Factor Analysis Suggesting Contrasting Determinants for Different Blood Pressure Measurements

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SUMMARY A multiple regression analysis was performed on statistically independent factors derived from blood pressure measurements and possible predictive variables in 618 Utah adults. Nine blood pressure factors obtained in a previous study composed the dependent variables; 35 anthropometric, questionnaire, and biochemical variables were reduced by factor analysis to 10 factors and used as independent variables. Body size and obesity had significant independent effects on different types of blood pressure: body size correlated most highly with systolic blood pressure, while obesity correlated most highly with sitting diastolic blood pressure measurements. Smoking did not correlate with sitting blood pressure but did show a significant positive correlation (after controlling for obesity) with tilt and supine diastolic pressure. Alcohol consumption correlated positively with sitting diastolic pressure when the effects of body size and obesity were controlled. No correlations were found between urinary potassium or sodium excretion and any blood pressure factors, but a significant positive correlation was seen between plasma sodium concentration and several different types of diastolic blood pressure measurements. Psychological stress showed a significant independent positive correlation with systolic blood pressure measurements that was strongest in adults over 35 years of age. The multiple correlation values for the multiple regression equations ranged from 0.19 to 0.52. (Hypertension 8: 243-251, 1986)

KEY WORDS • blood pressure determinants • factor analysis • causal factors • multiple regression

VIRTUALLY all previous analyses of multiple predictive factors for blood pressure have used systolic and diastolic blood pressure measured in subjects in a sitting position only.1-5 Because blood pressure can vary considerably depending on posture, activity levels, and external stimuli, a previous study examined 57 blood pressure measurements in six different clinic situations (sitting, standing, lying, tilting, gripping, and just before blood drawing).6 Factor analysis of these variables showed that all systolic blood pressure measurements composed one factor, while pulse and diastolic blood pressure measurements formed eight separate additional factors. The present study used these nine factors as dependent variables and evaluated the effects of 35 independent variables by using correlation and multiple regression techniques.

The purpose of this analysis was to determine whether different types of blood pressure measurements have similar or different associations with variables suggested to be determinants of blood pressure levels. If these different types of measurements show distinct patterns of association with possible determinants of blood pressure, such as body size, obesity, or biochemical variables, a better understanding of the underlying physiological mechanisms may be reached. In addition, because different persons do exhibit varying blood pressure responses to stimuli such as tilting or handgrip exercise, examination of these patterns of association may help to characterize population heterogeneity in normal blood pressure and hypertension. To our knowledge, this study represents the first analysis of the relationships between suggested predictor variables and blood pressure measured in a variety of controlled situations.

Subjects and Methods

Data are reported on 618 healthy adults (age ≥ 18 years) who are members of large Utah kindreds. The study protocol described herein was approved by the Institutional Review Board of the University of Utah School of Medicine. Although many of these subjects are from hypertension-prone kindreds, none of them were receiving medication for hypertension at the time.
of evaluation. All subjects attended clinic on weekdays from 0800 to 1200 in a fasting state, having consumed their last meal on the previous evening. They had been instructed to avoid smoking cigarettes before coming to clinic and during the clinic examination.

Fifteen determinations of systolic blood pressure, fourth-phase and fifth-phase diastolic blood pressure, and simultaneous heart rate measurements were obtained during six controlled clinic situations as detailed previously. Correlation analysis of these variables produced a $57 \times 57$ matrix of correlation coefficients that was reduced by using factor analysis. The nine factors obtained with this analysis constitute the dependent variables used in the present study. The factors, in descending order of the amount of variance subsumed, consist of the following: 1) all systolic blood pressure measurements, 2) diastolic measurements in tilted and supine positions, 3) sitting diastolic pressure, 4) all pulse measurements, 5) diastolic pressure while gripping a dynamometer, 6) standing diastolic pressure, 7) diastolic pressure before blood drawing, 8) pulse while gripping a dynamometer, and 9) pulse before blood drawing.

In addition to the blood pressure and pulse measurements, data were collected for each subject by the following methods: detailed personal questionnaires assessing exercise, psychological stress, diet, and other items; evaluation of three 12-hour overnight urine samples for sodium, potassium, and creatinine; analysis of standard blood chemistry values as well as plasma renin activity, Na⁺-Li⁺ countertransport, high density lipoprotein (HDL) cholesterol, total serum cholesterol, and sodium, potassium, and creatinine concentrations; detailed anthropometric measurements; standard and 32-lead electrocardiograms; and history taking and examination by a physician. The correlations between these variables and the dependent variables were assessed to eliminate those independent variables that had low correlations with all dependent variables. The independent variables used in this analysis procedure described previously was applied. Ten factors were produced; these are given in Table 1.

In an earlier analysis, sex was included as an independent variable. It loaded very highly on Factor 1 (body size) and not on any other factors. Since it is a dichotomous variable not well suited to parametric analyses, and since it contributed little additional information, it was not included in the analyses reported here.

For each subject, $z$ scores were created for each variable by subtracting the mean value of the variable from the subject's individual value and then dividing by the standard deviation. Factor scores for each individual were next created by multiplying the individual's $z$ score for each variable by that variable's correlation with each factor and summing within factors. Each subject thus has a score for each factor. For the body size factor, for example, a large subject would have a high positive factor score.

Stepwise multiple regression was performed, using the factor scores from the nine blood pressure and pulse factors as dependent variables. The independent (predictor) variables were the factor scores from the 10 factors described in Table 1. Four variables (plasma renin activity, plasma HDL cholesterol, stress, and exercise) did not correlate highly with any of these 10 factors. Since these were variables of interest, they were added as independent variables in the multiple regression analysis. There were no missing values in the data set.

### Results

Table 1 indicates the percentage of the total variance of the independent variables accounted for by each of the 10 factors. Taken together, the factors accounted for 74% of the variance of the original variables. The first factor can be interpreted as a body size factor, since it correlated highly with height, weight, wrist diameter, and dynamometer grip strength. Plasma creatinine and uric acid also correlated fairly highly with this factor. Factor 2 represents obesity, since it includes weight, abdominal girth, and the three skinfold measurements. Note that body size and obesity were independent, nonoverlapping factors in this analysis.
### Table 1. Independent Factors

<table>
<thead>
<tr>
<th>Factor</th>
<th>Variable</th>
<th>Factor loading</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Body size</td>
<td>Hematocrit (%)</td>
<td>0.63</td>
<td>44.6 ± 3.9</td>
</tr>
<tr>
<td></td>
<td>Weight (lb)</td>
<td>0.60</td>
<td>160.3 ± 34.4</td>
</tr>
<tr>
<td></td>
<td>Height (in)</td>
<td>0.79</td>
<td>67.0 ± 3.6</td>
</tr>
<tr>
<td></td>
<td>Abdominal girth (cm)</td>
<td>0.53</td>
<td>83.0 ± 13.8</td>
</tr>
<tr>
<td></td>
<td>Wrist diameter (in)</td>
<td>0.84</td>
<td>6.5 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>Triceps skinfold (mm)</td>
<td>-0.48</td>
<td>178.4 ± 86.7</td>
</tr>
<tr>
<td></td>
<td>Grip strength (lb)</td>
<td>0.79</td>
<td>56.8 ± 22.8</td>
</tr>
<tr>
<td></td>
<td>Plasma creatinine (mg/dl)</td>
<td>0.64</td>
<td>1.0 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>Plasma uric acid (mg/dl)</td>
<td>0.53</td>
<td>5.5 ± 1.4</td>
</tr>
<tr>
<td>2. Obesity</td>
<td>Weight (lb)</td>
<td>0.73</td>
<td>160.3 ± 34.4</td>
</tr>
<tr>
<td></td>
<td>Abdominal girth (cm)</td>
<td>0.71</td>
<td>83.0 ± 13.8</td>
</tr>
<tr>
<td></td>
<td>Triceps skinfold (mm)</td>
<td>0.70</td>
<td>17.8 ± 8.7</td>
</tr>
<tr>
<td></td>
<td>Scapular skinfold (mm)</td>
<td>0.89</td>
<td>18.9 ± 9.7</td>
</tr>
<tr>
<td></td>
<td>Suprailiac skinfold (mm)</td>
<td>0.79</td>
<td>225.0 ± 10.5</td>
</tr>
<tr>
<td>3. Flux</td>
<td>Na slope*</td>
<td>0.96</td>
<td>0.423 ± 0.139</td>
</tr>
<tr>
<td></td>
<td>Mg slope*</td>
<td>0.45</td>
<td>0.164 ± 0.076</td>
</tr>
<tr>
<td></td>
<td>Na+ - Li+ Countertransport*</td>
<td>0.81</td>
<td>0.265 ± 0.104</td>
</tr>
<tr>
<td>4. SGOT/SGPT</td>
<td>SGOT (IU/L)</td>
<td>0.87</td>
<td>20.7 ± 10.3</td>
</tr>
<tr>
<td></td>
<td>SGPT (IU/L)</td>
<td>0.86</td>
<td>26.4 ± 22.8</td>
</tr>
<tr>
<td>5. Plasma proteins</td>
<td>Ca (mg/dl)</td>
<td>0.73</td>
<td>9.6 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>Total protein</td>
<td>0.63</td>
<td>7.1 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>Albumin (g/dl)</td>
<td>0.64</td>
<td>4.4 ± 0.3</td>
</tr>
<tr>
<td>6. Smoking, alcohol</td>
<td>Years of smoking</td>
<td>0.81</td>
<td>2.9 ± 7.2</td>
</tr>
<tr>
<td></td>
<td>Packs/day (avg)</td>
<td>0.78</td>
<td>0.6 ± 1.1</td>
</tr>
<tr>
<td></td>
<td>Alcohol consumption (oz/wk)</td>
<td>0.41</td>
<td>1.9 ± 7.1</td>
</tr>
<tr>
<td>7. Urine specific gravity, creatinine</td>
<td>Specific gravity (g/ml)</td>
<td>0.81</td>
<td>1.020 ± 0.007</td>
</tr>
<tr>
<td></td>
<td>Creatinine concentration (mg/dl)</td>
<td>0.85</td>
<td>147.6 ± 68.8</td>
</tr>
<tr>
<td>8. Age, cholesterol</td>
<td>Plasma cholesterol (mg/dl)</td>
<td>0.52</td>
<td>192.1 ± 42.5</td>
</tr>
<tr>
<td></td>
<td>Age (yr)</td>
<td>0.60</td>
<td>35.3 ± 13.5</td>
</tr>
<tr>
<td>9. Plasma Na, Cl</td>
<td>Plasma Na (mEq/L)</td>
<td>0.68</td>
<td>140.0 ± 2.0</td>
</tr>
<tr>
<td></td>
<td>Plasma Cl (mEq/L)</td>
<td>0.65</td>
<td>105.4 ± 2.4</td>
</tr>
<tr>
<td>10. Urinary Na, K</td>
<td>Urinary Na (mEq/L)†</td>
<td>0.53</td>
<td>132.1 ± 56.3</td>
</tr>
<tr>
<td></td>
<td>Urinary K (mEq/L)†</td>
<td>0.43</td>
<td>45.2 ± 23.7</td>
</tr>
</tbody>
</table>

Additional single variables

- Plasma HDL cholesterol (mg/dl) — 49.8 ± 12.4
- Plasma renin activity (ng/dl/hr) — 280.0 ± 328.1
- Psychological stress questionnaire — 27.3 ± 4.9
- Exercise questionnaire — 11.7 ± 6.5

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SGOT = serum glutamic-oxaloacetic transaminase; SGPT = serum glutamic-pyruvic transaminase; HDL = high density lipoprotein.

*Moles of Li per liter of red blood cells per hour.

†Concentrations of sodium and potassium in 12-hour urine sample adjusted for creatinine excretion to approximate Na and K excretion adjusted for body mass and urine volume.

Factor 3 contains the three variables used to measure sodium-lithium countertransport and is thus labeled a flux factor. The liver enzymes serum glutamic-oxaloacetic transaminase (SGOT) and serum glutamic-pyruvic transaminase (SGPT) compose Factor 4, and three plasma variables (calcium, total protein, and albumin) compose Factor 5. Cigarette and alcohol consumption make up Factor 6. Since most of the clinic population neither smoked nor drank, the distributions of these variables were skewed. Factor 7 consists of specific gravity of the urine and urinary creatinine, and Factor 8 includes age and plasma cholesterol level. Plasma...
sodium and chloride levels make up Factor 9. The last factor is composed of urinary sodium and potassium excretion, adjusted for creatinine. These variables both correlated positively with Factor 10, which indicates a positive correlation with one another.

Correlation coefficients for the dependent and independent factors are given in Table 2. For those independent factors and variables that entered into the multiple regression equation for each dependent factor, the standardized regression coefficients are also given. To enter into the regression equation, the partial correlation coefficient of the independent variable with the dependent variable had to reach a 0.05 significance level after adjusting for the variables already in the equation. Multiple correlation values, which indicate the overall strength of the relationship between the dependent variable and all of the independent variables in the equation, are also given in Table 2. Since the independent factors were orthogonal and thus essentially uncorrelated, the standardized regression coefficients were very similar in value to the correlation coefficients. This is not necessarily true of the four variables (HDL, renin, stress, and exercise) that were entered singly.

For brevity in the following discussion, the term factor usually will be omitted in referring to the dependent and independent factors.

Body size showed significant correlations with nearly all of the dependent factors. Especially strong correlations were seen with systolic blood pressure ($r = 0.41$), pulse ($r = -0.26$), and diastolic pressure during handgrip exercise ($r = 0.27$). Body size was by far the strongest predictor of systolic blood pressure.

The second independent factor, obesity, was the best predictor of the most commonly employed measure of blood pressure, sitting diastolic pressure ($r = 0.29$). The association between obesity and systolic blood pressure was much lower ($r = 0.129$), although still significant. It is especially interesting that, while body size was positively correlated with standing diastolic pressure ($r = 0.14$), obesity was inversely correlated with standing diastolic pressure ($r = -0.12$).

**TABLE 2. Correlation and Regression Coefficients**

<table>
<thead>
<tr>
<th>Independent factors</th>
<th>Systolic blood pressure</th>
<th>Diastolic blood pressure</th>
<th>Venipuncture</th>
<th>Heart rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body size</td>
<td>0.41*</td>
<td>0.08†</td>
<td>-0.14*</td>
<td>-0.14*</td>
</tr>
<tr>
<td>Obesity</td>
<td>0.13*</td>
<td>0.15*</td>
<td>0.09†</td>
<td>0.27*</td>
</tr>
<tr>
<td>Age, cholesterol</td>
<td>0.23*</td>
<td>0.28 (1)</td>
<td>-0.12*</td>
<td>0.26*</td>
</tr>
<tr>
<td>Flux</td>
<td>0.01</td>
<td>0.14 (2)</td>
<td>0.01</td>
<td>0.07†</td>
</tr>
<tr>
<td>Plasma Na, Cl</td>
<td>0.01</td>
<td>0.12* (1)</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Urinary Na, K</td>
<td>0.01</td>
<td>0.10* (3)</td>
<td>-0.03</td>
<td>-0.03</td>
</tr>
<tr>
<td>Urine specific gravity, creatinine</td>
<td>-0.07†</td>
<td>0.02</td>
<td>-0.07†</td>
<td>-0.07†</td>
</tr>
<tr>
<td>Plasma SGOT/SGPT</td>
<td>0.12*</td>
<td>0.09 (2)</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Plasma proteins</td>
<td>-0.05</td>
<td>0.04</td>
<td>-0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>Smoking, alcohol</td>
<td>0.07†</td>
<td>0.04</td>
<td>0.10†</td>
<td>0.11†</td>
</tr>
<tr>
<td>Plasma renin activity</td>
<td>-0.04</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Plasma HDL cholesterol</td>
<td>-0.04</td>
<td>0.03</td>
<td>-0.10*</td>
<td>-0.09 (4)</td>
</tr>
<tr>
<td>Exercise questionnaire</td>
<td>0.06</td>
<td>0.08 (6)</td>
<td>0.08</td>
<td>0.08†</td>
</tr>
<tr>
<td>Psychological stress questionnaire</td>
<td>0.10*</td>
<td>0.08 (6)</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Multiple R</td>
<td>0.52</td>
<td>0.34</td>
<td>0.35</td>
<td>0.27</td>
</tr>
</tbody>
</table>

*Correlation coefficients are given on first line for each independent factor. Regression coefficients, when significant, are given on the second line. Numbers in parentheses indicate the order of entry of the independent variable into the regression equation. See Table 1 for key to abbreviations.

*p < 0.001, †p < 0.05, ‡p < 0.01.
Note that, because these independent factors were uncorrelated, the obesity factor represents body fat after controlling for body size.

The flux factor showed a significant correlation with only one dependent factor, tilt and supine diastolic pressure \((r = 0.11)\). Sitting diastolic pressure, the variable against which flux usually is tested, showed a nonsignificant correlation \((r = 0.02)\).

The liver enzymes SGOT and SGPT entered only into the equation for systolic blood pressure. The plasma calcium, total protein, and albumin factor showed positive correlations with most of the blood pressure and pulse factors taken under stress conditions (pulse and diastolic blood pressure before blood drawing and pulse during dynamometer grip exercise).

The smoking and alcohol factor exhibited low positive correlations with most of the dependent factors, reaching significance with systolic blood pressure \((r = 0.07)\), tilt and supine diastolic pressure \((r = 0.10)\), and pulse before blood drawing \((r = 0.07)\). A similar level of predictive association was seen for the factor of urine specific gravity and creatinine, which showed significant but low inverse correlations with systolic pressure, tilt and supine pressure, and threatened diastolic pressure.

The age and cholesterol factor entered into a large number of equations, showing relatively high correlations with systolic pressure \((r = 0.23)\), tilt and supine diastolic pressure \((r = 0.26)\), sitting diastolic pressure \((r = 0.15)\), and pulse before blood drawing \((r = -0.15)\). The only blood pressure factor with which age and cholesterol had a significant inverse correlation was standing diastolic blood pressure \((r = -0.07)\). These correlations appear to be due primarily to age rather than to cholesterol, since the partial correlations between the dependent factors and cholesterol alone, controlling for age, were not statistically significant.

Plasma sodium and chloride, the next independent factor, entered into several equations with fairly low but significant correlations: sitting diastolic pressure \((r = 0.12)\), grip exercise diastolic pressure \((r = -0.10)\), diastolic pressure before blood drawing \((r = 0.10)\), and pulse during grip exercise \((r = -0.08)\).

The urinary sodium and potassium factor entered into only two equations, both of which are pulse factors: pulse during grip exercise \((r = -0.09)\) and pulse before blood drawing \((r = -0.10)\).

The HDL cholesterol variable showed significant inverse correlations with tilt and supine diastolic pressure \((r = -0.15)\) and diastolic pressure during grip exercise \((r = -0.15)\), but it had a positive correlation with diastolic pressure before blood drawing \((r = 0.12)\). This variable was the only one in which there was a substantial difference between the simple correlation with a dependent variable \((r = -0.03)\) for systolic pressure) and the standardized regression coefficient \((0.11)\). This difference reflects the effects of correlations between HDL and other independent factors and variables.

Plasma renin activity showed significant correlations primarily with the stress blood pressure and pulse measurements: diastolic pressure before blood drawing \((r = -0.12)\), pulse during grip exercise \((r = -0.08)\), and pulse before blood drawing \((r = 0.08)\). Renin's highest correlation was with resting pulse \((r = 0.13)\).

The psychological stress variable correlated significantly and in the expected direction with systolic blood pressure \((r = 0.10)\) and resting pulse \((r = 0.14)\). It had a significant inverse correlation with diastolic pressure during grip exercise \((r = -0.09)\), but it did not correlate at all with any of the other "stress" blood pressure or pulse measurements.

The last variable, exercise, showed the expected inverse correlations with two of the pulse variables \((r = -0.12\) for resting pulse; \(r = -0.12\) for pulse before blood drawing). However, it was positively correlated with two diastolic blood pressure factors \((r = 0.08\) for tilt and supine diastolic; \(r = 0.07\) for diastolic pressure during grip exercise). It correlated inversely with diastolic pressure before blood drawing \((r = -0.08)\). Most of these correlations were marginally significant, and exercise was entered into only two of the multiple regression equations (tilt and supine diastolic pressure and pulse before blood drawing).

The multiple correlation values shown at the bottom of Table 2 indicate that, in general, the combined predictive power of the independent variables is only moderate. The highest multiple correlation was 0.524 (systolic pressure); the lowest was 0.189 (standing diastolic pressure). The remaining correlations ranged from 0.20 to 0.35.

The adult sample was divided into two groups, 18 to 35 years of age and older than 35 years of age. Some differences were seen in the correlation patterns of these two groups, but they were similar for the most part. One of the more interesting differences between the two groups is that psychological stress was a significant predictor of systolic blood pressure in the older adult group but not in the young adult group.

Two samples of children also were analyzed: 127 young children (age, 1-11 years) and 128 adolescents (age, 12-17 years). The young children presented correlation patterns totally different from those of the adults (see Reference 6 for a presentation of their blood pressure results). Most of their blood pressure factors were best predicted by an independent factor composed of age and size variables. Few other variables had significant predictive power. The adolescents had patterns much more similar to those of the adults, although an independent factor consisting of age and size variables was the most important predictor for systolic blood pressure, pulse, and diastolic pressure during grip exercise.

Discussion

These findings demonstrate that different types of blood pressure measurements have contrasting determinants. Without a statistical separation into independent factors, both blood pressure variables and potential causal variables tend to exhibit blurred common
associations. For example, as variables, systolic and diastolic blood pressure, weight, and height all correlate highly with one another. However, after separation into independent statistical factors, different blood pressures show distinct associations with different predictive factors. Although, to our knowledge, this factor analytic approach has not previously been applied to blood pressure data, our results do have interesting parallels with published studies, as will be discussed.

Some of the highest correlations found in this study were those between body size and most of the blood pressure variables. This finding is not surprising, since body weight, a main component of body size, is consistently a good predictor of blood pressure. In addition, change in body weight is positively correlated with change in blood pressure. Obesity, measured by body mass index or skinfold thickness, is also a good predictor of blood pressure. Consistent with this study, most other studies report correlations in the range of 0.2 to 0.3.

Some have argued that obesity is a better predictor of blood pressure than is weight, while others have argued that weight is a better predictor. Concluded that obesity is a "secondary" factor whose effect on blood pressure is due only to its correlation with body weight. The results of this study suggest that body size and obesity exert independent effects on blood pressure and that they affect different types of blood pressure differently. Body size was most highly correlated with systolic pressure, a finding that agrees with a previous report that weight is more highly correlated with systolic than diastolic pressure. Obesity, on the other hand, was most highly correlated with sitting diastolic pressure. An intriguing, but as yet unexplained, finding was the positive correlation between body size and standing diastolic pressure as opposed to the inverse correlation between obesity and standing diastolic pressure.

Dahl et al. suggested that the effect of obesity on blood pressure may be mediated by salt consumption; obese persons consume more food generally, thereby increasing their total salt intake. Table 2 demonstrates that the effects of body size and obesity on blood pressure were both independent of sodium and potassium excretion, weighing against this hypothesis. Other analyses have also found evidence against this hypothesis.

Several studies have shown that hypertensive persons have significantly higher sodium-lithium countertransport values than do normotensive persons. This study did not show a significant correlation between countertransport and sitting blood pressures, although a significant positive correlation was found with tilt and supine diastolic pressures. The lack of correlation with sitting blood pressures may be due to the fact that nearly all of the subjects in this study were normotensive. Also, a substantial overlap of countertransport values has been observed between hypertensive and normotensive persons.

Smoking and alcohol consumption formed a single factor in this study since most of the study subjects who smoked also consumed alcohol. This occurrence presents a problem in analysis, since alcohol has often been shown to correlate positively with blood pressure, while smoking tends to show an inverse correlation with blood pressure. Further correlation analysis was done on the alcohol and cigarette consumption variables separately. A significant positive correlation was observed between "number of years having smoked" and systolic blood pressure, but this became nonsignificant when age was controlled for in a partial correlation analysis. A nonsignificant inverse correlation was seen between "average number of packs per day" and sitting diastolic blood pressure. After controlling for obesity, this correlation became slightly positive but nonsignificant. This finding provides weak confirmation for the assertion that the observed inverse correlation between sitting blood pressure and smoking is due to lower weight among smokers. Significant positive correlations were observed for "years of smoking" and "average number of packs per day" after controlling for obesity, alcohol consumption, and age. Thus, although smoking had no independent effect on sitting blood pressures, it did have an independent effect on tilt and supine diastolic pressures.

Alcohol consumption had significant positive correlations with the systolic pressure factor and with sitting diastolic pressure. These correlations remained significant when obesity was controlled for, but when body size was also controlled for, the correlation with systolic blood pressure disappeared. However, a significant positive correlation was still seen for sitting diastolic pressure. It should also be noted that at least two studies have shown a curvilinear relationship between alcohol consumption and blood pressure, in which light drinkers had the lowest blood pressures.

Numerous cross-sectional studies of industrialized populations have demonstrated significant positive correlations between age and blood pressure. However, this correlation is often not found in nonindustrialized societies, and a longitudinal study demonstrated that blood pressure increases through time in only about half of the men examined. The data analyzed herein are in agreement with other studies, showing strong positive correlations between the age and cholesterol factor and most blood pressure factors. In accord with other studies, the correlation of the age-cholesterol factor and systolic pressure was substantially higher than that with sitting diastolic pressure. This finding reflects in part the fact that systolic pressure continues to rise throughout
life, while diastolic pressure tends to drop after the age of 50 years. Interestingly, the highest correlation was seen with tilt and supine diastolic pressures. The multiple regression results demonstrate that age was correlated with most blood pressure measurements independently of body size and obesity. Thus, the rise in blood pressure with age is not due simply to weight gain.

Since plasma cholesterol is a variable of interest in itself, simple correlations were estimated for this variable alone with each blood pressure factor. Although several significant correlations were found, none reached significance after controlling for age. Other studies have found either low positive correlations between cholesterol and blood pressures or no correlation. Sive et al. obtained a correlation of 0.14 between systolic blood pressure and cholesterol, but this correlation became nonsignificant after adjusting for age and weight.

Although many other studies have examined the relationship between total cholesterol and blood pressure, fewer have considered plasma HDL cholesterol. This variable, which appears to confer a protective effect against coronary heart disease, showed significant inverse correlations with two diastolic blood pressure factors, tilt/supine and handgrip. It also had a positive correlation with diastolic pressure before blood drawing. After adjusting for five other variables, it had a significant positive regression coefficient for the systolic pressure factor. In a study of Framingham data, HDL cholesterol had no correlation with blood pressure in men, but it had weak significant inverse correlations with systolic and diastolic blood pressure in women.

The relationship between salt intake and blood pressure has been the subject of much controversy. Although populations that consume less salt tend to have lower blood pressures, intrapopulation studies generally have shown little or no relationship between sodium intake and blood pressure. or between urinary sodium excretion and blood pressure. However, reported one of the few studies in which a higher level of sodium excretion was found in hypertensive subjects than in normotensive subjects. In general, reviewers of the subject conclude that there is no solid evidence for intrapopulation associations between sodium intake and blood pressure. Even the benefits of dietary sodium restriction for hypertensive persons, while supported by some, are contested by others.

This study essentially confirms previous results and further amplifies them. Not only were no significant correlations found between the urinary sodium and potassium factor and resting blood pressures (the commonly reported finding), but no correlations were found with any of the blood pressure factors. It is interesting, however, that the plasma sodium and chloride factor had significant positive correlations with sitting diastolic blood pressure and with diastolic pressure before blood drawing.

Since potassium intake may have a protective effect against high blood pressure, potassium excretion were analyzed separately. No significant relationship was found for either single variable with any blood pressure factor, although a positive correlation was found between potassium and sitting diastolic pressure \( r = 0.05 \), while an inverse correlation was found between sodium and sitting diastolic pressure \( r = -0.04 \). The finding of no significant correlations is in agreement with several other studies showing no relationship between potassium excretion and blood pressure. For dietary potassium, one study reported a negative correlation with blood pressure while another reported a positive correlation. It may be, as Tannen has suggested, that high potassium diets affect only hypertensive persons, since potassium supplementation appears to have little or no effect in normotensive persons and in persons with mild hypertension. In a populationwide study such as this one, such an effect probably would not be apparent.

Harlan et al. found a weak but significant positive correlation between the ratio of dietary sodium and potassium and diastolic blood pressure. The present study, however, found no correlation between the ratio of sodium excretion to potassium excretion and any blood pressure factor.

It has been suggested that some persons may be salt-sensitive while others are not and that this could account for the generally observed lack of correlation between salt and blood pressure. This theory is supported by a study demonstrating a correlation of 0.71 between sodium excretion and blood pressure in a small sample of subjects with family histories of hypertension. This study has been criticized, however, and another study found no increase in salt sensitivity among persons with family histories of hypertension. Nevertheless, this area of research clearly deserves further attention.

Plasma renin activity was correlated with only one blood pressure factor, diastolic pressure before blood drawing. Its strongest correlation, 0.132, was with resting pulse. This variable would not be expected to correlate highly with blood pressure, since both high renin and low renin levels are associated with hypertension. In addition, many persons with normal renin levels are hypertensive.

In spite of the intuitive appeal of a positive relationship between psychological stress and blood pressure, the evidence is conflicting. Some reports show a positive relationship between blood pressure and general stress levels measured by personality tests, while others do not. This inconsistency, combined with skepticism as to the reliability of personality tests, has led reviewers to conclude that there is little solid evidence for a relationship between psychological stress and blood pressure. The results presented herein indicate a weak but significant positive relationship between self-perceived stress level and systolic blood pressure \( r = 0.10 \). Stress remained an important predictive variable when other risk variables were controlled in the multiple regression. Thus, its effect is not mediated by obesity or salt intake, as has been suggested previously. It is particularly interesting that the
correlation was much stronger in the subset of subjects older than 35 years of age. This finding would be expected if stress has a cumulative effect on blood pressure.49 It is also noteworthy that stress showed no positive correlations with any of the blood pressure or pulse factors measured under stress conditions (blood drawing or handgrip exercise).

As noted previously, some of the correlations of exercise with the dependent factors were in the expected direction while others were not. All of the correlations were weak. Some studies have shown that exercise can decrease blood pressure in hypertensive persons and that the effect is independent of obesity.20,52 Population-wide studies, however, tend to show little evidence of a consistent relationship between exercise level and blood pressure.12 One problem in such studies, and one that may have affected the present study, is the difficulty of obtaining accurate assessments of exercise levels through questionnaires.53

The multiple correlation values, which ranged from 0.189 to 0.524, indicate that most of the variance in the dependent factors is not explained by this set of independent variables. A scatter plot of most pairs of dependent and independent variables would undoubtedly show a large dispersion about a regression line. Other studies in which multiple variables have been examined have also obtained multiple correlations ranging from 0.1 to 0.5.4,13 As in this study, Stamler et al.3 found that the amount of explained variance was greater for systolic blood pressure than for diastolic blood pressure.

The level of these correlations reflects some of the limitations of these types of studies. First, linear relationships are assumed to exist between all pairs of variables. This is not always the case, as demonstrated by the curvilinear relationships often found between blood pressure and both alcohol consumption and plasma renin. Also, considerable heterogeneity exists in most study populations with regard to risk factors. For example, some people may be salt-sensitive, while others are not. Finally, the effects of other variables not measured in this study may be partly responsible for the relatively low correlation coefficients. The advantage of this type of study is that the effects of a large number of variables can be assessed independently, and, in this study in particular, their effects on many different aspects of blood pressure can be evaluated to understand better the physiological variation underlying risk factors for high blood pressure.

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