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Familial Risk of Obesity and Central Adipose Tissue Distribution in the General Canadian Population

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The purpose of this study was to determine the familial risk of obesity and of an android profile of fat distribution in the general Canadian population. A sample of 15,245 participants aged 7–69 years from 6,377 households from the Canada Fitness Survey of 1981 was used. The body mass index (BMI), sum of five skinfolds (SF5), ratio of trunk-to-extremity skinfolds, adjusted for SF5, and waist circumference, adjusted for BMI were used as indicators of obesity and central fat distribution. Age- and sex-standardized risk ratios (SRRs) for spouses and first-degree relatives of obese probands indicate that there is significant familial risk for obesity and an android fat distribution in the Canadian population. SRRs for spouses and first-degree relatives of probands exceeding the 99th percentile are 3.01 and 4.96 for BMI, 7.36 and 4.15 for SF5, 1.41 and 3.18 for ratio of trunk-to-extremity skinfolds, adjusted for SF5, and 1.02 and 2.18 for waist circumference, adjusted for BMI, respectively. The SRRs are smaller for less extreme obesity (lower percentile cutoffs) than for more extreme obesity. The SRRs are greater in spouses than in first-degree relatives for SF5; however, the risk for BMI and an android fat distribution was greater among first-degree relatives than among spouses, suggesting a greater role for genetic factors. *Am J Epidemiol* 1999;149:933–42.

family; genetics; obesity, prevalence; risk

There is substantial familial resemblance in obesity and obesity-related phenotypes. However, the relative roles of genetic versus environmental factors in explaining the observed familial resemblance remain less clear. Estimates of the contribution of genetic factors to the variability in the body mass index (BMI), for example, range from a high of 90 percent (1) to a low of about 5 percent (2). The most probable values for the contribution of additive genetic effects range from 25 to 40 percent (3), while the broad-sense heritability (additive and nonadditive factors) may be as high as 70 percent (4). Heritability estimates provide an index of the contribution of genetic factors relative to the total variation in a trait. A related concept to heritability is that of familial risk. For discrete traits, familial risk can be expressed as Risch's lambda (λ_R), which is defined as $[P(A|R)]/[P(A)]$, where $P(A)$ is the general population prevalence, and $P(A|R)$ is the prevalence among relatives of degree R of a proband who is affected (5, 6). This concept has been extended to cover the case of quantitative traits through the introduction of generalized relative risk ratios (7). These are defined as $\lambda_R(h,l) = [P_R(l|h)/P(l)]$, where $P(l)$ is the probability that a randomly selected person in the general population has a trait value in the lth segment of the trait distribution, and $P_R(l|h)$ is the probability that a person has a trait value in the lth segment, given that a relative of type R has a trait value in the hth segment. For obesity and obesity-related phenotypes, this could be done by the use of percentiles or other biologically meaningful cutoffs (6, 8, 9).

Allison et al. (6) have presented λ_R values for BMI for several populations, including the Second National Health and Nutrition Examination Survey (NHANES II) sample from the United States. In general, the value of λ_R increases as the percentile cutoff for defining obesity is increased from the 50th to the 95th percentile. Likewise, the risk decreases as relatives are farther removed from an obese proband. Ziegler et al. (8) projected λ_R values for siblings, offspring, and monozygotic twins by using segregation analysis. Similar trends were seen in their projected values; however, at low cutoffs, their λ_R values were considerably lower than those presented by Allison et al. (6).

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Abbreviations: BMI, body mass index; CFS, Canada Fitness Survey; NHANES II, Second National Health and Nutrition Examination Survey; SF5, sum of five skinfolds; SRR, standardized risk ratio; TER, trunk-to-extremity skinfolds; TER_{adj}, trunk-to-extremity skinfolds, adjusted for SF5; $WAIST_{adj}$, waist circumference, adjusted for BMI; WHR, waist-to-hip circumference ratio.

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In addition to estimating λ_R values for the general population, there has been a focus on assessing the risk of obesity among family members of morbidly obese individuals, who are particularly prone to medical complications. Lee et al. (9) reported that parents and siblings of 840 extremely obese female probands (BMI ≥ 40) were (greater than) five times more likely than the general population to be obese. Similarly, 221 morbidly obese probands (45.5 kg over ideal body mass) had about eight times the risk of having a family member who was also morbidly obese than did an age-matched sample from the general population (10).

As of yet, estimates of the familial risk of obesity have been limited to measures related to body mass or the BMI and to biologically related individuals. The purpose of this study is to extend these analyses to indicators of subcutaneous adiposity and adipose tissue distribution. In addition, our study challenges the assumption that the familial risk for obesity is purely due to genetic transmission by including spouses in the analysis. Familial risk ratios for obesity have not been presented for the Canadian population. To this end, data from the Canada Fitness Survey (CFS) in 1981 were used to assess the degree of familial risk for obesity and an android distribution of adipose tissue.

MATERIALS AND METHODS

Sample

The 1981 CFS was composed of 13,440 households chosen by Statistics Canada to be representative of the general Canadian population (11). Of the total sample, 88 percent (11,884 households) participated. Within the participating households, while 23,400 people agreed to take part in one form or another, obesity and obesity-related measurements were available on 15,818 people. The family relationships among participants were available for 6,377 households with a family size greater than one. A reference individual was identified as the person within each household first contacted by the CFS staff. Within the context of this study, probands were defined as reference individuals who exceeded a given percentile cutoff. The final sample considered here includes 15,245 participants and consists of 6,377 referents, 3,395 spouses, and 5,473 first-degree relatives (mothers, fathers, sons, daughters, and siblings) of the referents.

Measures

Anthropometric dimensions were taken following the procedures of the CFS (12). Stature was measured to the nearest millimeter by using a Harpenden tape (British Indicators, Ltd., Burgess Hill, West Sussex, England) while body mass was measured to the nearest 0.1 kg using a standing beam balance scale (Seca Corporation, Columbia, Maryland). Circumference of the waist was measured to the nearest millimeter using an anthropometric tape. Skinfolds at the triceps, biceps, medial calf, subscapular, and suprailiac sites were measured to the nearest 0.2 mm using a Harpenden skinfold caliper (British Indicators, Ltd.). All skinfold measurements were made on the right side of the body.

Several indices were derived from the anthropometric measurements. The BMI (kg/m^2) was calculated. The five skinfold measures were summed (SF5) to provide a single measure of subcutaneous adiposity. The ratio of trunk-to-extremity skinfolds (TER) [TER = (subscapular + suprailiac)/(triceps + biceps + medial calf)] was calculated to provide an index of subcutaneous truncal adipose tissue distribution. This study uses two ratio indices (BMI and TER) as indicators of fatness and relative adipose tissue distribution. Although commonly used indices in obesity research, ratios have several limitations that should be kept in mind, including difficulties in their interpretation (13). However, given the common use of these indices in studies of the epidemiology of obesity, they were retained as indicators of obesity and relative adipose tissue distribution for this investigation. Table 1 provides the sample sizes, means, and standard deviations, by age and sex, for the indicators of obesity and adipose tissue distribution in the CFS.

Given that TER and waist circumference are correlated with overall fatness in this sample (see results below), the TER and waist circumference were adjusted for fatness using regression procedures. TER was adjusted by regressing it on SF5, $SF5^3$, and $SF5^3$ in a forward stepwise manner, retaining terms significant at the 5 percent level. Likewise, waist circumference was adjusted for the BMI by regressing out the significant effects of BMI, BMI^2, and BMI^3. The residuals were added to the grand mean, and these adjusted values (TER_{adj} and $WAIST_{adj}$) were retained for further analysis as indicators of central adiposity, adjusted for overall level of fatness.

The fatness adjustments were made separately by sex in participants aged 7–19 and 20–69 years. In males aged 7–19 years, SF5 and $SF5^3$ accounted for 7.1 percent of the variation in TER, while SF5 and $SF5^2$ accounted for 8.1 percent of the variation in TER among adult males. Among females aged 7–19 years, $SF5^2$ and $SF5^3$ accounted for 16.7 percent of the variation in TER, while a third-order cubic polynomial on SF5 accounted for 8.9 percent of the variability in TER among adult females. A third-order cubic polynomial on BMI accounted for 81.5 percent of the variance in waist circumference in males aged 7–19 years, while BMI^2 and BMI^3 accounted for 76.8 percent of the variance in

TABLE 1. Sample sizes, means, and standard deviations for BMI,* SF5,* TER,* and waist circumference in males and females in the Canada Fitness Survey, 1981

Age (years)†	BMI (kg/m²)			SF5 (mm)			TER (mm/mm)			Waist circumference (cm)		
	No.	Mean	(SD)*	No.	Mean	(SD)	No.	Mean	(SD)	No.	Mean	(SD)
Males												
7–8	402	16.5	(2.3)	401	34.9	(14.6)	401	0.52	(0.11)	402	57.3	(5.0)
9–10	436	17.3	(2.2)	433	39.0	(17.8)	433	0.57	(0.15)	436	60.9	(5.9)
11–12	430	18.2	(2.5)	431	43.8	(20.7)	431	0.61	(0.15)	432	64.7	(6.3)
13–14	424	19.6	(2.9)	414	42.2	(19.4)	414	0.70	(0.17)	425	69.4	(7.1)
15–16	401	21.1	(3.0)	399	42.2	(19.4)	399	0.80	(0.20)	400	74.0	(7.2)
17–19	508	22.3	(3.2)	509	43.6	(18.6)	509	0.97	(0.25)	510	77.2	(7.0)
20–29	1,639	24.0	(3.2)	1,622	50.8	(21.5)	1,622	1.20	(0.32)	1,640	82.9	(8.2)
30–39	1,408	25.2	(3.4)	1,386	56.9	(21.8)	1,386	1.36	(0.37)	1,405	87.5	(9.1)
40–49	889	26.2	(3.5)	873	59.9	(20.1)	873	1.38	(0.36)	888	91.4	(9.5)
50–59	648	26.2	(3.6)	615	57.1	(19.4)	615	1.37	(0.36)	636	92.9	(9.7)
60–69	455	26.4	(3.9)	431	57.3	(19.4)	431	1.41	(0.38)	445	94.9	(10.0)
Females												
7–8	366	16.5	(2.2)	359	43.1	(16.7)	359	0.54	(0.15)	366	55.8	(5.3)
9–10	392	17.5	(2.7)	387	50.5	(20.8)	387	0.57	(0.15)	392	59.6	(6.7)
11–12	431	18.4	(3.1)	426	51.6	(20.6)	426	0.60	(0.16)	431	62.4	(6.6)
13–14	398	20.4	(3.0)	392	60.0	(22.5)	392	0.63	(0.16)	397	67.0	(6.9)
15–16	401	21.1	(3.0)	396	62.2	(21.9)	396	0.63	(0.15)	404	68.0	(6.5)
17–19	504	21.7	(3.2)	488	66.5	(24.3)	488	0.66	(0.17)	502	69.8	(7.6)
20–29	1,772	22.0	(3.3)	1,730	65.1	(24.1)	1,730	0.66	(0.19)	1,764	70.6	(7.5)
30–39	1,566	23.5	(4.0)	1,500	74.4	(28.3)	1,499	0.67	(0.21)	1,565	74.8	(9.6)
40–49	997	24.7	(4.5)	931	82.0	(30.6)	929	0.68	(0.21)	983	77.6	(10.5)
50–59	817	25.8	(4.5)	747	88.6	(29.3)	747	0.70	(0.22)	796	80.6	(10.5)
60–69	534	26.1	(4.4)	454	87.2	(28.6)	453	0.74	(0.24)	518	82.1	(10.0)

* BMI, body mass index; SF5, sum of five skinfolds (biceps + triceps + subscapular + suprailiac + medial calf); TER, trunk-to-extremity skinfold ratio; SD, standard deviation.

† Age refers to age at last birthday (i.e., 7.00–7.99 years).

males aged 20–69 years. BMI^2 and BMI^3 accounted for 79 percent of the variance in waist circumference in both females aged 7–19 and 20–69 years.

Statistical analyses

The sample was divided into 2-year age groups in children (with the exception of those aged 17–19 years) and into decades in adulthood to preserve sample sizes. Six percentile cutoffs were established for defining the upper distribution of the obesity and obesity-related phenotypes (table 2). For children and youth 7–19 years, age- and sex-specific 50th, 75th, 85th, 95th, 97th, and 99th percentiles were determined for the BMI, SF5, TER_{adj}, and $WAIST_{adj}$ and were used as cutoffs. For adults, sex-specific percentiles were determined for those aged 20–29 years and were applied as the cutoffs across all adult age groups.

The standardized risk ratio (SRR) for a group of first-degree relatives or spouses was calculated by dividing the age- and sex-standardized prevalence rate among the relatives or spouses by the age- and sex-standardized general population prevalence rate. The prevalence rate for each group of relatives or spouses was standardized for age and sex by weighting each age and sex group prevalence by the number of participants in the group relative to the total sample and adding (22 groups total). The prevalence rate for the general population was standardized for each ratio by using the same weights as in the group of first-degree relatives or spouses, to ensure a similar age and sex profile in both samples.

The 95 percent confidence intervals (CI) around the SRRs were constructed using the following equation (14):

$$95\% \text{ confidence interval} = \exp\left[\ln(\text{SRR}) \pm 1.96 \times \text{standard deviation}\left[\ln(\text{SRR})\right]\right],$$

where

$$\text{standard deviation}\left[\ln(\text{SRR})\right] = \sqrt{\frac{\text{total } n \text{ not above cutoff}}{n \text{ above cutoff} \times \text{total } n} + \frac{n \text{ relatives not above cutoff}}{n \text{ relatives above cutoff} \times \text{total } n \text{ relatives}}}$$

TABLE 2. Percentile cutoffs for BMI,* SF5,* TER_{adj},* and $WAIST_{adj}$* for the Canada Fitness Survey, 1981

	Age (years)†													
	Males							Females						
	7–8	9–10	11–12	13–14	15–16	17–19	20–29	7–8	9–10	11–12	13–14	15–16	17–19	20–29
BMI														
99	23.5	25.5	25.7	28.5	32.4	32.9	33.5	24.0	28.0	27.9	30.3	31.8	32.6	33.1
97	21.5	22.6	24.1	25.9	27.6	29.4	30.9	22.0	24.2	25.3	27.1	27.1	29.3	29.6
95	20.0	21.7	23.2	24.9	26.8	27.3	29.9	20.6	22.1	23.9	25.8	25.9	27.9	28.4
85	18.0	19.3	20.3	22.2	23.5	24.8	27.3	18.4	20.2	21.2	23.2	23.8	24.8	24.9
75	17.1	18.1	19.3	20.9	22.5	23.7	25.9	17.5	18.9	19.6	21.9	22.5	23.1	23.3
50	16.1	16.8	17.8	19.2	20.7	21.9	23.6	16.0	17.0	17.7	19.9	20.7	21.2	21.4
SF5														
99	89.9	99.5	123.1	114.3	123.2	104.1	118.0	100.8	120.4	117.9	143.7	125.9	146.7	141.2
97	74.5	90.1	100.0	92.4	99.6	93.5	102.2	88.2	96.0	104.0	112.8	113.6	124.7	124.9
95	64.4	76.7	87.8	84.6	78.1	85.5	94.1	78.8	91.2	91.5	98.6	103.1	114.7	113.3
85	43.9	52.3	60.0	55.8	55.9	60.8	72.8	59.1	69.2	73.5	82.2	83.1	89.2	86.9
75	37.9	43.7	50.8	47.1	47.6	49.1	62.6	47.9	59.1	60.2	72.0	73.7	77.4	76.4
50	31.0	33.5	37.7	36.4	36.1	37.9	45.8	38.6	45.7	45.3	56.1	57.7	61.2	59.9
TER_{adj}														
99	0.84	0.96	0.99	1.15	1.29	1.68	2.03	0.92	0.93	1.03	1.10	1.03	1.06	1.25
97	0.74	0.84	0.90	1.02	1.14	1.45	1.87	0.82	0.88	0.97	0.97	0.94	0.97	1.11
95	0.71	0.80	0.84	0.99	1.12	1.40	1.76	0.78	0.83	0.88	0.87	0.88	0.92	1.03
85	0.66	0.69	0.75	0.85	0.99	1.18	1.54	0.68	0.71	0.75	0.78	0.78	0.80	0.85
75	0.61	0.64	0.70	0.79	0.91	1.10	1.41	0.65	0.66	0.69	0.71	0.70	0.73	0.78
50	0.55	0.56	0.59	0.68	0.79	0.95	1.21	0.57	0.57	0.59	0.60	0.61	0.62	0.66
$WAIST_{adj}$														
99	71.1	77.1	74.6	77.8	77.3	80.4	97.1	73.8	74.9	72.9	73.7	72.5	73.6	83.9
97	70.2	72.7	72.9	73.6	75.6	75.3	93.6	67.2	70.0	71.1	71.4	71.6	71.2	81.8
95	69.8	71.3	72.0	72.9	74.4	74.5	91.8	66.1	68.7	69.9	70.7	70.4	70.3	80.8
85	68.0	69.2	70.2	71.6	72.5	72.5	89.4	64.7	66.3	67.5	68.1	68.3	68.2	78.1
75	67.0	68.1	69.4	70.5	71.2	71.3	88.1	63.7	65.2	66.4	66.9	66.9	67.0	76.8
50	65.0	66.3	67.5	68.2	69.1	69.3	85.8	62.0	63.7	64.7	64.8	64.5	64.7	74.4

* BMI, body mass index; SF5, sum of five skinfolds (biceps + triceps + subscapular + suprailiac + medial calf); TER_{adj}, trunk-to-extremity skinfold ratio adjusted for SF5; $WAIST_{adj}$, waist circumference adjusted for BMI.

† Age refers to age at last birthday (i.e., 7.00–7.99 years)

RESULTS

In general, the standardized risks of obesity are similar among spouses and first-degree relatives of obese probands. Table 3 presents the proportions of spouses and first-degree relatives who exceed the same cutoff as the proband, along with the associated SRRs. Figures 1–4 display the SRRs of spouses and first-degree relatives for each percentile cutoff, within each cutoff for the proband. In other words, the figures show the risk of exceeding the 50th, 75th, 85th, 95th, 97th, or 99th percentile, given that a spouse or first-degree relative also exceeds one of these cutoffs. The group in the back corner illustrates the risk of exceeding the 99th percentile among relatives of probands who also exceed the 99th percentile.

For both BMI and SF5, the SRRs decrease with decreasing cutoff values in both spouses and first-degree relatives of obese probands. For families of probands exceeding the 50th percentile of the BMI and SF5, the risk is essentially the same as in the general population (approximately 1.0). For spouses and first-degree relatives of the probands exceeding the 85th percentile, the SRRs are 1.19 and 1.34 for BMI and 1.25 and 1.34 for SF5, respectively. Likewise, the risks associated with exceeding the 95th percentile are 1.60 and 2.09 for BMI and 1.74 and 2.00 in spouses and first-degree relatives, respectively. The highest risk is in families of probands exceeding the 99th percentile. SRRs for those exceeding the 99th percentile are 3.01 and 4.96 for BMI and 7.36 and 4.15 for SF5 in spouses and first-degree relatives, respectively. With the exception of high SRRs for SF5 in spouses exceeding the 99th and 97th percentiles, the risks are generally slightly higher for first-degree relatives at each cutoff.

First-degree relatives have consistently higher SRRs than do spouses for TER_{adj} and $WAIST_{adj}$ at each percentile cutoff (table 3 and figures 3 and 4). Similar to the pattern observed for BMI and SF5, the SRRs decrease with decreasing cutoff values in both first-degree relatives and spouses. The SRRs for spouses and first-degree relatives of probands exceeding the 85th percentile are 1.17 and 1.67 for TER_{adj} and 1.11 and 1.24 for $WAIST_{adj}$, respectively, while those for the 95th percentile are 1.42 and 2.38 for TER_{adj} and 1.25 and 1.93 for $WAIST_{adj}$, respectively. SRRs for those exceeding the 99th percentile are 1.41 and 3.18 for

TABLE 3. Age- and sex-standardized risk ratios (SRRs*) comparing the prevalence rates for obesity and central fat distribution in spouses and first-degree relatives of probands who exceed the 50th, 75th, 85th, 95th, 97th, and 99th percentiles for BMI,* SF5,* TER_{adj},* and $WAIST_{adj}$* for the Canada Fitness Survey, 1981

	Spouses				First-degree relatives			
	Population prevalence (%)	Prevalence (%)	SRR	95% CI*	Population prevalence (%)	Prevalence (%)	SRR	95% CI
BMI								
99	3.43	10.31	3.01	1.11 to 4.91	1.28	6.37	4.96	1.76 to 8.16
97	9.18	17.65	1.92	1.39 to 2.45	3.25	8.80	2.71	1.86 to 3.56
95	13.12	20.98	1.60	1.27 to 1.93	5.68	11.88	2.09	1.62 to 2.56
85	32.82	39.05	1.19	1.09 to 1.29	16.57	22.12	1.34	1.21 to 1.47
75	46.96	52.41	1.12	1.06 to 1.18	27.07	31.71	1.17	1.09 to 1.25
50	70.90	73.60	1.04	1.01 to 1.07	52.97	55.18	1.04	1.01 to 1.07
SF5								
99	1.64	12.07	7.36	1.72 to 13.00	1.19	4.93	4.15	0.84 to 7.46
97	3.69	9.70	2.63	1.19 to 4.07	3.00	7.75	2.58	1.49 to 3.67
95	6.88	11.95	1.74	1.10 to 2.38	5.47	10.93	2.00	1.45 to 2.55
85	23.38	29.16	1.25	1.10 to 1.40	16.01	21.48	1.34	1.19 to 1.49
75	37.95	45.32	1.19	1.11 to 1.27	26.32	31.73	1.21	1.12 to 1.30
50	67.76	73.49	1.08	1.05 to 1.11	51.82	55.20	1.07	1.03 to 1.11
TER_{adj}								
99	2.05	2.89	1.41	−1.19 to 4.01	1.04	3.30	3.18	−1.17 to 7.53
97	4.71	6.82	1.45	0.46 to 2.44	2.84	6.37	2.24	1.00 to 3.48
95	7.33	10.43	1.42	0.83 to 2.01	5.26	12.50	2.38	1.65 to 3.11
85	20.10	23.45	1.17	0.98 to 1.36	15.42	25.74	1.67	1.47 to 1.87
75	30.48	34.56	1.13	1.02 to 1.24	25.68	35.90	1.40	1.29 to 1.51
50	54.39	56.88	1.05	1.00 to 1.10	50.55	57.93	1.15	1.11 to 1.19
$WAIST_{adj}$								
99	5.51	5.61	1.02	0.14 to 1.90	1.07	2.34	2.18	−0.30 to 4.66
97	13.50	18.77	1.39	1.05 to 1.73	3.24	7.84	2.42	1.59 to 3.25
95	20.62	25.86	1.25	1.05 to 1.45	5.53	10.68	1.93	1.48 to 2.38
85	36.45	40.63	1.11	1.02 to 1.20	15.77	19.55	1.24	1.10 to 1.38
75	45.97	49.12	1.07	1.01 to 1.13	26.49	31.37	1.18	1.10 to 1.26
50	66.20	68.64	1.04	1.01 to 1.07	51.10	56.35	1.10	1.06 to 1.14

* SRRs, standardized risk ratios; BMI, body mass index; SF5, sum of five skinfolds (biceps + triceps + subscapular + suprailiac + medial calf); TER_{adj}, trunk-to-extremity skinfold ratio adjusted for SF5; $WAIST_{adj}$, waist circumference adjusted for BMI; CI, confidence interval.

TER_{adj} and 1.02 and 2.18 for $WAIST_{adj}$ in spouses and first-degree relatives, respectively.

DISCUSSION

There is significant familial resemblance for indicators of obesity in the general Canadian population. Pérusse et al. (15) used the TAU path analytic model to determine estimates of transmissibility from parents to offspring for the BMI, SF5, TER, and waist-to-hip ratio (WHR) in the CFS of 1981. Their estimates were 28 percent for WHR, 36 percent for the BMI, and 37 percent for the SF5 and TER. This suggests that approximately 30–40 percent of the variability in these phenotypes is due to familial factors, including both biologic and cultural paths.

Our study extends the findings of Pérusse et al. (15) by examining the risk associated with being a spouse or a biologic relative of an individual who is in the upper half to the extremes of the Canadian population distributions for obesity-related phenotypes (i.e., ≥50th, 75th, 85th, 95th, 97th, or 99th percentile). The results suggest that there is a greater risk of obesity or an android adipose tissue distribution if a family member is in the upper percentiles of the population distribution.

The SRRs for spouses and first-degree relatives of probands exceeding the 95th percentile of BMI in the CFS are 1.60 and 2.09, respectively (table 3). Given that the 95th percentile of BMI in the CFS corresponds to 29.9 kg/m^2 for males and 28.4 kg/m^2 in females (table 2), the SRRs are comparable with those of Lee et al. (9) who calculated a SRR of 1.76 for relatives of obese probands in women with a BMI exceeding 30 kg/m^2. Similarly, Allison et al. (6) estimated λ_R values for BMI in NHANES II from Pearson correlations

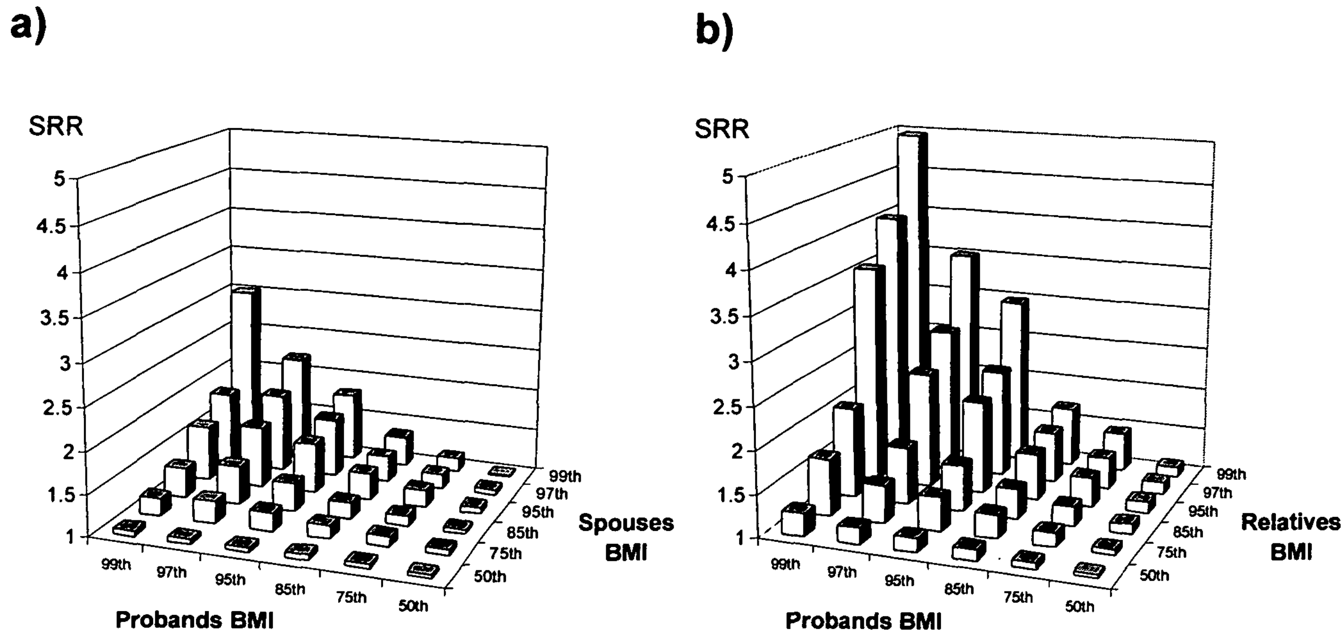

FIGURE 1. SRRs for the BMI in spouses and first-degree relatives of probands who exceeded the 50th, 75th, 85th, 95th, 97th, and 99th percentiles in the CFS of 1981.

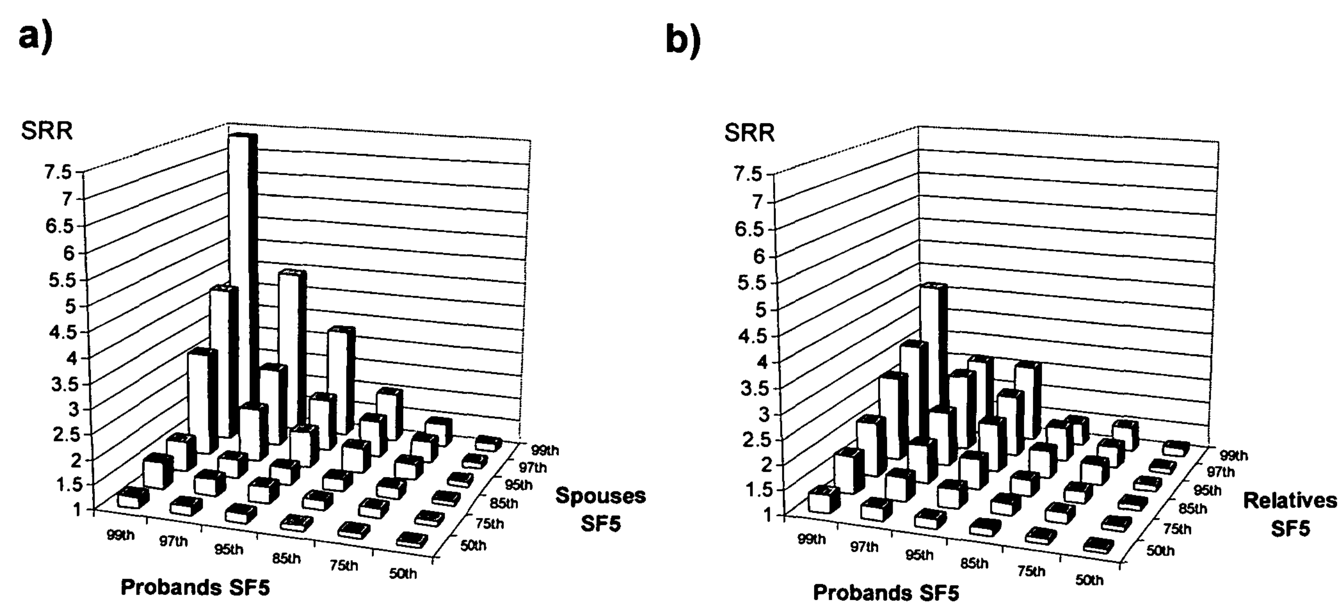

FIGURE 2. SRRs for the SF5 in spouses and first-degree relatives of probands who exceeded the 50th, 75th, 85th, 95th, 97th, and 99th percentiles in the CFS of 1981.

among parents and offspring and from population prevalences of obesity. According to Najjar and Rowland (16), the 90th percentiles for BMI among males and females in NHANES II aged 20–29 years are 29.2 kg/m^2 and 29.1 kg/m^2, respectively, which are similar to the 95th percentiles of the CFS. The λ_R values for the 90th percentile of NHANES II presented by Allison et al. (6) are 1.74 for mothers and children and 1.75 for fathers and children. Although SRRs derived from different samples are not directly comparable, the numbers from these three studies are quite similar and suggest significant familial risk among relatives of

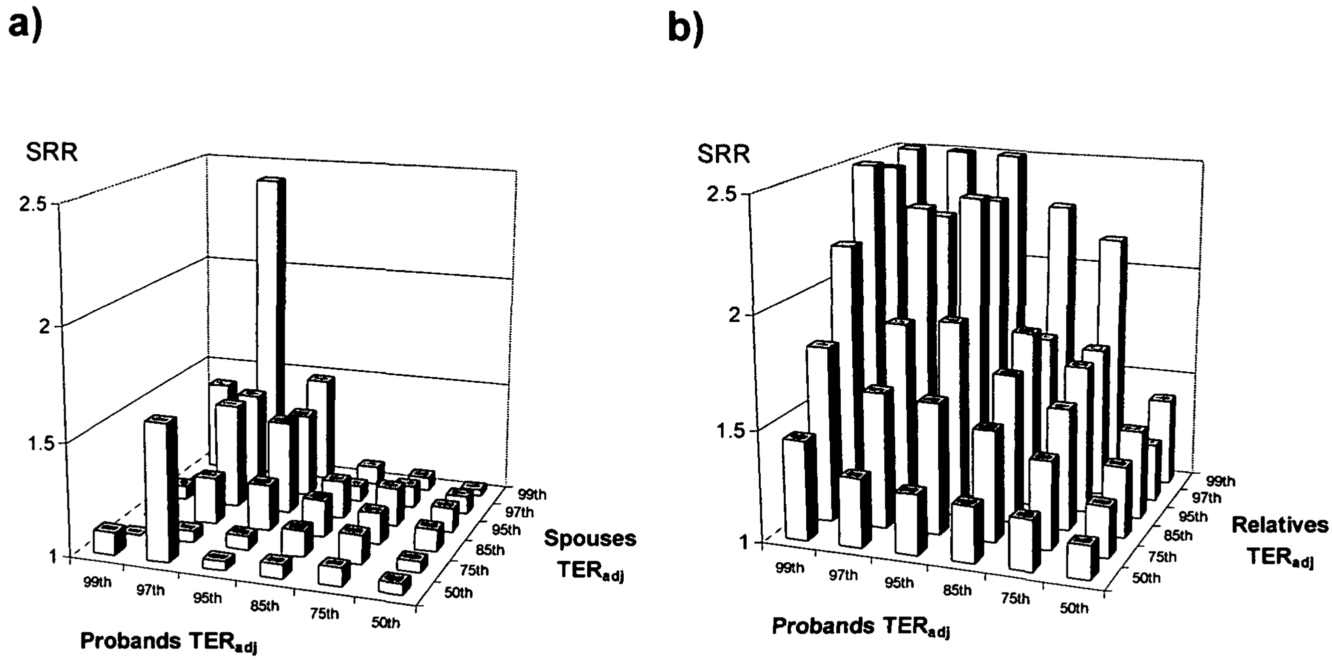

FIGURE 3. SRRs for the TER_{adj} in spouses and first-degree relatives of probands who exceeded the 50th, 75th, 85th, 95th, 97th, and 99th percentiles in the CFS of 1981.

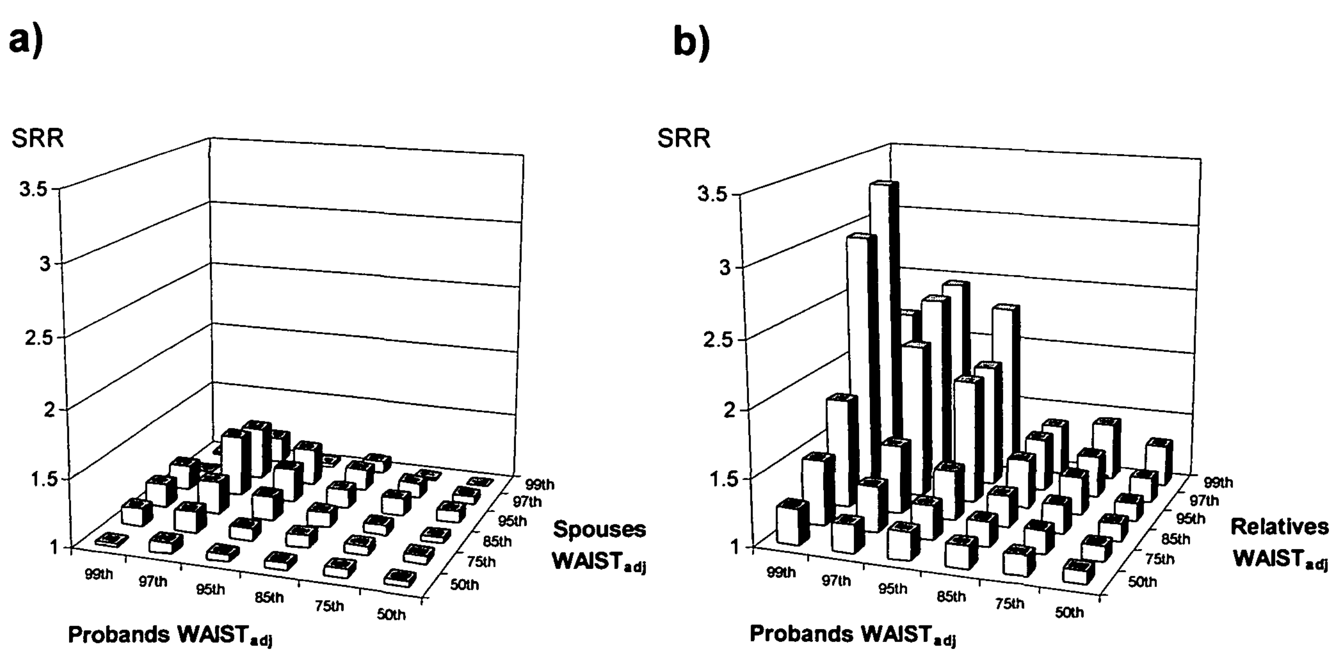

FIGURE 4. SRRs for $WAIST_{adj}$ in spouses and first-degree relatives of probands who exceeded the 50th, 75th, 85th, 95th, 97th, and 99th percentiles in the CFS of 1981.

individuals exceeding a BMI in adulthood of approximately 29–30 kg/m^2.

For BMI, the familial risk of obesity in relatives of obese probands increases with the severity of obesity. These findings are consistent with other evidence (6, 8); however, the values for the CFS are more similar to those presented by Ziegler et al. (8) than to those of the study by Allison et al. (6) at the lower cutoffs. At lower cutoffs (50th, 75th, and 85th percentiles), the values of Allison et al. (6) are considerably higher. Part of these differences may be due to the fact that the same percentiles correspond to different BMI values in different populations. In our study, the sample was large and represented the entire Canadian population. Thus, the CFS data set itself was used to calculate both the general population prevalences and the prevalences among relatives of the probands.

The results for subcutaneous fatness are similar to those for the BMI. The familial risk for high SF5 decreases with decreasing percentile cutoffs, and the values are similar to those of the BMI, with the exception of a high spousal SRR for the 99th percentile of SF5 (table 3). These findings are concordant with those of Pérusse et al. (15), who found similar transmissibility estimates for BMI and SF5 in the same population. The results are not surprising because the BMI is reasonably well correlated with body fatness in the general adult population (17–19). To our knowledge, this study is the first to estimate the familial risk of obesity by using subcutaneous fatness as an indicator of obesity. Thus, comparative data are unavailable.

The familial risks for BMI are higher in first-degree relatives than in spouses at each percentile cutoff. The differences between the two sets of relatives decrease as the percentile cutoffs decrease from the 99th to the 50th percentile, ranging from 1.95 at the 95th percentile to zero at the 50th percentile. The results suggest that the contribution of genetic factors in determining the familial risk obesity increases with the severity of obesity. The differences in SRRs for SF5 follow a different pattern than for BMI. There appear to be more shared familial environmental influences on subcutaneous fatness, since the SRRs for the extremes of SF5 (97th and 99th percentiles) are higher in spouses than in first-degree relatives. At lower percentile cutoffs, the pattern is similar to that of the BMI, with first-degree relatives having somewhat greater SRRs than do spouses. The results observed for SF5 could also be explained by cohort effects, whereby familial environmental factors affecting subcutaneous fatness are more alike within than between generations. Alternatively, spousal resemblance due to positive assortative mating for fatness, such as that demonstrated for the BMI (20), could be a factor in explaining the significant spousal risks. The results for BMI and SF5 suggest that the relative contribution of genes versus environmental factors and/or cohort effects may be different in the expression of these phenotypes. The BMI is a composite measure that cannot distinguish between lean and fat tissues; thus, any estimate of heritability or familial risk is contaminated by unknown contributions from the lean and fat compartments of the body. Although the finding of significant SRRs for spouses does not necessarily suggest that the SRRs are not solely genetic in origin, these results do suggest caution in interpreting SRRs or λ_R values based only on biologic relatives as a support for a genetic hypothesis.

There is substantial evidence suggesting a genetic contribution to adipose tissue distribution. The transmissibility of TER across generations reached approximately 37 percent, while a lower estimate for WHR (28 percent) was obtained for Canadians (15). Further, evidence from the Québec Family Study indicates that genetic factors account for between 30 and 50 percent of the phenotypic variance in fat distribution (21) and that different genes may be influencing total body fat and fat distribution (22). The results of these family studies are supported by a study of male twins, in which the authors indicated a significant genetic influence on the central deposition of subcutaneous body fat (23).

The SRRs for TER_{adj} are greater for first-degree relatives than for spouses at each percentile cutoff (table 3). Additionally, SRRs generally decrease with decreasing cutoff points of the probands.

Figure 3 clearly indicates the differences in risk between spouses and first-degree relatives for the TER_{adj}. It should be emphasized that TER_{adj} captures an element of subcutaneous adipose tissue distribution that is independent of subcutaneous fatness (SF5). Thus, the predisposition to store fat primarily on the trunk at any level of body fat content appears to be influenced by genetic factors, particularly at the extremes of the distribution.

Recent evidence suggests that the waist circumference is a better indicator of health risks (24–26) and amount of visceral adipose tissue (27–29) than is the WHR. Transmissibility estimates for the WHR were lower than for other fatness indicators in the CFS (15), and an analysis of familial risk for extreme values of WHR indicated low estimates of familial risk in the Canadian population (Katzmarzyk, unpublished data). Thus, the waist circumference was chosen as an index of abdominal obesity for this analysis. The results indicate similar patterns of risk for $WAIST_{adj}$ as for TER_{adj}. Although $WAIST_{adj}$ and TER_{adj} are both indices of adipose tissue distribution, TER_{adj} incorporates total trunk subcutaneous fat relative to fat on the limbs, whereas $WAIST_{adj}$ reflects the total level of abdominal fat including visceral fat. Although the results are promising, more work is required in this area, using a more direct assessment of abdominal visceral fatness such as those derived from computed tomography. Unfortunately, comparative data on the familial risk of central android adipose tissue distribution are unavailable.

The pattern of differences in SRRs between first-degree relatives and spouses is greater at higher percentile cutoffs, and the risks among relatives are generally greater than for spouses. These findings suggest that genes that influence the propensity to store body fat on the trunk at a given level of body fatness may be more important in those families with individuals characterized by extreme truncal distributions of body fat.

The CFS sample was a representative sample of the general Canadian population (30). The prevalence of overweight and obesity (BMI > 27 kg/m^2) has been estimated at 29 percent for men and 19 percent for women aged 20–69 years in this survey (31). These estimates are slightly lower than those from the 1978 Canada Health Survey (32), which estimated that 34 percent of men and 29 percent of women had BMI values over 27 kg/m^2. A more recent analysis of 19,841 people from the Canada Heart Health Surveys (1986–1992) indicates that 35 percent of the men and 27 percent of the women aged 18–74 years have BMI values ≥27 kg/m^2 (33). The same study also reported that the prevalence of BMI ≥ 30 was 13 percent in males and 15 percent in females. In this sample from the CFS, the raw unadjusted prevalence of BMI ≥ 30 is 6.5 percent in males and 5.7 percent in females aged 20–69 years. Thus, the prevalence of obesity may be slightly lower in the CFS than in other samples of the Canadian population; however, given the different time frames of data collection of the various surveys, coupled with the current epidemic of obesity in the Western world, these differences are expected. Given that the population prevalences and prevalences among relatives were calculated using the same survey data, the results of this study are not affected by changes in the prevalence of obesity over time in Canada.

Although the SSRs for BMI presented here are consistent with those of other studies when similar cutoffs are chosen, the familial risk of obesity in the general population is quite different from that in families characterized by morbid obesity. The risk of obesity in family members of extremely or morbidly obese individuals has been estimated to be 5–8 times that in the general population (9, 10). This suggests that genetic factors may play a more important role in the susceptibility to extreme obesity. The 99th percentiles for BMI in the CFS correspond to BMI values of 33.5 kg/m^2 in males and 33.1 kg/m^2 in females. Thus, the familial risk of extreme obesity is limited to observations based on this cutoff, rather than a specific cutoff of a BMI such as 40–45 kg/m^2. However, the familial risk of obesity at the extremes of the distribution of the BMI and SF5 (i.e., the 99th percentile) in the Canadian population is still significant. The SRRs for BMI (SRR = 4.96) and SF5 (SRR = 4.15) among first-degree relatives of obese probands approach the risks obtained by Lee et al. (9) for a BMI cutoff of 40 kg/m^2 (SRR = 5.54). Thus, the results of our study are concordant with those that have focused only on extremely or morbidly obese probands.

Results of this study suggest that family members of those in the upper 5 percent of the BMI distribution may have up to 60–100 percent greater risk of being obese than the baseline population risk, and for relatives of probands in the upper 1 percent of BMI, the risk is up to 5 times greater. Comparisons of first-degree relatives and spouses suggest that caution must be used when interpreting significant SRRs or λ_R values as support for a genetic hypothesis, based only on biologic relatives. Additionally, family members of individuals characterized by an android profile of fat distribution or abdominal obesity are also at increased risk for this risk factor, and the risk is greater among first-degree relatives than spouses.

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