

PAPER

Body mass index, abdominal adiposity and blood pressure: consistency of their association across developing and developed countries

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BACKGROUND: Obesity is increasing worldwide because developing countries are adopting Western high-fat foods and sedentary lifestyles. In parallel, in many of them, hypertension is rising more rapidly, particularly with age, than in Western countries.

OBJECTIVE: To assess the relationship between adiposity and blood pressure (BP) in a developing country with high average BP (The Seychelles, Indian Ocean, population mainly of African origin) in comparison to a developed country with low average BP (Switzerland, population mainly of Caucasian origin).

DESIGN: Cross-sectional health examination surveys based on population random samples.

SETTING: The main Seychelles island (Mahé) and two Swiss regions (Vaud-Fribourg and Ticino).

SUBJECTS: Three thousand one hundred and sixteen adults (age range 35–64) untreated for hypertension.

MEASUREMENTS: Body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), systolic and diastolic blood pressure (SBP and DBP, mean of two measures).

METHODS: Scatterplot smoothing techniques and gender-specific linear regression models.

RESULTS: On average, SBP and DBP were found to increase linearly over the whole variation range of BMI, WHR and WC. A modest, but statistically significant linear association was found between each indicator of adiposity and BP levels in separate regression models controlling for age. The regression coefficients were not significantly different between the Seychelles and the two Swiss regions, but were generally higher in women than in men. For the latter, a gain of 1.7 kg/m² in BMI, of 4.5 cm in WC or of 3.4% in WHR corresponded to an elevation of 1 mmHg in SBP. For women, corresponding figures were 1.25 kg/m², 2.5 cm and 1.8% respectively. Regression coefficients for age reflected a higher effect of this variable on both SBP and DBP in the Seychelles than in Switzerland.

CONCLUSION: These findings suggest a stable linear relation of adiposity with BP, independent of age and body fat distribution, across developed and developing countries. The more rapid increase of BP with age observed in the latter countries are likely to reflect higher genetic susceptibility and/or higher cumulative exposure to another risk factor than adiposity.

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Keywords: body mass index; waist circumference; waist-to-hip ratio; blood pressure; population of African origin; developing countries

Introduction

The prevalence of obesity has largely increased over the last decade in both developed and developing countries.^{1,2} In the

former, the decline in physical activity and the excessive consumption of high-fat diets are thought to be major contributors.³ In the latter, the same causes are possibly operating due to urbanization, aging of the population, improvement in socioeconomic standards and Westernization of food processing, dietary habits and lifestyles.^{4,5} Obesity and hypertension have been shown to increase in parallel across populations along with their degree of development and Western acculturation. In particular, this gradient was observed in black communities across Western

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Africa, the Caribbean Islands and the United States^{6,7} to such an extent that, in the latter country, hypertension has been found to be more widespread among black people than among white people.⁸ These observations have raised the possibility that the populations of developing countries, or at least those of African origin, have a higher susceptibility of blood pressure (BP) to excessive adiposity than Western populations and will be more severely affected, particularly in terms of hypertension-driven cardiovascular morbidity and mortality, by the current global upward trend in obesity.^{9,10}

This assumption has to be tested against the background of existing knowledge about the hypertensive effect of obesity. Since long-term cohort studies are difficult to conduct, the magnitude of this effect in a given population is generally assessed by examining the cross-sectional association between measures of adiposity and BP levels after adjustment for potential confounders. Usual anthropometric measures of adiposity are body mass index (BMI) and waist circumference (WC), reflecting total body fat and abdominal fat deposition, respectively. In addition, the ratio of waist to hip circumference or waist-to-hip ratio (WHR), is frequently used as an index for abdominal adiposity. All these adiposity parameters have been shown to correlate significantly with systolic blood pressure (SBP), diastolic blood pressure (DBP) and hypertension at an individual level over a broad spectrum of ethnic origins and socioeconomic conditions.^{6,11–13} Age has to be considered as a potential confounder because both adiposity and BP are generally increasing over the course of life. The increase of BP with age was found to accelerate in black populations adopting Western lifestyles⁷ and to be more rapid in Americans of African origin than in those of Caucasian origin.¹⁴

The present study was aimed at determining whether there were significant differences in the relation of several indicators of adiposity (BMI, WC and WHR) with BP, after adjustment for age, between a developing country (The Seychelles, Indian Ocean, population mainly of African origin) and a developed country (Switzerland, population of Caucasian origin). Population-based health examination surveys were conducted recently in these two countries according to a common protocol. In addition to their differences in genetic and economic backgrounds, the Seychelles population has a higher average BP compared to similar populations¹⁵ while the Swiss population is characterized by a low average BP compared to other Western countries.¹⁶

Methods

Subjects

Swiss data were collected as part of the international research project MONICA (MONItoring trends and determinants in CARDiovascular disease). Among the 40 regions in 25 countries taking part in this project, two Swiss regions (cantons of Vaud-Fribourg and canton of Ticino) were included. Time trends in cardiovascular risk factors were assessed through

three health examination surveys based on independent random population samples. Data from the last survey (1992–93) is used in the present study. The sampling and recruitment procedures have been described elsewhere,¹⁷ but are summarized here. The two-stage sampling procedure consisted of a random selection of communes, after stratification by their number of residents, and then of a random selection of residents in the population files of the communes in such a way that each person in the population had the same probability to be drawn. The selected persons were invited to attend a health examination and answer a self-administered questionnaire about their sociodemographic and health related characteristics. In Vaud-Fribourg, 3299 individuals aged 25–74 y were invited to participate in the study, and 1742 (53%) attended. Corresponding figures in Ticino were 2000 invitees aged 35–64 y and 1510 (76%) participants.

Full details on the Seychelles Heart Study have been reported elsewhere.¹⁸ The general framework was basically the same as the one used in the MONICA project. The present study refers to data from the second population survey (1994) based on a random sample stratified by age and sex. A total of 1280 subjects aged 25–64 y were drawn from the resident population on the island of Mahé (28 695 inhabitants), which accounts for 90% of the total population of the Seychelles. Overall, 1067 persons (87%) out of the 1226 eligible individuals attended the survey and were submitted to a face-to-face structured interview and a physical examination performed by trained health professionals.

For the purpose of comparison, the present study was restricted to the age range (35–64 y) common to the three regions and comprised 3456 subjects (1140 in Vaud-Fribourg, 1510 in Ticino and 806 in the Seychelles). Furthermore, of these, subjects reporting current use of antihypertensive medication (7, 10 and 14%, respectively) were excluded in order to explore the true relationship between the adiposity indicators and BP, undisturbed by drug treatment. This left 3116 persons for analysis (1065 from Vaud-Fribourg, 1361 from Ticino, and 690 from the Seychelles).

Measures and cut-off points

In the Swiss surveys, BP was measured twice consecutively on the right arm using a random-zero sphygmomanometer, with subjects in a sitting position after at least 15 min of rest. In the Seychelles, BP was measured three times in a sitting position at intervals greater than 2 min, using a mercury sphygmomanometer, after the subject had been resting for at least 30 min. Large cuffs, adapted to arm circumference, were used systematically on obese participants in the Seychelles, while only medium size (12 cm wide) cuffs were used to measure BP in Switzerland. In all three populations, the observed values were recorded to the nearest 2 mmHg, with DBP being determined at the beginning of Korotkoff phase V. BP levels were taken as the mean

value of two readings (first and second in Switzerland, second and third in the Seychelles) and the latest WHO criteria were adopted in this analysis for the definition of elevated BP (SBP ≥ 140 mmHg and/or DBP ≥ 90 mmHg).¹⁹

The standardized procedures recommended by the MONICA project²⁰ were used for the measurement of the anthropometric variables in the three study regions. Height, WC and hip circumference (HC) were measured to the nearest 0.5 cm, and weight to the nearest 100 g with all participants standing without shoes and heavy outer garments. WC was assessed at a level midway between the lower rib margin and iliac crest and HC was recorded as the maximal circumference over the buttocks. Overweight was defined as a BMI in the range 25–30 and obesity was defined as a BMI ≥ 30 . Based on previous studies, high WC was defined using the cut-off points of 94 and 80 cm for men and women²¹ and high WHR was based on the gender-specific cut-off points of 0.9 and 0.8 respectively.²²

Statistical analysis

All the statistical analyses were carried out separately for each gender using the statistical software Stata.²³ First, the shape of the relation between adiposity and BP was assessed using a scatterplot smoothing method based on robust

locally weighted regression and named the LOWESS technique.²⁴ This technique was applied to the scatterplots of SBP and DBP against the three adiposity indicators (BMI, WC, WHR) in each study population and by considering three age groups (35–44, 45–54 and 55–64 y). In each region, the age-specific smoothed BP curves (not shown) generally displayed a linear trend with fluctuations due to the small number of subjects. A clearer linear pattern was obtained by aggregating the three age groups together, as shown for BMI, WC and WHR in Figures 1, 2 and 3 respectively.

Based on these findings, the relation of these adiposity indicators to BP was estimated using multivariate linear regression models. Age was added as a control variable and its relation to BP was assessed by the same smoothing technique. SBP was found to increase linearly with age in the three populations as well as DBP in the Seychelles. In the two Swiss regions, DBP was found to rise steadily in the lower range of age and then to stabilize beyond the age of 45 y in men and beyond the age of 55 y in women (data not shown). Therefore SBP and DBP were treated as linear and quadratic functions of age respectively. BMI, WC and WHR were not considered simultaneously as explanatory variables in the regression models because, if one of these indicators of adiposity was entered in a model, no other could improve significantly its explanatory power. Interaction terms

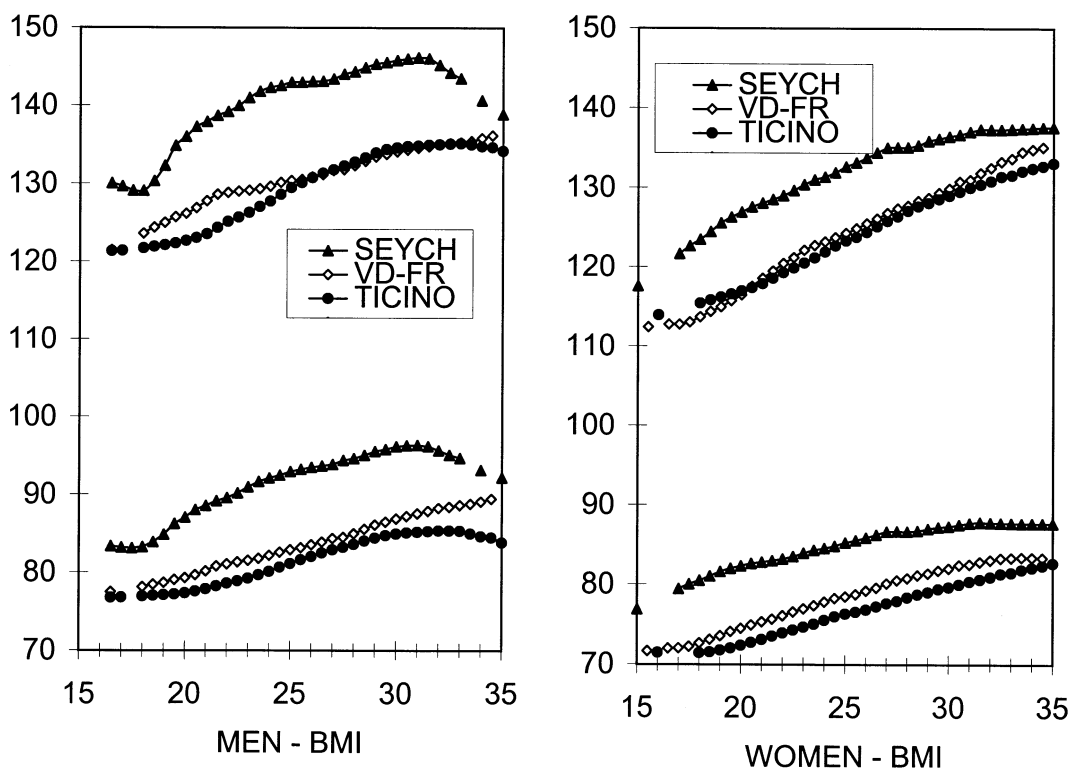


Figure 1 Smoothed curves of systolic blood pressure (upper part) and diastolic blood pressure (lower part) in relation to body mass index, by study region and gender. Individual points are not shown on the figure because of excessive overprinting.

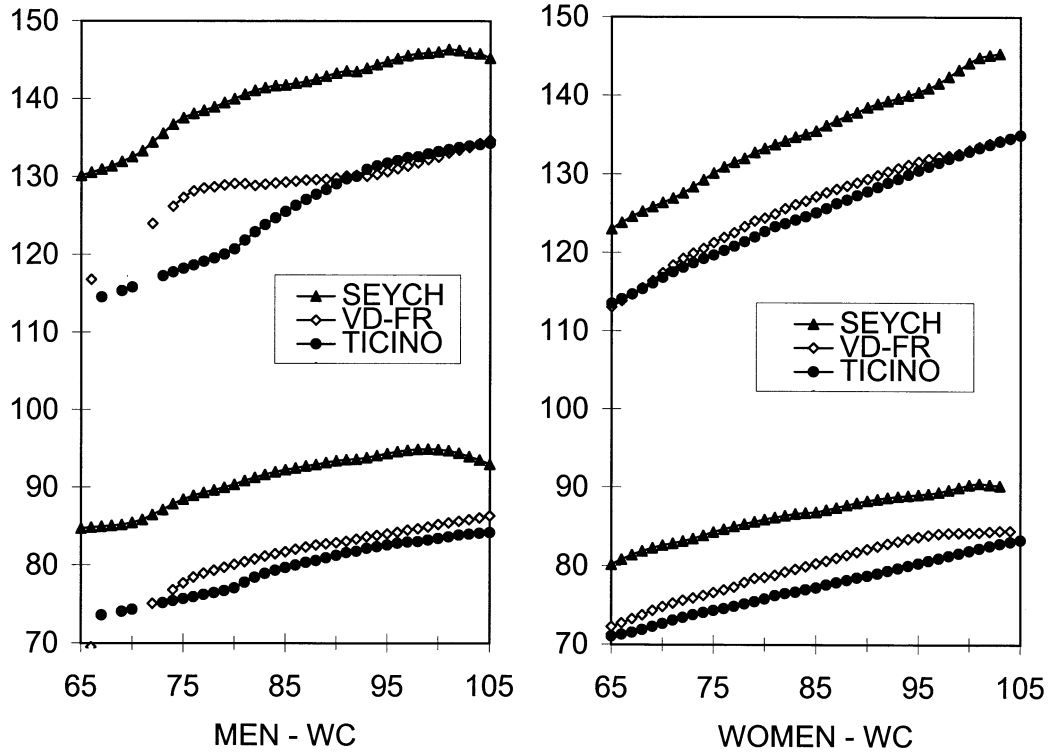


Figure 2 Smoothed curves of systolic blood pressure (upper part) and diastolic blood pressure (lower part) in relation to waist circumference, by study region and gender. Individual points are not shown on the figure because of excessive overprinting.

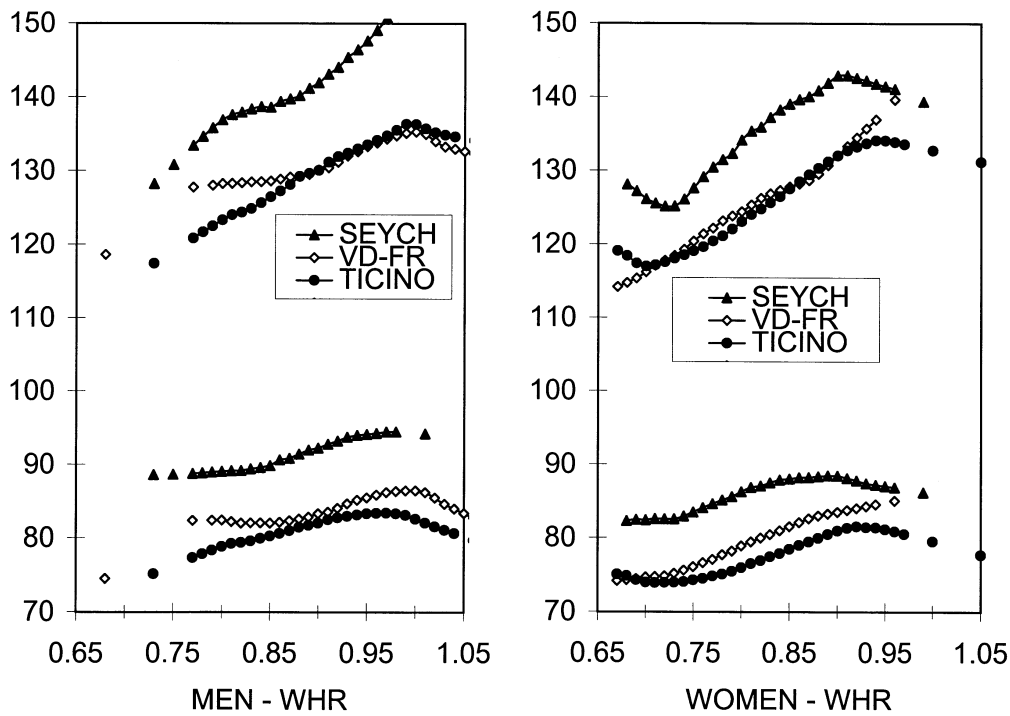


Figure 3 Smoothed curves of systolic blood pressure (upper part) and diastolic blood pressure (lower part) in relation to waist-to-hip ratio, by study region and gender. Individual points are not shown on the figure because of excessive overprinting.

between the different measures of adiposity and age were not added to the models because the corresponding regression coefficients were never found to be significantly different from zero.

The gender-specific multivariate linear regression models were performed on the pooled data of the three study populations within the framework of classical analysis-of-variance. The consistency of these models across the populations was tested by estimating the regression coefficients for Vaud-Fribourg, considered as the reference population, and by calculating the deviations from these coefficients for the other Swiss region (Ticino) and The Seychelles region (Mahé). The final specification of the models was the following (as, for example, for regression of DBP on BMI):

$$DBP_{i0} = \alpha_0 + \beta_0 * BMI_{ij} + \gamma_0 * (AGE_{i0} - 35) + \delta_0 * (AGE_{i0} - 35)^2 + \varepsilon_{i0} \text{ for the reference region (j = 0)}$$

$$DBP_{ij} = (\alpha_0 + \alpha_j) + (\beta_0 + \beta_j) * BMI_{ij} + (\gamma_0 + \gamma_j) * (AGE_{ij} - 35) + (\delta_0 + \delta_j) * (AGE_{ij} - 35)^2 + \varepsilon_{ij} \text{ for any region j > 0}$$

where the indexes *i* and *j* refer to a person *i* of region *j* and ε_{ij} denotes the error term. Age was diminished by 35 in order that model intercepts reflect baseline BP levels of the youngest subjects included in the study (age range 35–64). The proportion of the variation in BP explained by the models was indicated by the determination coefficient (R^2).

Results

The epidemiological characteristics of the study population are presented in Table 1. Mean age was similar across the three regions and for both genders. Average BMI, as well as the prevalence rates of overweight and obesity, were higher in Swiss men than in Seychelles men and lower in Swiss women than in the Seychelles women. Differences in WC and WHR were similar to those observed for BMI, but generally of lesser magnitude. Among the six population groups under study, the prevalence of abdominal obesity (as indicated by WC) was the lowest in Seychelles men, while the prevalence of overall obesity (as indicated by BMI) was the highest in Seychelles women. Mean levels of SBP and DBP were substantially higher in the Seychelles than in the Swiss regions, with the rate of elevated BP being double in men and nearly triple in women.

The three indicators of adiposity (BMI, WC and WHR) were correlated only moderately with BP levels. The unadjusted pairwise correlation coefficients (data not shown) were generally lower in men than in women, in the Seychelles than in the Swiss regions and for WHR relative to BMI and WC. For the two latter measures, the correlation coefficients with SPB and DBP varied from 0.12–0.18 in Seychelles men, from 0.16–0.25 in Swiss men, from 0.20–0.28 in Seychelles women and from 0.30–0.36 in Swiss women. Despite these loose associations, the scatterplot smoothing technique generally detected a modest, consistent linear trend towards greater BP (systolic and diastolic) with greater BMI, WC and WHR in all three regions and for both genders,

Table 1 Blood pressure and adiposity indicator levels in the three study populations, according to gender

Gender	Men			Women		
	VD-FR	TI	SEY	VD-FR	TI	SEY
Region ^a						
Sample size ^b (n)	524	667	340	541	694	350
Age						
Mean (y)	47.2	48.0	48.8	46.9	48.4	48.5
Standard deviation (y)	(8.2)	(8.0)	(8.7)	(8.1)	(8.2)	(8.5)
Body mass index (BMI)						
Mean (kg/m ²)	26.5	26.4	24.2	24.4	25.0	27.3
Standard deviation (kg/m ²)	(3.5)	(3.4)	(3.9)	(4.0)	(4.6)	(5.6)
% overweight and obesity (≥ 25)	62.6	65.7	40.3	38.6	41.9	64.0
% obesity (≥ 30)	16.2	13.2	8.0	8.1	14.4	29.4
Waist circumference (WC)						
Mean (cm)	95.3	94.6	84.5	78.8	81.0	82.7
Standard deviation (cm)	(9.7)	(8.5)	(10.1)	(10.0)	(10.6)	(11.3)
% high WC (M: ≥ 94 ; W: ≥ 80)	54.5	53.9	19.9	38.7	51.5	56.0
Waist-to-hip ratio (WHR)						
Mean	0.91	0.90	0.87	0.78	0.79	0.80
Standard deviation	(0.05)	(0.04)	(0.05)	(0.05)	(0.05)	(0.06)
% high WHR (M: ≥ 0.9 ; W: ≥ 0.8)	60.2	55.6	30.5	38.0	49.3	57.7
Blood pressure (BP)						
Mean systolic BP (mmHg)	131.4	130.7	141.0	123.1	123.0	134.0
Standard deviation (mmHg)	(15.3)	(16.3)	(22.5)	(15.5)	(16.9)	(22.3)
Mean diastolic BP (mmHg)	84.0	82.1	91.3	78.0	76.1	86.0
Standard deviation (mmHg)	(10.0)	(10.2)	(13.0)	(9.4)	(9.7)	(12.4)
% elevated BP ($> 140/90$)	35.0	31.6	63.2	17.6	16.5	42.3

^aVD-FR: Vaud-Fribourg; TI: Ticino; SEY: Seychelles (Mahé Island).

^bPersons reporting current use of antihypertension drugs were excluded from the study.

as shown in Figures 1, 2 and 3. Remarkably, these smoothed BP curves displayed a linear pattern over the whole variation range of each adiposity indicator, apart from upturns frequently observed at the highest values. These curves were nearly parallel between the regions, with the two curves for the Swiss regions being close to each other and that for the Seychelles being systematically shifted upward.

The estimations of the gender-specific linear regression models of SBP against either BMI, WC or WHR, along with age, are shown in Table 2a (models 1, 2 and 3). The results were congruent between the three models. In the reference region (Vaud-Fribourg), highly significant positive regression coefficients were found in both genders for the adiposity indicator and for age, indicating a direct and independent linear association between these two variables and SBP. No significant departure from the model estimations based on the Vaud-Fribourg data was observed in the other Swiss region (Ticino). Similarly, no consistent deviation was detected in the Seychelles region (Mahé), apart from a higher regression coefficient for age in Seychelles men (models 1 and 2). Overall, these regression models contributed to explain 13–14% in men and 22–25% in women of the variations in SBP within and between the three regions.

The corresponding linear regression models of DBP are shown in Table 2b (models 4, 5 and 6). Again, the results

were comparable between the three models. In the reference region (Vaud-Fribourg), the regression coefficients, all highly significant, were positive for the adiposity indicator and for age by itself, and negative for age squared, indicating a linear relation of DBP with adiposity and a concave (first increasing, then stabilizing) relationship with age. Regional deviations from the regression coefficients of the Vaud-Fribourg model were not significant in Ticino, but reached statistical significance in Mahé for the model intercepts in women and for some of the coefficient regressions linked to age. These deviations indicated for the Seychelles, as compared with Vaud-Fribourg, a higher baseline level of DBP in women and a different pattern in the relation of DBP to age. The pattern was found to be nearly linear in men, with regression coefficients close to zero for age squared, and convex (first increasing slowly, then more rapidly) in women, with negative coefficients for age and positive coefficients for age squared. The part of the variation in DBP explained by these models were 14–17% in men and 21–23% in women.

The gender-specific linear relation of the adiposity indicators to SBP and DBP was not significantly different between the three regions in the regression models adjusting for age. The regression coefficients were generally higher in women than in men (apart from BMI in relation to DBP) and their inverse values indicated which increase in adiposity

Table 2a Linear regression models of systolic blood pressure on age and three indicators of adiposity (separately), according to gender and study region

Region ^b	Men			Women		
	Coefficient in reference population ^a	Deviation from coefficient in reference population ^a		Coefficient in reference population ^a	Deviation from reference population ^a	
	VD-FR (n = 521)	TI (n = 657)	SEY (n = 335)	VD-FR (n = 541)	TI (n = 691)	SEY (n = 350)
Model 1						
Intercept	110.6*** (5.6)	- 8.5 ^{NS} (7.6)	0.2 ^{NS} (8.3)	95.6*** (4.3)	5.1 ^{NS} (6.2)	- 2.3 ^{NS} (5.4)
Age — 35	0.43*** (0.09)	0.04 ^{NS} (0.12)	0.34* (0.14)	0.67*** (0.09)	0.18 ^{NS} (0.13)	0.07 ^{NS} (0.12)
BMI	0.59*** (0.21)	0.26 ^{NS} (0.29)	0.22 ^{NS} (0.32)	0.80*** (0.18)	0.00 ^{NS} (0.24)	- 0.01 ^{NS} (0.22)
	R ² = 0.14			R ² = 0.24		
Model 2						
Intercept	105.4*** (7.3)	- 10.1 ^{NS} (10.4)	0.8 ^{NS} (10.8)	84.6*** (5.5)	0.1 ^{NS} (8.4)	0.6 ^{NS} (7.3)
Age — 35	0.41*** (0.09)	0.03 ^{NS} (0.12)	0.33* (0.14)	0.62*** (0.09)	0.15 ^{NS} (0.13)	0.11 ^{NS} (0.12)
WC	0.22*** (0.08)	0.09 ^{NS} (0.11)	0.07 ^{NS} (0.12)	0.39*** (0.07)	0.75 ^{NS} (0.11)	- 0.05 ^{NS} (0.09)
	R ² = 0.14			R ² = 0.25		
Model 3						
Intercept	99.4*** (12.3)	- 11.2 ^{NS} (18.2)	- 5.4 ^{NS} (19.5)	71.6*** (10.4)	3.6 ^{NS} (15.6)	7.3 ^{NS} (13.7)
Age — 35	0.41*** (0.09)	0.03 ^{NS} (0.13)	0.27 ^{NS} (0.15)	0.68*** (0.09)	0.06 ^{NS} (0.14)	0.09 ^{NS} (0.12)
WHR	29.4* (13.6)	11.2 ^{NS} (20.4)	13.5 ^{NS} (22.3)	55.3*** (13.6)	5.2 ^{NS} (20.0)	- 13.2 ^{NS} (17.8)
	R ² = 0.13			R ² = 0.22		

^aStandard deviations are given in brackets. Significance levels refer to the test against null value. NS = not significant; *P < 0.05; **P < 0.01; and ***P < 0.005.

^bVD-FR: Vaud-Fribourg; TI: Ticino; SEY: Seychelles (Mahé Island).

Table 2b Linear regression models of diastolic blood pressure on age and three indicators of adiposity (separately), according to gender and study region

	Men			Women		
	Coefficient in reference population ^a	Deviation from coefficient in reference population ^a		Coefficient in reference population ^a	Deviation from coefficient in reference population ^a	
	VD-FR (n = 521)	TI (n = 657)	SEY (n = 335)	VD-FR (n = 541)	TI (n = 691)	SEY (n = 350)
Model 1						
Intercept	62.1*** (3.5)	1.1 ^{NS} (4.8)	8.0 ^{NS} (5.3)	60.1*** (2.6)	-2.6 ^{NS} (3.4)	11.4*** (3.8)
Age — 35	0.76*** (0.20)	-0.28 ^{NS} (0.27)	-0.57 ^{NS} (0.32)	0.47** (0.18)	0.11 ^{NS} (0.25)	-0.52 ^{NS} (0.29)
(Age — 35)**2	-0.022*** (0.007)	0.008 ^{NS} (0.009)	0.023* (0.011)	-0.010 ^{NS} (0.006)	0.000 ^{NS} (0.009)	0.020* (0.010)
BMI	0.66*** (0.13)	-0.05 ^{NS} (0.18)	0.11 ^{NS} (0.20)	0.59*** (0.11)	-0.05 ^{NS} (0.14)	-0.12 ^{NS} (0.14)
	R ^b = 0.17			R ^b = 0.23		
Model 2						
Intercept	58.2*** (4.6)	4.7 ^{NS} (6.6)	11.0 ^{NS} (6.9)	52.1*** (3.4)	0.8 ^{NS} (4.5)	13.9*** (5.1)
Age — 35	0.78*** (0.20)	-0.30 ^{NS} (0.28)	-0.56 ^{NS} (0.32)	0.46*** (0.18)	0.12 ^{NS} (0.30)	-0.62* (0.30)
(Age — 35)**2	-0.024*** (0.007)	0.009 ^{NS} (0.010)	0.022* (0.011)	-0.011*** (0.006)	0.000 ^{NS} (0.009)	0.024* (0.010)
WC	0.23*** (0.05)	-0.05 ^{NS} (0.07)	0.00 ^{NS} (0.08)	0.29*** (0.04)	-0.06 ^{NS} (0.06)	-0.06 ^{NS} (0.06)
	R ^b = 0.15			R ^b = 0.23		
Model 3						
Intercept	56.7*** (7.7)	3.6 ^{NS} (11.5)	6.7 ^{NS} (12.4)	41.6*** (6.3)	9.8 ^{NS} (8.4)	18.5* (9.5)
Age — 35	0.81*** (0.20)	-0.30 ^{NS} (0.28)	-0.71 ^{NS} (0.33)	0.52*** (0.18)	0.12 ^{NS} (0.25)	-0.60* (0.30)
(Age — 35)**2	-0.024*** (0.007)	0.008 ^{NS} (0.010)	0.026* (0.011)	-0.012 ^{NS} (0.007)	0.000 ^{NS} (0.009)	0.021* (0.010)
WHR	24.8*** (8.6)	-4.0 ^{NS} (12.8)	5.2 ^{NS} (14.0)	41.6*** (8.2)	-17.7 ^{NS} (10.8)	-10.8 ^{NS} (12.2)
	R ^b = 0.14			R ^b = 0.21		

^aStandard deviations are given in brackets. Significance levels refer to the test against null value. NS = not significant; * $P < 0.05$; ** $P < 0.01$; and *** $P < 0.005$.

^bVD-FR: Vaud-Fribourg; TI: Ticino; SEY: Seychelles (Mahé Island).

corresponded to an increase of 1 mmHg in BP. To experience such an elevation in SBP, men had to gain 1.7 kg/m² in BMI, 4.5 cm in WC or 3.4% in WHR while women had to gain only 1.25 kg/m² in BMI, 2.5 cm in WC or 1.8% in WHR. The corresponding figures for DBP amounted to 1.5 kg/m², 4.3 cm and 4.0% in men and to 1.7 kg/m², 3.4 cm and 2.4% in women.

Discussion

The present study shows a modest, but statistically significant linear association of both SBP and DBP with adiposity, independent of age. The linear regression coefficients for each adiposity indicator did not differ significantly between the three regions under study, indicating the consistency of the relationship within Switzerland and its external validity in comparison to the Seychelles. These findings, in agreement with other studies,⁶ support a stable relationship

between body mass and abdominal adiposity, and BP across developed and developing countries.

Furthermore, these results bring a new piece of information into the puzzle of determinants for the still unexplained excess of hypertension among black people. Recent epidemiological research has focused on Afro-American comparisons controlling either for ethnicity (ie, between black communities in Africa and the United States) or for environment (ie, between black and white populations in the United States). The present study compared two populations, one predominantly of African origin and the other of Caucasian origin, which are situated at the opposite end of their inter-ethnic variation range in average BP levels and are living in contrasted economic backgrounds. The absence of a significant differences in the relationship of BP with adiposity between these two populations provides substantial argument against a higher hypertensive effect of obesity in black people than in white people.

The evidence presented above supports a common general physiopathological mechanism linking the excessive fat deposition to elevated BP independently of genetic and environmental background. The mechanism of obesity-associated hypertension appears to be an inadequate vasodilatation in the face of the increased blood volume and cardiac output, which are the natural consequences of an increased body mass. This defect in control of vascular resistance has been attributed to increased activity of the sympathetic nervous system, abnormal renin-angiotensin-aldosterone relations, and insulin resistance.²⁵ Obesity seems to accentuate the development of a cluster of metabolic disorders (including hypertension and dyslipidemia) in subjects presenting the syndrome X, referred to as the insulin resistance syndrome.^{26,27}

The three adiposity parameters under study (BMI, WC and WHR) do not provide independent information on the relationship between adiposity and BP, suggesting that body fat distribution does not modulate this relationship. This finding, which may be due to the strong inter-correlation of the three adiposity indicators, is at variance with those of other investigations. A previous study²⁸ on the Swiss MONICA populations showed that the subscapular-to-triceps and trunk-to-arm ratios, derived from skinfold thickness measurements as indices of centrally located fat, were *negatively* correlated with BP and added significant power to regression models on BP already controlling for age and BMI. Conversely, American population-based data showed that WHR was *directly* associated with hypertension, independently of BMI, in young to middle-aged black adults.²⁹ It was hypothesized that these specific relations of BP with upper-body obesity in white people and lower-body obesity in black people are due to stronger interactions with insulin resistance in the former and with increased sodium sensitivity in the latter. Data about these factors were not collected in the present study.

Some important gender differences have been found in the relationship between BP and adiposity. First of all, the linear regression coefficients for each indicator were substantially greater in women than in men (except for BMI in relation to DBP), suggesting a greater female responsiveness of BP to a gain in relative weight or abdominal deposition. Secondly, on average, men were leaner and women fatter in the Seychelles than in Switzerland, irrespective of which measure of adiposity was considered. A similar observation has been reported between black and white people in the United States.³⁰ According to these findings, factors other than a stronger hypertensive effect of adiposity in populations of African origin have to be identified for their contribution to the excess of elevated BP observed for both genders in the Seychelles, as compared with Switzerland.

The multivariate linear regression models in this study can be used to assess to what extent the higher average BP levels in the Seychelles are explained by a higher model intercept (reflecting genetic predisposition or background environmental exposure level to hypertension) and by a

higher effect of age (reflecting the cumulative exposure to any risk factor over the course of life). Models for SBP were not informative in this respect because the only regression coefficients significantly greater in the Seychelles were found for age in men. Models for DBP showed for the latter region a higher model intercept in women and a more rapid increase of DBP with age in both genders. Together with data from other studies,⁷ there is an overall convergence of evidence towards a steeper rise in BP with the advance of age in developing countries when compared to developed countries. In the present study, this mechanism proved to be independent of body mass and abdominal adiposity while some experts think that body mass is the dominant causal factor.¹⁴ Further research is needed to determine the etiology of this mechanism.

The present study explores the continuous relationship between BP and body mass and abdominal adiposity, while most studies have only assessed the strength of the association between these variables and the presence of hypertension. The relationship of BP to cardiovascular mortality has been found to be similar among different countries, continuous and linear, even at the lower range of BP, ie, below the cut-off points (140/90 or 160/95 mmHg) generally used to define hypertension.^{31,32} Therefore, changes in BP corresponding to defined gains in adiposity can directly be converted into their effect on the relative risk of death from cardiovascular diseases. Measuring the relation of the adiposity parameters (BMI, WC and WHR) to BP by only considering the prevalence of hypertension would underestimate their real impact on mortality.

Several limitations of this study have to be considered. First, the health examination surveys in both countries were not specifically designed to identify the determinants of BP. For this reason, the participants' birth weight was not recorded although it is suspected (as a marker of fetal life exposures) to affect the development of BP in adulthood.³³ However, the inclusion of birth weight as an explanatory variable in the regression models would likely have strengthened the observed association between the adiposity indicators and BP because low birth weight has been linked to an increased risk of hypertension in adults of both genders whereas high birth weight has been linked to an increased risk of obesity.^{34,35} The intake of sodium and potassium was not measured in any of the surveys. Several other important risk factors of hypertension, such as physical activity and alcohol consumption, were only assessed by a few questions in the Swiss surveys. When indicators derived from these questions were added to the multivariate regression models on BP, the regression coefficients of the adiposity indicators and age changed little and the explanatory power of the models increased only marginally (by 1%).

Secondly, the exclusion of the persons undergoing anti-hypertensive drug therapy from the study raised a concern about a possible bias in the assessment of the adiposity-BP relation, in particular at the highest values of the adiposity indicators and in the Seychelles where the proportion of

persons under treatment for high BP was greater (14%) than in Vaud-Fribourg and Ticino (7 and 10% respectively). To test the validity of this concern, the linear regression models were re-estimated by taking into account the subjects treated for high BP and by adding antihypertensive treatment (yes/no) as an explanatory variable. Only little change was found in the regression coefficients of the adiposity indicators obtained for the reference region (Vaud-Fribourg) and in the deviations from these coefficients observed in the other two regions. Another potential selection bias concerned the low participation rate (53%) into the health examination survey of the Vaud-Fribourg region. The non-participants of this region were asked to complete a short postal questionnaire and they reported using BP lowering drugs treated in a much higher proportion than did participants (54 vs 7%). However, both groups were no longer significantly different in their baseline characteristics (gender, age, etc) when only those not treated for high BP were considered, as in the present analyses.

Thirdly, while only standard cuffs were available in Switzerland to measure BP, two types of cuffs—large and standard—were used in the Seychelles according to whether the middle arm circumference of the subject exceeded 34 cm or not. A study in the Seychelles has shown that systematic differences between BP readings are caused by cuff type and that the adjusted effect of BMI on SBP and DBP decreased two-fold using BP readings made by arm-adapted cuffs instead of standard cuffs.³⁶ Therefore BP levels in Swiss obese subjects were likely to be overestimated, but this measurement bias should have only a marginal impact on the regression models because less than 2% of the Swiss subjects had an arm circumference beyond 34 cm.

Conclusion

Whether the hypertensive effect of obesity is greater in developing countries than in developed countries is important to know in order to design efficient strategies for controlling hypertension through weight control. The present study demonstrates the similarity of this effect in two contrasted countries differing by economic and genetic backgrounds and suggests that the developing countries could implement programmes—with all the necessary local adaptations—that have been successfully tested in developed countries. The observed steady and age-independent linear association between BP and adiposity, which is weak at individual level, favors the population approaches attempting to shift the whole distribution of BP in a more favorable direction by improving the population adiposity profile as measured by anthropometric parameters (BMI, WC, WHR). The present study supports the recommendations of WHO³⁷ for developing countries to put emphasis on primary prevention community programs promoting physical activity and healthy dietary habits, including the reduction of alcohol drinking and salt intake which are probably involved in the increase of BP with the advance of age. Such programs

should target particularly women for whom the expected effect of weight loss on BP appears to be greater than in men. Their benefits are likely to be extended to the control of other disorders such as dyslipidemia, as it was found by a similar study conducted in the Seychelles.³⁸

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