Physical activity and energy intake selectively predict the waist-to-hip ratio in men but not in women[1–3]

Antonia Trichopoulou, Charalambos Gnardellis, Areti Lagiou, Vassiliki Benetou, Androniki Naska, and Dimitrios Trichopoulos

ABSTRACT

Background: The waist-to-hip ratio (WHR) has emerged as an important risk factor for several chronic diseases, but little quantitative information exists about its relation with energy intake and expenditure in men and women.

Objective: We examined the relative role of energy intake and physical activity as determinants of WHRs in men and women, after adjustment for body mass index (BMI) and other likely confounding factors.

Design: In the context of the European Prospective Investigation into Cancer and Nutrition (EPIC), 16 433 women and 11 520 men aged 30–82 y, apparently healthy and from all over Greece, were examined between 1994 and 1999. Anthropometric measurements were taken, a validated semiquantitative food-frequency questionnaire was administered, and time-weighted occupational and leisure activities were assessed. The WHR was regressed, separately for men and women, on energy intake and energy expenditure after age and BMI were controlled for.

Results: Results for women and men differed. In women, neither energy intake nor energy expenditure was associated with the WHR in any way other than that mediated through BMI. In contrast, in men, higher energy intakes and higher energy expenditures were associated significantly, and largely independently of BMI, with higher and lower WHRs, respectively.

Conclusions: Because the WHR is an important predictor of several cardiovascular and other chronic diseases, documentation of a strong effect of physical activity on the WHR selectively in men may provide a partial explanation of how the effect of physical activity is mediated and why physical activity is more effective in men than in women in reducing disease risk. *Am J Clin Nutr* 2001;74:574–8.

KEY WORDS Body mass index, sex, energy intake, energy expenditure, physical activity, waist-to-hip ratio, Greece

INTRODUCTION

The distribution of adipose tissue in the body, usually derived from the waist-to-hip ratio (WHR), is an important independent risk factor for cardiovascular and possibly other chronic diseases (1, 2). Body mass index (BMI; in kg/m^2) is inherently linked to the WHR, and the relation is different in the 2 sexes because the distribution of adipose tissue differs between women and men. Relatively few studies have examined the determinants of the WHR after controlling for BMI. This is an important requirement because BMI and WHR may be independent risk factors for several chronic diseases. Moreover, among all relevant studies only one evaluated the effects of both diet and physical activity in both sexes (3).

We investigated the role of energy intake and expenditure as determinants of the WHR by sex in a large sample of both men and women from the general population. Our study relied on a validated interviewer-administered dietary questionnaire, on detailed information about occupational and recreational physical activity, and on tables of the amount of energy expended with a wide range of physical activities (4, 5).

SUBJECTS AND METHODS

Interviewers administered a validated semiquantitative food-frequency questionnaire to 27 953 apparently healthy men and women aged 30–82 y. The study subjects were recruited from regions throughout Greece to participate in the Greek component of the European Prospective Investigation into Cancer and Nutrition (EPIC) (6). EPIC is a multicenter prospective cohort study investigating the role of nutrition and other lifestyle and environmental factors on the etiology of cancer and other chronic diseases. Approximately 400 000 volunteers from 9 European countries participate in the study.

Each participant signed an informed consent form before enrollment. The study was performed in accordance with a protocol approved by the Ethics Committee of the University of Athens. In addition to information regarding nutritional habits, information on lifestyle factors and medical history was

[1] From the Department of Hygiene and Epidemiology, University of Athens Medical School, Athens, Greece, and the Department of Epidemiology, Harvard School of Public Health, Boston.

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[3] Address reprint requests to A Trichopoulou, Department of Hygiene and Epidemiology, University of Athens Medical School, 75 Mikras Asias Street, Goudi GR-115 27 Athens, Greece. E-mail: antonia@nut.uoa.gr.

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TABLE 1
Waist-to-hip ratio (WHR), energy intake, and energy expenditure by age and sex[1]

Age (y)	WHR[2] Men	WHR[2] Women	Energy intake[3] Men	Energy intake[3] Women	Energy expenditure[4] Men	Energy expenditure[4] Women
			kJ/d		*(MET·h)/d*	
<40 (*n* = 2081 M, 2766 F)	0.91 ± 0.07	0.76 ± 0.07	11 146 ± 3084	8929 ± 2586	36.4 ± 7.0	36.1 ± 4.4
40–54 (*n* = 4263 M, 5697 F)	0.95 ± 0.07	0.80 ± 0.07	10544 ± 3033	8477 ± 2372	36.3 ± 7.2	36.3 ± 4.6
55–64 (*n* = 2404 M, 4112 F)	0.97 ± 0.07	0.84 ± 0.08	9594 ± 2812	7594 ± 2243	35.5 ± 7.8	35.5 ± 5.0
≥65 (*n* = 2772 M, 3858 F)	0.97 ± 0.07	0.87 ± 0.08	8456 ± 2502	6791 ± 2059	30.8 ± 5.7	32.4 ± 4.4
Total (*n* = 11 520 M, 16 433 F)	0.95 ± 0.07	0.82 ± 0.08	9954 ± 3038	7933 ± 2435	34.8 ± 7.3	35.2 ± 4.9

[1] $\bar{x}$ ± SD.

[2] Comparisons between sexes for all age groups were highly significant ($P < 0.01$) after Bonferroni adjustment for multiple comparisons. The difference of the mean WHR between the 2 sexes decreased with age, and this interaction was significant ($P < 0.01$) after Bonferroni adjustment for multiple comparisons (multiple regression with interaction between age and sex).

[3] The sex-by-age interaction was not significant; differences between men and women were highly significant ($P < 0.01$) after Bonferroni adjustment. There was a significant decrease with age ($P < 0.01$).

[4] The sex-by-age interaction was not significant; there were no consistent differences between sexes, but there was a highly significant decrease with age ($P < 0.01$) after Bonferroni adjustment (multiple regression with interaction between age and sex).

recorded through an interviewer-administered lifestyle questionnaire. Anthropometric measurements of weight, height, sitting height, and waist and hip circumferences were taken while the subjects were lightly clothed and wearing no shoes or restrictive underwear. Waist circumference was measured around the smallest circumference between the lowest rib and iliac crest or midway between the lowest rib and iliac crest for obese subjects with no natural waist. The measurement was taken at the end of the normal respiration while the subject was standing erect with his arms at his side and feet together. Hip circumference was measured horizontally at the level of the greatest lateral extension of the hips. All circumferences were measured by using an inelastic tape without compressing the skin and were recorded to the nearest 0.1 cm. The WHR was calculated from the waist and hip measurements. Blood samples were also collected.

The semiquantitative food-frequency questionnaire was validated during the pilot phase of the study (4, 7). The questions covered the average consumption of ≈150 food items and beverages over a period of 1 y. Nutrient intakes were calculated through a food-composition database adapted to accommodate the characteristics of the Greek diet (8).

Occupational and leisure time activities were assessed by the use of a special section of the lifestyle questionnaire, which was also used for the overall evaluation of physical activity level. First, the average time spent per day on job-related work of variable intensity, household activities, walking (including walking to work, during shopping, and during leisure time), cycling (including cycling to work and during leisure time), repairing, and gardening (separately for summer and winter) was calculated. The average time spent per day was also assessed for the following leisure-time sporting activities: volleyball, swimming, basketball, soccer, jogging, gymnastics, climbing, dancing, exercise cycling, tennis, rowing, skiing, water skiing, and windsurfing. In assessing sporting activity, we took into account whether the activity was performed throughout the year or seasonally. Finally, the average time spent daily for sleeping (including afternoon naps) and commuting was assessed separately for weekends and weekdays. For subjects whose recorded total hours per day were < or >24 h, the total hours spent daily on each activity were proportionately increased or decreased so that they summed to 24.

Each activity was assigned a MET value (the ratio of the metabolic rate associated with a given activity to the resting metabolic rate) recorded in published tables (5). The time spent in each of the above activities was multiplied by the MET value of that activity, and all MET·h products were summed to give a total MET·h score for the day (5, 9). Thus, by assigning h_i to total hours spent per day for an activity i with MET value MET_i, the (MET·h)/d score for a set of k activities performed daily, on average, by an individual is defined as follows:

$$(\mathrm{MET}\cdot\mathrm{h})/\mathrm{d}\ \text{score} = \Sigma\mathrm{MET}_i \times h_i \qquad (1)$$

where $i = 1, 2, \ldots k$. This score essentially corresponds to the number of kilojoules per kilogram body weight expended by an individual during the day.

To assess whether energy intake and expenditure are associated with WHR, after control for the effect of BMI, we regressed WHR (multiplied by 100) on sex, age in years (categorically), total energy intake (in 2092 kJ/d, which corresponds to 500-kcal/d increments, continuously), energy expenditure [in 5-(MET·h)/d increments, continuously], and BMI (continuously). The SPSS 10.0 statistical package (SPSS Inc, Chicago) was used for the statistical analysis.

Regression models were estimated by using data from all 27 953 study participants and after exclusion of 8426 participants who reported following a reduced-energy, reduced-salt, or specific macronutrient-reducing diet (notably, a low-fat diet; all such participants are referred to hereafter as dieters), of however short a duration; after exclusion of 7860 study participants who were labeled as underreporters of energy intake; or after exclusion of 13 297 study participants who belonged to either of the 2 preceding categories. Study participants were labeled as underreporters of energy intake if their calculated energy intake was <1.14 × the basal metabolic rate (10–12). The multiple regression with 2 independent factors (age and sex) and their interaction, which was used in the present study, is a standard procedure for applying 2-factor analysis of variance with interaction.

RESULTS

Mean (±SD) WHRs, daily energy intake (kJ), and daily energy expenditure (MET·h) are shown by age and sex in **Table 1**.

TABLE 2

Multiple linear regression–derived coefficients (β), SEs, and *P* values for waist-to-hip ratio (×100) as dependent variable for all participants and after exclusion of those on a diet (A), those who underreported energy intake (B), or A and B[1]

Predictor variables	Men			Women		
	β	SE	*P*	β	SE	*P*
All participants						
Energy intake (per 2092 kJ/d, 500 kcal/d)	0.16	0.04	<0.001	−0.07	0.05	0.15
Energy expenditure [per 5 (MET·h)/d]	−0.23	0.04	<0.001	−0.02	0.06	0.76
BMI (kg/m^2)	0.57	0.01	<0.001	0.40	0.01	<0.001
All participants except A						
Energy intake (per 2092 kJ/d, 500 kcal/d)	0.19	0.05	<0.001	−0.01	0.06	0.83
Energy expenditure [per 5 (MET·h)/d]	−0.24	0.05	<0.001	0.05	0.07	0.52
BMI (kg/m^2)	0.52	0.01	<0.001	0.41	0.01	<0.001
All participants except B						
Energy intake (per 2092 kJ/d, 500 kcal/d)	0.19	0.06	<0.01	−0.09	0.07	0.16
Energy expenditure [per 5 (MET·h)/d]	−0.29	0.05	<0.001	−0.02	0.07	0.79
BMI (kg/m^2)	0.59	0.02	<0.001	0.45	0.01	<0.001
All participants except A and B[2]						
Energy intake (per 2092 kJ/d, 500 kcal/d)	0.22	0.07	<0.01	−0.07	0.08	0.37
Energy expenditure [per 5 (MET·h)/d]	−0.31	0.06	<0.001	0.01	0.08	0.95
BMI (kg/m^2)	0.55	0.02	<0.001	0.45	0.02	<0.001

[1] Values controlled for age.

[2] All *P* values for interactions by sex (*F* test) were <0.01.

WHRs and energy intakes were consistently and significantly higher in men than in women. Energy intake and expenditure decreased significantly with increasing age in both men and women. In contrast, WHRs increased with increasing age in both men and women, but this result was more evident in women ($P < 0.01$ in all instances). No consistent or significant differences in energy expenditure were noted between the 2 sexes.

Multiple linear regression–derived results for all men and women are shown in **Table 2**. The results for women and men differed significantly. In women, neither energy intake nor energy expenditure was associated with WHR in any way other than that mediated through BMI. BMI was an important predictor of WHR; for example, in women who were neither dieters nor underreporters of energy intake, a BMI that was 1 kg/m^2 higher corresponded to a WHR (multiplied by 100) that was higher by a value of 0.45 (95% CI: 0.42, 0.48). For men, the results were strikingly different. BMI was associated with WHR more strongly in men than in women. For example, in men who were neither dieters nor underreporters of energy intake, the regression coefficient was 0.55 (95% CI: 0.52, 0.58). The difference between 0.45 and 0.55 was significant (*P* for interaction < 0.001). More importantly, and in contrast with the finding for women, in men, higher energy intakes and higher energy expenditures were associated significantly, and largely independently of BMI, with higher and lower WHRs, respectively.

We also evaluated the overall effects of energy intake and energy expenditure on WHR, whether these effects were independent of BMI (as in Table 2) or were mediated through BMI. After deletion of the BMI variable from the models that generated the results shown in Table 2 and after exclusion of both underreporters and dieters, there was a weak and nonsignificant negative effect of energy expenditure in women, whereas energy intake was significantly positively associated with WHR (data not shown). In contrast, and as expected, in men the regression coefficient for energy intake increased from 0.22 to 0.57, whereas the regression coefficient for energy expenditure decreased from −0.31 to −0.37. Finally, when we ran the models in Table 2 with the inclusion of tobacco smoking as an additional predictor variable, the regression coefficients remained essentially unchanged. This finding indicates that tobacco smoking was not an important confounder of the studied correlations, despite its known relation with body weight.

DISCUSSION

The results of this large investigation indicated that energy intake and expenditure had essentially no association with WHR in women when BMI was controlled for. In other words, in women, higher energy intakes and higher energy expenditures corresponded to slightly higher and slightly lower WHRs, respectively, but both these effects were largely mediated through BMI, which is known to reflect the balance of energy intake and expenditure (13). On the contrary, in men, higher energy intakes and higher energy expenditures corresponded to significantly higher and significantly lower WHRs, respectively, even when BMI was accounted for. In addition, whereas reductions in BMI are more efficiently achieved with reductions in energy intake than with increases in energy expenditure in both sexes, the opposite appeared to be true for a reduction of WHR in men (13).

This investigation had the weaknesses inherent in cross-sectional investigations that have to account for energy intake and expenditure as well as BMI (13, 14). Our study, however, also had considerable advantages: the study was large, 5 times as large as any other investigation of the differential role of energy intake and expenditure on WHR by sex (3); the dietary questionnaire was validated and administered by specially trained interviewers (4, 7); and the assessment of physical activity relied on many questions covering the type, intensity, and duration of a broad range of activities. The physical activity questionnaire was also validated originally, albeit in a different population (15). From another point of view, each of our principal results was compatible with the findings of previous investigations (16–30), a fact that supports the validity of our results. Our study, however, was both larger and of broader scope than most previous investigations that focused on either energy intake or energy expenditure or physical activity.

Ever since WHR was proposed as an important independent risk factor for many chronic diseases (1, 31), several studies have indicated that changes in waist circumference and hip circumference and the corresponding ratio are associated with conditions such as type 2 diabetes (32–35), hypertension and stroke (33, 36), dislipidemias (33, 37), and benign prostatic hypertrophy (2). Although all of the studies did not confirm all aspects of the preceding constellation of findings (38), the WHR is now generally recognized as an important risk factor, possibly linked with the phenomenon of insulin resistance and the insulin-like-growth-factor system. Several studies evaluated the effect of energy expenditure on WHR in women (16, 17), men (18–21), or both sexes (22–27), whereas others have evaluated the effects of both energy intake and expenditure on WHR in women (28) or men (29, 30). To our knowledge, however, only the study by Slattery et al (3) evaluated the effects of both diet and physical activity in both men and women. In comparison with that pioneer study, our investigation was 5 times larger and relied on an energy expenditure metric [(MET · h)/d] that allows comparisons to be made between energy intake and expenditure.

Although the information in the existing literature on the relation between WHR and energy intake and expenditure is fragmentary, was obtained with different methods, and relied on different population samples, it is fairly consistent in indicating that, after BMI is controlled for, increases in energy intake and decreases in energy expenditure sharply reduce WHRs in men but not in women (25). These findings are intuitively appealing because physically inactive, middle-aged men are frequently recognized by their protruding abdomen. The findings, however, may have important implications, including an explanation of why physical activity may be more important for health in men than in women.

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