blood samples (~20 mL) were collected in Vacutainer tubes and stored in sodium EDTA before centrifuging. The resulting serum was sent to the Lipid Research Clinic Laboratory (University of Toronto, Ontario, Canada), where TC and HDL-C were assayed (8) in accordance with the National Heart, Lung, and Blood Institute Center for Disease Control Lipid Standardization Program, as described elsewhere (9).

The presence of diabetes (0 = no diabetes, 1 = physician-confirmed diabetes) and smoking status (0 = nonsmokers, 1 = regular cigarette or pipe smokers) was self-reported in the questionnaire portion of the survey. All study protocols were approved after an institutional ethics review, and written informed consent was obtained from all participants. Of those screened for the CHHS, 78% were interviewed, and 69% of those invited attended the clinic (8).

Framingham Algorithm

The Framingham coronary heart disease risk index (CHDRI) (10) is a primary care algorithm that was selected as the health outcome in this study, from which WC thresholds would be developed. The CHDRI is a clinically relevant index of 10-year cardiovascular risk (recognized and unrecognized myocardial infarction and coronary heart disease death) that is computed from age- and sex-specific categories of SBP, TC, HDL-C, and cigarette smoking status (10). Summary risk scores (range in men: -9 to ≥ 17; range in women: -7 to ≥ 25) were subsequently assigned and can be translated into a patient's risk of a 10-year coronary event.

Study 1: WC Threshold Development

The purpose of Study 1 was to develop health-based WC thresholds *within* BMI categories. To this end, data from NHANES III were used. Participants were included in the analysis if they had complete data for the calculation of the Framingham CHDRI, as well as measurements of WC and BMI. The sample was limited to individuals 20 to 65 years of age ($N = 11{,}968$), corresponding with the lower age restriction of the Framingham algorithm (≥ 20 years) and for consistency with current age recommendations (≤ 65 years) for the use of anthropometry in predicting health risk (11). All pregnant women were excluded.

Framingham CHDRI scores were computed and dichotomized (0 = low risk; 1 = high risk) based on the projected risk of adverse coronary events. The high-risk category included participants who were in the top quintile (20%) of the Framingham distribution in NHANES III (men: CHDRI ≥ 13; women: CHDRI ≥ 14), whereas the low-risk group included those in the bottom four quintiles (80%) of the distribution of the entire sample. The Third National Cholesterol Education Program Adult Treatment Panel designates diabetes as a risk equivalent to coronary heart disease; thus, 757 people with diabetes (men: $N = 307$; women: $N = 450$) were also included in the high-risk group. It should be noted that all analyses were also performed without people with diabetes in the high-risk group, and the results were virtually identical.

Receiver operating characteristic (ROC) curves were used to select the optimal anthropometric thresholds that identified individuals at high risk of future coronary events. ROC curves displaying the sensitivity (y axis) and 1 $-$ specificity (x axis) of the diagnostic (WC) were used to predict high risk of coronary events. The area under the curve (AUC) is considered a measure of the use of WC and the trade-off between sensitivity and specificity for predicting high risk coronary events. An AUC of 1.0 would be a perfect predictor of those at high risk, whereas an AUC of 0.5 would be expected to occur by chance alone. The optimal WC threshold was selected to be the point of convergence between sensitivity (correct identification of high-risk participants) and specificity (correct identification of low-risk participants) of each curve. We chose WC values one step above the point at which specificity exceeded sensitivity as the *optimal* threshold, rounded to the nearest centimeter (12).

BMI-specific analyses were conducted to identify the optimal WC threshold *within* normal weight (18 to 24.9 kg/m^2), overweight (25 to 29.9 kg/m^2), obese I (30 to 34.9 kg/m^2), and obese II+ (≥ 35 kg/m^2) categories. All analyses were weighted to be representative of the U.S. population using ROC graphics (version 11.0; SPSS, Chicago, IL) (13), and inferential statistics were conducted in STATA (STATA Inc., College Station, TX) (14) to account for the complex sampling strategy employed in the design of NHANES III.

Study 2: WC Threshold Cross-Validation

Once BMI-specific WC thresholds were obtained using the NHANES III sample, sensitivities and specificities were computed using data from the CHHS. For consistency with the developmental study, the sample was limited to those 20 to 65 years of age within the five CHHS provinces (Ontario, Québec, Manitoba, Saskatchewan, and Alberta; $N = 6286$) that measured WC. Together, these five provinces accounted for 79% of the Canadian population in 1991 (15). To ensure comparability across high-risk groups in the Canadian and U.S. samples, the high-risk group was defined using the same absolute CHDRI criteria as in Study 1 (men: CHDRI ≥ 13; women: CHDRI ≥ 14). An additional 340 people with physician-confirmed diabetes (men: $N = 157$; women: $N = 183$) were included in the high-risk group. It should be noted that the analyses were also performed without including those with diabetes in the high-risk group, and the results were virtually identical.

SAS (SAS Institute, Cary, NC) (16) was used for database management, and all inferential analyses were weighted to be representative of the population using STATA survey procedures (Intercooled 7; STATA) (14) that account for the stratified sampling design used in the CHHS.

Because of discrepancies in the position of WC measurement in NHANES III vs. CHHS, adjustments were made to the BMI-specific WC thresholds before they were tested in the CHHS, based on the results of Wang et al. (17). In their study, there was a statistically significant difference (-1.7 cm) between WC measured immediately above the iliac crest (as in NHANES) and WC measured at the narrowest waist (as in the CHHS) in men. In women, the difference between measurement of WC at the iliac crest and narrowest waist was -4.6 cm. Thus, based on these average differences, WC thresholds were lowered by 2 cm in men and by 5 cm in women before applying them to the CHHS sample to account for systematic measurement differences.

Table 1. Characteristics of participants in the CHHS and NHANES III, weighted to be representative of each population

	NHANES III (1988 to 1994)		CHHS (1986 to 1992)	
	Men (N = 5624)	Women (N = 6344)	Men (N = 3199)	Women (N = 3087)
Age (years)	39.0 ± 12.2	39.6 ± 12.5	39.5 ± 18.3	39.8 ± 11.3
BMI (kg/m^2)	26.6 ± 4.7	26.7 ± 6.3	25.8 ± 10.9	24.9 ± 18.6†
WC (cm)	94.8 ± 13.1	88.7 ± 15.3*	90.8 ± 33.7	78.6 ± 20.3†
SBP (mm Hg)	124 ± 15	118 ± 17*	125 ± 14	117 ± 41†
DBP (mm Hg)	78 ± 11	73 ± 11*	80 ± 15	75 ± 29†
TC (mM)	5.2 ± 1.1	5.2 ± 1.1	5.1 ± 2.0	5.0 ± 1.9†
HDL-C (mM)	1.2 ± 0.3	1.4 ± 0.4*	1.2 ± 0.7	1.5 ± 0.3†
CHDRI score	5 ± 7	6 ± 7*	4 ± 13	5 ± 10†

Values are mean ± SD; independent samples Student's t test.
* $P < 0.05$ between sexes in NHANES III.
† $P < 0.05$ between sexes in CHHS.

Unfortunately, information on race/ethnicity was not collected in the CHHS; thus, only the general WC thresholds from NHANES III were validated. Given that a similar (but higher) proportion of the Canadian population (2001; 86%) (18) consists of "white" or nonminority individuals compared with the United States (1990; 76%) (19), we are confident that the validation can be generalized to the population at large. However, where sample sizes permit, future studies should be aimed at validating the ethnic-specific thresholds.

Results

Table 1 describes the characteristics of study participants in the NHANES III and the CHHS. Cardiovascular risk (CHDRI scores), WC, and BMI measurements were somewhat lower in the CHHS compared with the NHANES III. Compared with Americans, fewer Canadian men (10.6% vs. 21.1%) and women (12.5% vs. 22.5%) were classified at high risk for future coronary events based on the cut-offs employed in this study (men: CHRI ≥ 13; women: CHRI ≥ 14). Independent samples Student's t tests show similar sex differences within the NHANES and CHHS samples, with the exception of BMI and TC.

Study 1

Table 2 presents the *optimal* WC thresholds for predicting future coronary events in the entire NHANES III sample, stratified by sex but not BMI category. The optimal WC thresholds were higher in men (96 cm) than in women (90 cm). The optimal WC thresholds also tended to vary slightly according to age and race/ethnicity.

BMI category-specific analyses indicated that the optimal WC thresholds for future coronary risk differed considerably from the single thresholds proposed by the NIH and Health Canada (men, 102 cm; women, 88 cm). In general, the WC threshold associated with coronary risk increased when moving from the normal weight to class II+ obese BMI categories. In men, WC thresholds of 87, 98, 109, and 124 cm were identified as optimal thresholds across normal weight, overweight, class I obese, and class II+ obese BMI groups, respectively (Table 3). The corresponding values in women were 79, 92, 103, and 115 cm. These thresholds also differed slightly (≤5 cm) according to age and race/ethnicity.

Study 2

Results of the cross-validation study (Table 4) indicate that the greatest improvements in sensitivity between the NIH and Health Canada cut-offs and the BMI-specific WC thresholds were seen in normal weight men and women. The balance between sensitivity and specificity (e.g., having a relatively high sensitivity and a relatively high specificity) improved in all groups. As expected, the sensitivity of the single NIH and Health Canada WC cut-offs increased across BMI categories at the expense of specificity, which consistently decreased. On the other hand, the BMI-specific thresholds had a balanced level of sensitivity and specificity across categories, indicating that the discrimination of health risk was improved.

Another way to compare the performance of the developed thresholds is by considering false-negative (1 − sensitivity) and false-positive (1 − specificity) cases. For example, using the single NIH and Health Canada WC

Table 2. Optimal WC thresholds for predicting participants at high risk of future coronary events in men and women 20 to 65 years of age in NHANES III

	Men				Women			
	AUC	Cut-off	Sensitivity	Specificity	AUC	Cut-off	Sensitivity	Specificity
Overall	0.71	96	69.0	63.0	0.73	90	69.4	66.3
≤40 years	0.70	94	63.6	63.1	0.74	88	72.2	66.5
>40 years	0.63	99	60.7	57.6	0.67	92	64.0	63.3
White	0.71	97	67.8	62.6	0.74	89	70.5	67.7
Black	0.72	94	70.0	66.0	0.69	95	63.4	63.3
Hispanic	0.74	96	67.9	65.8	0.71	94	65.9	63.6
Other	0.72	91	77.0	60.2	0.73	89	67.6	66.2

Cut-off, waist circumference (cm) threshold at which there is an optimal balance of sensitivity and specificity; sensitivity, true positive/(true positive + false negative); specificity, true negative/(true negative + false positive); other, all other race/ethnicities not classified into white, black, or Hispanic.

thresholds, ~97% of normal weight men and women at high risk for future coronary events would be misclassified. This is substantial, given that only 34% of normal weight men and 40.8% of normal weight women would be falsely classified as low risk according to the BMI-specific thresholds. Similarly, the number of false-positive cases drops dramatically when BMI-specific thresholds are used for obese I (men: 75.9% vs. 40.9%; women: 91.1% vs. 27.6%) and obese II+ (men: 90.3% vs. 11.7%; women: 98.2% vs. 28.3%) categories instead of the NIH and Health Canada thresholds. Using category-specific WC cut-offs means that more than twice the number of high-risk men (283 vs. 133) and slightly more women (215 vs. 196) would be correctly identified.

Discussion

The results of this study indicate that the current NIH and Health Canada recommendations to use a single WC threshold across all BMI categories are insufficient to identify those at increased health risk. Independent of sex, the use of BMI category-specific WC thresholds improved the identification of individuals at a high risk of future coronary events. To simplify their use in clinical settings, the WC thresholds determined in this study have been rounded and are presented in Table 5. These thresholds can be used as a simple clinical tool for the screening of future coronary risk based on WC measurements *within* specific BMI categories. Although these WC thresholds are reasonable guidelines for the identification of increased health risk within specific BMI categories, they should be considered preliminary until further studies confirm our findings in other representative samples.

The BMI-specific WC thresholds shift the prevalence of individuals with a high WC, within a given BMI category, compared with the single NIH and Health Canada WC threshold (Figure 1). The high sensitivity of the single NIH and Health Canada WC threshold within the normal weight BMI category can be explained by the low prevalence of normal weight individuals with WC levels above the proposed cut-off, whereas the high specificity in the obese II+ category is explained by the fact that almost all individuals in that category have a high WC. Although the resulting classification is impressive, the clinical use of the single thresholds is questionable. In contrast, the use of BMI-specific thresholds provides a more balanced prevalence of participants with a high WC across the BMI categories.

A previous ROC analysis in the CHHS (20) showed that WC thresholds of 94 and 80 cm in men and women, respectively, provided the best compromise between sensitivity and specificity for the prediction of a cluster of three or more cardiovascular risk factors (hypertension, dyslipidemia, diabetes, smoking, and sedentary lifestyle). After adjustment for differences in the site of WC measurement (men, +2 cm; women, +5 cm), the WC thresholds reported by Dobbelsteyn et al. (20) are identical to those reported here in men (96 cm), but differ by 5 cm in women (85 vs. 90 cm). In a sample of white men and women from NHANES III, Zhu et al. (21) reported that the presence of at least one obesity-related risk factor (low HDL-C, high blood pressure, high blood glucose, or high low-density lipoproteins) is predicted by WC thresholds of 98 cm in men and 87 cm in women. These WC values are comparable with the values we determined for prediction of future coronary risk in white men (97 cm) and women (89 cm).

Few studies have reported ethnic- or race-specific WC thresholds. Data from the Atherosclerosis Risk in Communities study of incident diabetes in middle-aged adults (40 to 65 years of age) provide the most relevant comparisons

Table 3. BMI-specific WC thresholds that identify participants at high risk of future coronary events in men and women 20 to 65 years of age in NHANES III

	Normal weight				Overweight				Obese I				Obese II+			
	AUC	Cut-off	Sensitivity	Specificity	AUC	Cut-off	Sensitivity	Specificity	AUC	Cut-off	Sensitivity	Specificity	AUC	Cut-off	Sensitivity	Specificity
Men																
Overall	0.75	87	71.9	66.3	0.69	98	62.6	62.1	0.64	109	61.0	56.4	0.58	124	63.5	52.7
≤40 years	0.70	84	67.8	57.9	0.66	96	65.4	57.0	0.62	108	60.8	60.5	0.59	125	75.0	60.6
>40 years	0.65	89	64.0	56.1	0.60	99	61.4	49.8	0.53	110	55.9	46.5	0.53	125	54.2	53.8
White	0.74	88	69.6	65.7	0.67	98	64.7	57.0	0.64	109	63.3	53.1	0.57	125	61.7	54.5
Black	0.71	82	69.7	66.0	0.73	95	72.3	60.9	0.68	106	71.5	60.8	0.53	122	52.5	48.8
Hispanic	0.80	86	80.1	69.7	0.71	96	66.3	62.1	0.65	108	61.0	60.4	0.55	120	59.5	48.8
Other	0.81	87	81.2	73.6	0.75	96	68.6	66.1	0.52	108	84.2	43.1	0.17	109	100	0.3
Women																
Overall	0.72	79	70.0	63.2	0.68	92	64.9	61.3	0.66	103	63.7	58.3	0.58	115	59.7	51.7
≤40 years	0.67	77	72.3	59.1	0.60	90	56.8	55.1	0.57	101	56.7	53.5	0.59	115	54.7	53.8
>40 years	0.64	81	62.4	56.1	0.64	93	61.7	57.1	0.63	104	63.1	59.6	0.54	116	54.6	52.2
White	0.73	79	70.4	65.5	0.67	92	64.3	60.6	0.63	104	62.5	60.2	0.55	115	55.9	49.5
Black	0.72	80	67.4	66.6	0.69	93	64.9	65.5	0.68	103	68.5	61.3	0.61	116	67.9	53.1
Hispanic	0.73	81	67.9	67.5	0.69	92	68.9	60.6	0.68	101	67.9	60.0	0.63	114	60.1	55.9
Other	0.66	80	63.0	57.8	0.70	90	73.9	64.1	0.80	100	82.7	65.7	0.74	112	84.5	69.1

Cut-off, waist circumference (cm) threshold at which there is an optimal balance of sensitivity and specificity; sensitivity, true positive/(true positive + false negative); specificity, true negative/(true negative + false positive); other, all other race/ethnicities not classified into white, black, or Hispanic.

Table 4. Capacity of BMI-specific and single (men, 102 cm; women, 88 cm) NIH and Health Canada WC thresholds to predict participants at high risk for future coronary events in men and women 20 to 65 years of age from the CHHS

	Prevalence of high risk*	NIH/Health Canada threshold		BMI-specific threshold	
		Sensitivity	Specificity	Sensitivity	Specificity
Men					
Normal weight	6.6	3.3	100.0	66.0	64.3
Overweight	16.5	21.7	39.9	69.5	61.2
Obese I	24.0	77.5	24.1	59.2	59.1
Obese II+	24.2	100.0	9.7	45.6	88.3
Overall	18.5	30.9	79.0	66.0	62.9
Women					
Normal weight	11.2	3.7	96.2	59.2	65.2
Overweight	16.5	52.6	54.0	39.4	67.0
Obese I	31.0	96.3	8.9	30.1	72.4
Obese II+	21.8	99.4	1.8	54.7	71.7
Overall	13.3	42.9	64.8	47.1	66.5

* Prevalence of participants at high risk of future coronary events, within BMI categories [normal weight (18.5 to 24.9 kg/m^2); overweight (25 to 29.9 kg/m^2); obese I (30 to 34.9 kg/m^2) and obese II+ (≥35 kg/m^2)].
See Table 2 for abbreviations.

(22). In that study, diabetes was best predicted by a WC of 101 cm in black men, whereas in white men, the optimal cut-off was 95 cm. In black and white women, WC values of 99 and 101 cm, respectively, were the optimal cut-offs. We also report similar WC thresholds from our analysis (Table 2) in Hispanics to the WC cut-offs reported in the Mexican National Health Survey 2000 (20 to 69 years of age) for identifying diabetes (men: WC = 95 cm, women: WC = 97 cm,) and hypertension (men: WC = 94 cm, women: WC = 94 cm) (23).

In this study, the WC thresholds were lower in younger (20 to 40 years of age) vs. older (41 to 65 years of age) participants, with a 5-cm difference in men and a 4-cm difference in women (Table 2). These findings are supported by the study of Dobbelsteyn et al. (20), who also reported higher WC cut-points with increasing age for the prediction of risk factor clustering. Once stratified by BMI categories, the age differences persisted for normal weight and overweight men and women but were attenuated in the obese II+ category (Table 3). The adjustment of WC thresholds for a patient's age has been recommended (24); however, the clinical significance of such an adjustment within BMI categories has not yet been established, given the small sample sizes that would result from further subset

Table 5. Clinical guide for the measurement of WC within BMI categories in the assessment of health risk*

	BMI Category (kg/m^2)			
Waist circumference (cm)†	Normal weight (18.5 to 24.9 kg/m^2)	Overweight (25 to 29.9 kg/m^2)	Obese I (30 to 34.9 kg/m^2)	Obese II and III (≥35 kg/m^2)
Men	≥90	≥100	≥110	≥125
Women	≥80	≥90	≥105	≥115

* High risk of future coronary events (based on 10-year risk of coronary events or the presence of diabetes).
† WC threshold indicating increased health risk within each BMI category.

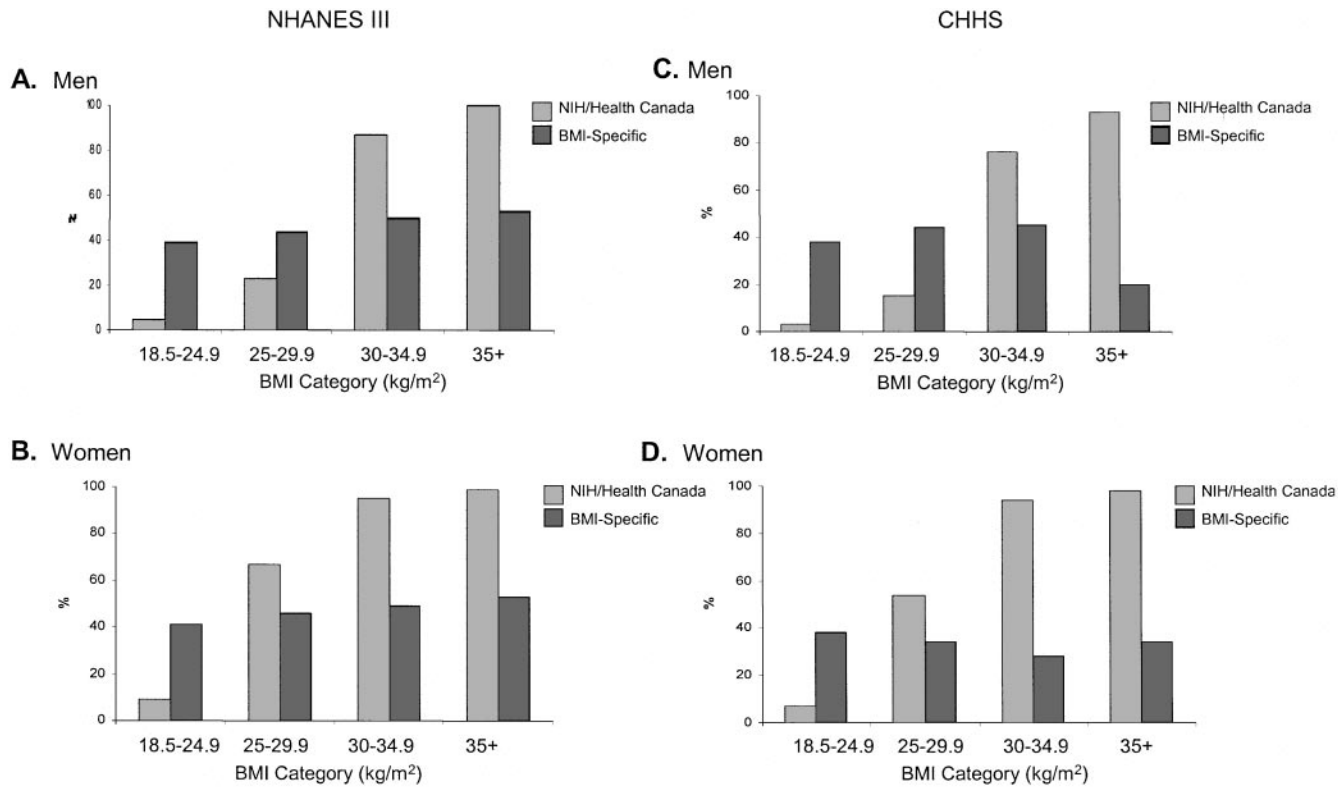

Figure 1: Prevalence of high WC within BMI categories. Data are from NHANES III for (A) men and (B) women and the CHHS for (C) men and (D) women. The NIH and Health Canada WC thresholds (men: 102 cm; women: 88 cm) and BMI-specific WC thresholds (men: 87, 98, 109, and 124 cm; women: 79, 92, 103, and 115 cm) were compared across BMI categories [normal weight (18.5 to 24.9 kg/m^2), overweight (25 to 29.9 kg/m^2), obese I (30 to 34.9 kg/m^2), and obese II+ ($\geq$35 kg/m^2), respectively].

analyses. To accommodate age-related changes in body fat distribution and cardiovascular risk, Dobbelsteyn et al. (20) recommended adjusting WC thresholds according to 10-year age categories. When stratified by age categories (18 to 24; 25 to 34; 35 to 39; 40 to 54; 55 to 64; and 65 to 74 years), the optimal WC cut-off ranged from 88 to 99 and 72 to 85 cm in men and women, respectively.

There were consistent sex differences in the optimal WC thresholds across BMI categories. For a given level of BMI, men had a higher WC threshold than women. However, these values should not be used to interpret gender differences in the absolute risk of heart disease attributable to a high WC. The optimal thresholds were obtained in sex-specific analyses comparing participants at low and high risk of future coronary events; thus, the thresholds represent the best point of discrimination of *relative* risk rather than *absolute* risk. For example, the Framingham CHDRI thresholds used were $\geq$13 in men and $\geq$14 in women, which correspond to 10-year absolute risks of coronary heart disease of 12% for men and 2% for women (10).

Figure 2 presents the weighted mean Framingham CHDRI scores across the BMI-specific waist circumference categories in the NHANES III sample. As expected, the CHDRI was lowest in the normal weight/low WC groups and increased with the level of obesity. Furthermore, those with a high WC had higher scores than those with a low WC within each BMI category. The patterns were similar in men and women and show that the proposed WC thresholds provide further discrimination of health risk beyond that of the BMI categories alone, particularly in normal weight and overweight individuals.

There are several strengths and limitations to this study. A major strength is the use of large representative population samples from Canada and the United States, which ensures that the results can be generalized. The analyses are based on cross-sectional data; therefore, cause-and-effect conclusions cannot be inferred regarding the relation between WC and health risk. However, the use of the Framingham risk score for predicting 10-year risk of coronary events is a clinical tool that is strongly associated with the risk of future coronary events (25). Because the Framingham algorithm was derived using a predominately white sample, the CHDRI may not be entirely appropriate to predict 10-year risk in other ethnic groups (26,27).

At this time, comparisons among studies and temporal analyses of changes in WC are hampered by methodological

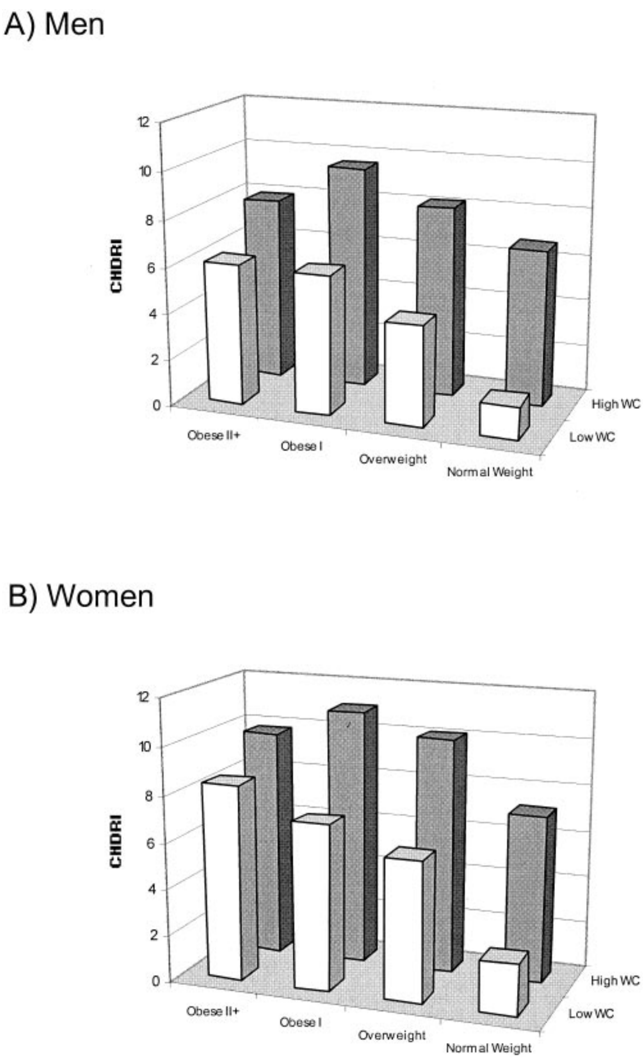

Figure 2: Framingham CHDRI scores in low and high BMI-specific WC categories across normal weight, overweight, obese class I, and obese class II+ categories in (A) men and (B) women in the U.S. NHANES III.

concerns, including the training of technicians, the use of different equipment, and the site of WC measurement. The adjustment of WC thresholds according to the site of measurement in our cross-validation study was based on the results of Wang et al. (17), who conducted three same-day measurements at four common WC sites in a sample of 93 individuals (intraclass correlation > 0.99). The magnitude of the differences across sites highlights the need for standardized guidelines for WC measurement.

In summary, our findings provide strong support for the use of specific WC thresholds within different BMI categories for identifying increased health risk. In comparison, the currently recommended NIH and Health Canada WC thresholds are inadequate to discriminate health risk within all BMI categories.

Acknowledgments

This research was supported by the Heart and Stroke Foundation of Ontario (T4946). C. Ardern is supported by a fellowship from the Heart and Stroke Foundation of Canada and the Canadian Institutes of Health Research (Institutes of Gender and Health). I. Janssen is supported by a postdoctoral fellowship from the Canadian Institutes of Health Research. The analyses are, in part, based on the Canadian Heart Health Database 1986 to 1992, which contains anonymized data collected in a coordinated series of heart health surveys carried out in the 10 provinces of Canada between 1986 and 1992. The database was constructed by the Conference of Primary Investigators of provincial heart health programs from survey questions and clinical measures that were common to all surveys. All computation of these microdata was prepared by C. Ardern, and the responsibility of the use and interpretation of these data are entirely that of the authors.

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