The Relative Contribution of Body Fat and Fat Pattern to Blood Pressure Level

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SUMMARY Although the association between body weight and blood pressure is irrefutable, body fat mass and blood pressure level may not necessarily be directly related. To clarify the relative contribution of fat mass to blood pressure level, we analyzed data on 399 adults consecutively entering a weight control program. Although most subjects were notably overweight (mean ideal body weight 177%), the population represented a wide spectrum of body weights and blood pressure levels. Study parameters included body fat mass (by total body water, $^{40}$K, and Stein Kamp formula), lean body mass, body build (chest to height ratio), fat cell number and size from bilateral buttock biopsy specimens, upper fat pattern by arm to thigh circumference ratio, and central fat pattern by subscapular to triceps skinfold ratio. Our results concurred with previously noted correlations between obesity and blood pressure (as mean arterial pressure): weight ($r = 0.44$), percentage of body fat ($r = 0.19$), and absolute fat mass ($r = 0.38$; all $p < 0.01$); however, lean body mass, age, and body build correlated highly with both fat mass and mean arterial pressure, thereby confounding this relationship. Multivariate analysis was performed to evaluate the relative contribution of fat mass to mean arterial pressure in the presence of these and other potentially confounding variables. Lean body mass, age, body build, and an upper body fat pattern were found to contribute significantly to the variation in mean arterial pressure ($p < 0.01$). In their presence, percentage of body fat, absolute fat mass, central fat pattern, fat cell characteristics, and age of onset of obesity did not significantly improve the predictability of mean arterial pressure. Thus, blood pressure level may be related to the aforementioned correlates of obesity and to body fat pattern rather than to fat mass per se. (Hypertension 7: 578-585, 1985)

KEY WORDS • obesity, blood pressure • lean body mass • fat pattern • body build • fat cell number and size • weight • hypertension

CONSIDERABLE epidemiological and clinical evidence exists to support an association between obesity and hypertension. The increased prevalence of obesity among hypertensive subjects and hypertension among the obese is well documented. In addition, prospective trials have demonstrated blood pressure lowering with weight reduction. Several observations lead us to question the presumed causal relationship of obesity and hypertension: (1) the majority of the obese are not hypertensive, (2) not all cross-sectional studies show a significant association between indices of obesity and blood pressure level, and (3) the positive coefficients of correlation are consistently small, with indices of obesity explaining only 3 to 14% of the variability in blood pressure level. In addition, several cross-sectional studies using a limited number of prognostic variables suggest the existence of confounding variables in the association of fatness and blood pressure. Thus, the association between indices of obesity and blood pressure may simply be an artifact of the mutual dependence of obesity and blood pressure on other variables such as age and body build.

This study was undertaken to identify variables that might be indirectly responsible for the observed asso-
cation of body weight and blood pressure and to determine, in their presence, the relative contribution of fatness to blood pressure level. In addition, we examined the data for the existence of other factors independently predictive of blood pressure level.

Methods

Study subjects included 399 adults (87 men, 312 women) consecutively admitted to the Weight Control Unit of the Obesity Research Center, St. Luke's–Roosevelt Hospital Center, New York, between December 1977 and May 1981. Seventy-four subjects who were taking antihypertensive medication, including diuretics for any reason, were omitted from the analyses involving blood pressure level. Patients were either self-referred or physician-referred for weight control.

Because there was a fee for services often not reimbursed by health insurance, subjects probably were more affluent than the obese population in general.

Age, race, sex, age of onset of obesity, current blood pressure lowering medications, and presence of hypertension among first-degree relatives were obtained from a questionnaire completed on admission to the Weight Control Unit. Fat cell size was determined from bilateral buttock biopsy specimens, total body water by tritium dilution, and by whole body counter. Weight was taken after an overnight fast from bilateral buttock biopsy specimens, 12 total body water and ^K by whole body counter. Weight was taken after an overnight fast while the subjects were wearing an examining gown.

Height and 12 other anthropometric measurements (skinfold thickness at thorax, abdomen, upper arm, and subscapular region; length of arm and thigh; and circumference at waist, iliac crest, wrist, upper arm, chest, and thigh) were obtained in the fashion described by Steinkamp et al., all on the right side of each subject. Measurements were carried out by a laboratory technician who had been trained for more than 6 months. Lengths and circumferences were examined with good reproducibility; within individuals, each of the skinfold measurements had a coefficient of variation of 15 to 20%. Blood pressure measurements were taken in the right arm after a brief period of rest in the sitting position. A large adult cuff size was used when upper arm circumference exceeded 32 cm. The diastolic cutoff was the first muffling of the sound rather than its disappearance. A blood pressure level of greater than 140/90 mm Hg was used to distinguish hypertension among first-degree relatives was obtained from a questionnaire completed on admission to the Weight Control Unit. Fat cell size was determined from bilateral buttock biopsy specimens, total body water by tritium dilution, and by whole body counter. Weight was taken after an overnight fast while the subjects were wearing an examining gown.

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Derived data were calculated as follows:

1. Percent ideal body weight = (actual weight/ideal weight) × 100. 16
2. Lean body mass (kg)
   a. By total body water = total body water/0.732, where 0.732 represents the hydration factor for fat-free tissue.
   b. By ^K = K/lean body mass = age-sex constant for K content of lean body mass in milliequivalents per kilogram. 14
3. Body fat mass (kg)
   a. Body fat by total body water = weight — lean body mass.
   b. Adipose tissue by = fat × 1.2, where fat equals weight — lean body mass, and the factor of 1.2 allows for inclusion of the water content of fat tissue (25%) and the exclusion of nonadipose tissue lipid (10%). 18
   c. Skinfold fat by the age-, sex-, and race-specific formula of Steinkamp et al. If the patient was outside the 25- to 45-year age range, the formula for all ages combined was used.
4. Fat cell number = fat (kg)/mean fat cell size. Three separate values of fat cell number were obtained from calculations of fat derived from ^K, total body water, and Steinkamp formula.
5. Body mass index, or Quetelet's index, = weight/height2.
7. Body build was defined as chest circumference to height ratio. A more lateral build refers to a relatively high chest to height ratio.
8. Fat patterning was defined by 14 separate ratios representing all permutations of anthropometric measurements potentially descriptive of body fat pattern.
9. Mean arterial pressure (MAP) = diastolic pressure plus one-third of the pulse pressure.

The study was approved by the Joint Research Review Committee of St. Luke's–Roosevelt Hospital Center.

Pearson rank correlation coefficients were calculated for all independent variables with each other and with blood pressure as systolic, diastolic, and mean arterial pressure. Scatter plots of the correlations between blood pressure level (systolic, diastolic, and mean arterial pressure) and each of the study variables were examined visually to see if the pattern of correlation changed at higher blood pressure levels. Since the plots showed continuous patterns of distribution and since correlation coefficients among the hypertensive and normotensive subgroups were comparable (see Results), subsequent analyses were performed combining all blood pressure groups (high, intermediate, and normal).

To test the relative contribution of selected study parameters to the variability of blood pressure level, multivariate analyses were performed with a multiple linear regression model using a stepwise variable selection procedure. The independent variables in the regression procedure were potential correlates of blood pressure level and were selected to minimize multicollinearity, or interdependence, such that two parameters did not describe a common phenomenon. For example, if arm to thigh circumference ratio were selected as a variable in the model to describe upper body fat pattern, then waist to hip ratio would not be used because of their high interdependence and correlation.
The adequacy of the model was confirmed by inspecting separate plots of the residuals against the predicted values and the residuals against the independent variables as described in Draper and Smith.20

Results

Characteristics of Patient Population

The majority of subjects were white (94% white, 5% black, 1% other) women (312/399 or 78%). A broad range of age, weight, and blood pressure was present, as shown in Figures 1 and 2. All subjects entered the Weight Control Unit because of a concern about body weight; however, 19 of the 399 subjects (5%) were actually within a normal body weight range (80-120% of ideal body weight) and 1 subject was less than 100% of ideal body weight. A family history of hypertension was present in 43% of the subjects.

The study population is described in Table 1. The results of every parameter were available in 218 of the 399 subjects. Their characteristics were similar to the total population, as shown in Table 1.

Univariate Correlates of Blood Pressure

The correlation coefficients of the various study parameters and systolic, diastolic, and mean arterial pressure (MAP) are given in Table 2. Of note was the finding that measures of body fatness (fat mass and percent body fat) had weaker correlations with blood pressure than did measures reflecting body build (chest to height ratio, weight, and weight to height indices). The magnitude and relative order of the correlations were essentially identical for the subgroup of 218 individuals for whom all study parameters were available.

### Table 1. Characteristics of the Study Population

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n</th>
<th>Mean ± sd</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>399</td>
<td>41 (41) ± 12 (12)</td>
<td>14-74 (17-74)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>399</td>
<td>103 (104) ± 27 (26)</td>
<td>53-213 (60-205)</td>
</tr>
<tr>
<td>% Ideal body weight</td>
<td>399</td>
<td>177 (177) ± 41 (40)</td>
<td>96-332 (101-332)</td>
</tr>
<tr>
<td>% Body fat*</td>
<td>374</td>
<td>39 (40) ± 8 (8)</td>
<td>14-58 (21-58)</td>
</tr>
<tr>
<td>Age of onset of obesity (yr)</td>
<td>399</td>
<td>17 (17) ± 12 (12)</td>
<td>1-67 (1-67)</td>
</tr>
<tr>
<td>Blood pressure (mm Hg)</td>
<td>320†</td>
<td>126/82 (128/82) ± 18/11 (17/10)</td>
<td>80-200/50-121 (96-200/50-121)</td>
</tr>
</tbody>
</table>

*The characteristics of the subgroup of 218 patients for whom all study parameters were available are shown in parentheses.

*From total body water.

†Subjects taking antihypertensive medications are excluded.
Because selection of individuals for a genetic predisposition to hypertension could increase the association between measures of fatness and blood pressure, subpopulations with and without a family history of hypertension were examined, as shown in Table 3. There were no significant differences in the slopes of the regression lines between MAP and any of these variables by analysis of covariance. Thus, the relationship between MAP and these measures of fatness appears to be unrelated to a family predisposition to hypertension.

Because body build was estimated as the chest to height ratio, which may have been affected by chest wall fatness, the effect of the latter was removed by stratification of the population according to subscapular skinfold thickness. The correlation of body build and MAP remained highly significant (p < 0.01) at skinfold thickness levels of less than 20, 20 to 40, and greater than 40 mm. In addition, analysis of covariance controlling for subscapular skinfold thickness showed a highly significant regression of MAP on chest to height ratio (p < 0.001). Hence, the association of chest to height ratio and MAP appeared to be independent of chest wall fatness as measured by subscapular skinfold thickness.

Arm to thigh circumference ratio was chosen as the measure of upper body fat pattern, and subscapular to triceps skinfold ratio as the measure of central body fat pattern. Justification for selecting these two indices of fat patterning, defined by arm to thigh circumference ratio; central pattern defined by subscapular to triceps skinfold ratio.

Because of the high intercorrelation among the three measures of body fat (i.e., from total body water, ⁴⁰K, and Steinkamp formula), all with r values of 0.90, reported results reflect calculation of body fat from the total body water determination unless otherwise stated.
body fat patterning was twofold: (1) the indices do not overlap in delineating an upper and a central pattern of obesity (i.e., the arm to thigh ratio describes an upper versus lower pattern, while both measures are peripheral; the subscapular to triceps ratio describes a central versus peripheral pattern, while both measures are upper) and (2) neither index had a significant correlation with percentage of body fat \( (r = 0.08 \text{ and } 0.003 \text{ respectively}) \). By contrast, a previously used index, waist to hip ratio, does not distinguish between upper and central fat patterns, and it had a significant correlation with percentage of body fat \( (r = -0.22, p = 0.0001) \). Although both of the chosen indices correlated with MAP, they were only weakly associated with each other \( (r = 0.14, p = 0.01) \), which suggests that upper and central fat patterns may be distinct.

Of interest was the finding that age of onset of obesity was not significantly associated with the distribution of body fat (as determined by these or 9 other ratios of anthropometric measurements descriptive of body fat pattern). The only exceptions were the weak but significant correlations \( (r = 0.2-0.3) \) among men between age of obesity onset and three trunk to thigh circumference ratios.

Several variables confounded the association of blood pressure and fatness. Lean body mass correlated with MAP \( (r = 0.38, p < 0.0001) \) and absolute fat mass \( (r = 0.43, p < 0.0001) \). Body build correlated with MAP \( (r = 0.47, p < 0.0001) \) and absolute fat mass \( (r = 0.76, p < 0.0001) \). Age correlated with MAP \( (r = 0.33, p < 0.0001) \) and percentage of body fat \( (r = 0.11, p = 0.04) \), although it did not correlate significantly with absolute body fat mass \( (r = -0.01) \).

Analysis of the Independent Contribution of Fatness to Blood Pressure

Since univariate correlations revealed the confounding associates of fatness and blood pressure noted above, a multivariate procedure was needed to quantify the relative contribution of each parameter to blood pressure level when examined in the presence of the others. Twelve study parameters were analyzed using a stepwise regression model among the 218 subjects who had the results of all 12 study parameters available (see Table 4). As the results of this analysis were essentially identical when examined separately for systolic, diastolic, and mean arterial pressure, only the results of the latter are reported. Body build (chest to height ratio) and body mass index \( (\text{weight/height}^2) \) were entered into the model by substitution because of their high intercorrelation (among men, \( r = 0.94 \); among women, \( r = 0.85 \)).

Four parameters were found to be highly predictive of blood pressure level: lean body mass, age, lateral body build, and an upper body fat pattern. Presence or absence of a family history of hypertension contributed to a smaller extent. Substitution of lean body mass by \(^{40}\)K technique for that by total body water did not alter the results. Nor did substitution of body mass index as the measure of body build alter the results. These five parameters explained 37% of the variation of MAP. In their presence, the power of the model to predict blood pressure level was not significantly increased by body fat mass, percentage of body fat, central body fat pattern, fat cell number or size, age of onset of obesity, or sex. The regression equation for this model is as follows: MAP = 66.76 + 0.40 lean body mass (kg) + 0.26 age (yr) + 26.42 chest to height ratio + 10.14 arm to thigh ratio + 2.19 (if family history of hypertension).

As the order of entry of each of the parameters into the stepwise regression procedure can potentially alter the results, the maximum R² model (to examine all combinations of variables) was also employed and gave identical results. Finally, to be certain that percentage of body fat was given the best opportunity to correlate with MAP, this parameter was forced into the regression model first. Even this procedure failed to increase its relative contribution to the variability of MAP.

Discussion

The well-documented association between weight and blood pressure observed in heterogeneous groups may be due to the mutual dependence of weight and blood pressure on confounding variables such as age and body build. Age correlates with both weight and blood pressure among industrialized populations, and has been found to account for as much as 35% of the variation in MAP and 45% of the variation in percentage of body fat. Knowledge of the confound-
ing effect of body build on the association of obesity and hypertension dates back to the early studies of Robinson and Bruce, 11, 21, 22 who documented a strong association between chest to height ratio and relative weight, which suggested a tendency toward obesity in lateral build groups. At the same time, persons with a lateral build had 4 to 11 times the frequency of hypertension compared with persons of linear build. When body build was controlled, weight accounted for less than 1% of the variation in blood pressure. Several investigators have documented stronger associations of blood pressure with weight or weight to height indices than with more direct indices of fatness, such as skinfold thickness. 1, 24, 25 Stanton et al. 9 reported similar results and also showed that percentage of body fat derived from skinfold measurements in the presence of age and body mass index had little effect on the accuracy of classifying individuals as hypertensive or normotensive. In the present study we used a similar method of multivariate analysis but included parameters of body fat pattern, fat cell characteristics, family history of hypertension, and more sophisticated measures of body composition. We found that the relative contribution of measures of fatness to blood pressure level was insignificant compared with the effects of lean body mass, age, a lateral body build, an upper body fat pattern, and a family history of hypertension. Collectively, these data suggest that the well-documented association between weight and blood pressure may be due to age or to some aspect of body composition other than fatness per se.

To our knowledge, this is the first study to demonstrate in both univariate and multivariate models of analysis an association between lean body mass and blood pressure level. Data from the 1971 to 1975 National Health and Nutrition Examination Survey 26 support our findings that skinfold thickness did not correlate with blood pressure as closely as did the body mass index, which suggests that non-fat components may be more important. Most obese individuals have an increased lean body mass. 27 Although a physiological explanation for the relationship between lean body mass and blood pressure is not evident, it is quite possible that the changes in lean mass that accompany changes in body weight could directly affect blood pressure levels. In contrast to our findings, Berglund et al. 28 and Siervogel et al. 21 were unable to document a significant correlation between fat cell size and blood pressure level, regardless of whether the biopsy site was the abdomen 29 or buttock. 30 Only in a subgroup of normotensive subjects did Berglund et al. 28 find a positive association. The importance of the site of biopsy relative to pathological states is suggested by the data of Kissebah et al. 31 In a study of adipose tissue morphology, fat patterning, and metabolic profiles, they noted increased fat cell size in the abdominal region in subjects with upper body compared with lower body obesity, and highly significant correlations between fat cell size and glucose (r = 0.41) and insulin (r = 0.87) responses to a glucose challenge. On the other hand, fat cell size determined from a thigh biopsy specimen was not significantly different between groups with upper and lower fat patterns and was not associated with the metabolic parameters. In our study of a mixed population unselected for blood pressure level, we were able to document a weak but significant univariate association of both fat cell size (0.20) and fat cell number (0.18) with blood pressure level. When evaluated in the presence of the other study parameters, however, neither fat cell size nor number contributed significantly to the variability in blood pressure level, which suggests that fat cell morphology as described from buttock biopsy specimen is a relatively unimportant associate of blood pressure level. It could be, however, that the site of biopsy limits the significance of these data.

Recognizing the findings of Pietinen et al., 32 who showed that a family history of hypertension was an important factor in determining the strength of the association between weight and blood pressure level, we specifically tried to evaluate the role of heredity on the relationship between fatness and blood pressure. We found that the presence or absence of a family history of hypertension made little difference in the relationship between weight or body fatness and blood pressure level. Our study population included a wide spectrum of pathological states is suggested by the data of Kissebah et al. In a study of adipose tissue morphology, fat patterning, and metabolic profiles, they noted increased fat cell size in the abdominal region in subjects with upper body compared with lower body obesity, and highly significant correlations between fat cell size and glucose (r = 0.41) and insulin (r = 0.87) responses to a glucose challenge. On the other hand, fat cell size determined from a thigh biopsy specimen was not significantly different between groups with upper and lower fat patterns and was not associated with the metabolic parameters. In our study of a mixed population unselected for blood pressure level, we were able to document a weak but significant univariate association of both fat cell size (0.20) and fat cell number (0.18) with blood pressure level. When evaluated in the presence of the other study parameters, however, neither fat cell size nor number contributed significantly to the variability in blood pressure level, which suggests that fat cell morphology as described from buttock biopsy specimen is a relatively unimportant associate of blood pressure level. It could be, however, that the site of biopsy limits the significance of these data.

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A potentially important limitation of our study was the unavailability of dietary variables in the analysis. Dietary sodium, 33 potassium, 34 calcium, 35, 36 fat, 37 and...
alcohol,38 as well as foods of animal origin,39-41 have been shown to be potential contributors to blood pressure level. On the other hand, recent data by Stanton et al.3 suggest that these variables may have contributed little to the variation of blood pressure level. In the presence of age and body mass index they found that the accuracy of classifying individuals as hypertensive or normotensive was not increased significantly by inclusion of dietary intake of fat, sodium, calcium, potassium, and alcohol. All dietary variables combined accounted for less than 1% of the variance in blood pressure.

The present data suggest that the blood pressure level of a population consisting predominantly of obese, affluent, white women is unlikely to reflect fatness per se relative to their lean body mass, age, body build, distribution of body fat, or their family history of hypertension. The evident implication is that fat loss in itself would be expected to have a relatively small effect on blood pressure level. There is ample data indicating that weight reduction results in blood pressure reduction3; however, the hypertensive response to weight loss within individual studies is not uniform,4 5 33 42 and several studies report no significant relationship between change in body fatness and change in blood pressure.6 42 43 If excess body fat were a major determinant of increased blood pressure, a significant, permanent, and proportionate reduction in blood pressure would be expected with loss of excess body fat. This remains unproved, although the data of Reisin et al.4 suggest that some factor associated with reduced body weight may account for blood pressure reduction. Animal studies44 45 and clinical observations46 47 suggest that negative energy balance may be more closely related to the fall in blood pressure than are changes in body fat. Factors that have been or should be considered contributors to the hypertensive response to weight reduction include the fall in levels of insulin,43-45 triiodothyronine,49 and sympathetic nervous system activity44; changes in intake of sodium,33 potassium,45 calcium,45 fat,33 alcohol,45 and foods of animal origin44-45; altered exercise patterns50; and — as yet untested — changes in lean body mass. Pending the availability of appropriate prospective studies to clarify the hemodynamic response to weight reduction, the results of the present investigation warrant caution in the assumption that body fat itself is a major determinant of blood pressure level among obese hypertensive individuals.

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