Blood Pressure and Obesity

By H. M. Whyte, D.Phil.

Previous surveys have shown that height of observed blood pressure and degree of overweight are related. However, excess weight does not necessarily mean excess fat and the possibility of error in the measurement of blood pressure due to variations in the size of the arm has not been excluded. The present survey, taking these factors into account, shows that blood pressure is influenced by the total bulk of the body but not especially by fat except insofar as it contributes to total bulk. A possible explanation of the findings is offered.

IT IS WIDELY accepted that hypertension is more common among the obese than among the lean and that a positive relationship exists between the level of blood pressure and the degree of obesity. The evidence upon which these common beliefs are based comes largely from numerous surveys that are fully discussed in standard books on blood pressure. However, there are several reasons why the conclusion that obesity and hypertension are related should not be accepted too readily.

Age has an important influence on blood pressure and care must be taken in analyzing observations to avoid confusion due to differences in age, even within relatively narrow age groups. Height and weight are obviously related and in seeking the true relationship between blood pressure and weight, or bulk, of the body, proper heed must be paid to variation in height among individuals. This is not easy and the problem is not satisfactorily overcome by referring to tables of standard weights or by using the ponderal index of bulk, weight per unit of height. Then there is the difficulty relating to the circumference of the arm. It is well established that our ordinary method of measuring blood pressure gives readings that are falsely high when the arm is big. Since big people generally have big arms, this error will exaggerate any true association that might exist between obesity and blood pressure. In analyzing the results of a survey among more than 17,000 individuals, Bøe and co-workers drew the conclusion that age has a very marked influence on blood pressure, whereas the influence of weight, relative to age and height is very small. Indeed, when corrections were made for the probable errors attributable to size of arm, in the small number of subjects in which arm circumference was measured, it seemed that weight, or obesity, had no significant effect on blood pressure.

Thus, 3 factors likely to obscure the true relation between obesity and blood pressure are age, height, and size of arm. No previous surveys, to my knowledge, have taken into account all 3 of these factors, nor a fourth very important factor, obesity itself. It has always been assumed that excess weight is a measure of excess fat.

We have been interested in reexamining the question of obesity and blood pressure, among the natives of New Guinea as well as in Australian men, taking into account these various factors. Skinfold thicknesses have been accepted as a measure of obesity. Neither the amount of fat nor the total bulk of the body had any demonstrable influence on blood pressure in the natives. In Australians, on the other hand, blood pressure was related to over-all bulk but not apparently to obesity per se. This latter conclusion was somewhat indefinite because of the influence of a wide age scatter and an unsatisfactory site for skinfold measurements. These drawbacks have been avoided in the survey which forms the subject of the present report.

From the Clinical Research Department, Kanematsu Institute, Sydney Hospital, Sydney, Australia.
TABLE 1.—Correlation Coefficients

<table>
<thead>
<tr>
<th></th>
<th>Systolic B.P.</th>
<th>Diastolic B.P.</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>Arm circumference</th>
<th>Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diastolic B.P.</td>
<td>+.583*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>+.049†</td>
<td>+.019†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>-.005†</td>
<td>-.038†</td>
<td>+.127†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>+.419*</td>
<td>+.373*</td>
<td>+.150†</td>
<td></td>
<td>+.481*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm circumference</td>
<td>+.417*</td>
<td>+.399*</td>
<td>+.139†</td>
<td>+.156†</td>
<td>+.733*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat</td>
<td>+.347*</td>
<td>+.306*</td>
<td>+.094†</td>
<td>+.003†</td>
<td>+.698*</td>
<td>+.573*</td>
<td></td>
</tr>
<tr>
<td>Serum cholesterol</td>
<td>-.028†</td>
<td>+.040†</td>
<td>+.290‡</td>
<td>+.203§</td>
<td>+.233§</td>
<td>+.105†</td>
<td>+.071†</td>
</tr>
</tbody>
</table>

*To 0.1 per cent level of probability.  
†Not significant of probability.  
‡To 1 per cent level of probability.  
§To 5 per cent level of probability.

METHODS

Observations were made on 100 apparently healthy men, 20 to 40 years of age. Height, without shoes, to the nearest inch was recorded, and weight, allowing for clothes, was recorded to the nearest pound. Circumference of the right upper arm was measured in centimeters. Subcutaneous fat was measured as the width, to the nearest millimeter, of the double fold of skin and subcutaneous fat that could be pinched up at each of 3 sites: para-umbilical, over the triceps, and over the inferior angle of the scapula. Measurements are valid only for the purpose of making comparisons, since the spring calipers which were used had spherical contacts and their closing pressure varied with thickness. The sum of measurements made in the 3 sites was used as an index of fatness.

Blood pressure was measured in the sitting position from the right arm with an aneroid type of machine, which was frequently checked against a mercury manometer. The cuff was 13 cm. wide and of the type fitted with metal braces and a clip. Pressure was recorded to the nearest even number of millimeters, the diastolic being taken at the point of disappearance of sound. Blood pressures were by no means basal, as most of the subjects were prospective donors of blood. It has been assumed that the obese and the lean did not differ in their reaction to the circumstances of the examination.

A sample of blood was taken at the conclusion of each subject’s donation of blood, and serum cholesterol was measured by the method of Abel and colleagues. The serum cholesterol level was also measured before blood donation in 10 subjects and found to be 2.8 per cent higher than the post-donation level.

RESULTS

Average values found in this series, together with standard deviations, were as follows: age 27.5 ± 4.9 years, height 69.0 ± 2.7 inches, weight 159.8 ± 22.6 pounds, circumference of arm 28.3 ± 2.5 cm., fat measurement 38.0 ± 14.6 mm., systolic blood pressure 132.5 ± 15.3 mm. Hg, and diastolic pressure 80.6 ± 11.2 mm. Hg. The total fat measurement was made up of abdominal fat 15.7 mm., arm fat 10.1 mm., and fat over the scapula 12.2 cm. The average weight relative to age and height was 107 per cent of the standard drawn from the tables of the Metropolitan Life Insurance Company; 95 per cent of observations fell between the limits of 80 and 134 per cent.

The coefficient of correlation for each pair of attributes is shown in table 1. The true significance of these coefficients is obscured by the fact that they take account of only 2 attributes while ignoring all others: the coefficient is made up of contributions from correlations involving the hidden attributes as well as the true correlation between the nominated attributes. For this reason partial correlation coefficients and regression equations were calculated to test the truth of the principal relationships in question.

Blood Pressure and Body Weight

The simple correlation coefficients indicate a strong correlation between blood pressure and body weight, as illustrated in figure 1. However, as weight is also related to height, fatness, and circumference of the arm, a positive relationship between blood pressure and
any of these other features could be causing an erroneous impression of the influence of weight on blood pressure. Age appeared to exert no influence. When allowance was made for the possible influences of age, height, fatness, and size of arm, there still remained a significant relationship between blood pressure and body weight that was significant at a 5 per cent level of probability (partial correlation coefficients were 0.243 for systolic and 0.223 for diastolic pressure). This is illustrated in figure 2 and means that blood pressure would be expected to increase with body weight in a population of men who were of uniform age and height and had the same size of arm and thickness of subcutaneous fat. The reduction in size of the coefficient when these other factors were taken into account was due mostly to the influence of size of arm, partly to height, and not at all to age and fatness.

Another indication of the relative importance of the influence of each of these factors on blood pressure comes from the regression equations. When each of the variables is expressed in its 'normalized' form, that is, as deviation from its mean divided by the standard deviation, the regression coefficients are closely analogous to partial correlation coefficients and prove a measure of the relative importance of each item. The best fitting linear relationships expressed in these terms were found to be as follows:

Systolic pressure = +0.513 (weight) - 0.004 (age) - 0.272 (height) - 0.086 (fat) + 0.133 (arm size) (r = +0.241)

Diastolic pressure = +0.482 (weight) - 0.028 (age) - 0.292 (height) - 0.122 (fat) + 0.165 (arm size) (r = +0.220)

With the other variables being held constant, it is obvious that weight exerts the greatest influence on blood pressure. The negative influence of height is an indication that it is not the absolute body weight, but rather weight relative to height that is the important factor. When the data were analyzed in other ways, it was found that the best index of body bulk relative to height was given by the ratio,2 body weight/height. The partial correlation coefficients and regression coefficients derived by using this index were just as significant as when weight and height were included separately.

Expressed in ordinary units, the regression equations became:

Systolic pressure (mm. Hg) = 165 + 0.35 weight (lb.) - 0.01 age (yr.) - 1.55 height (in.) - 0.09 fat (mm.) + 0.81 arm size (em.)

Diastolic pressure (mm. Hg) = 111 + 0.24 weight (lb.) - 0.06 age (yr.) - 1.22 height (in.) - 0.09 fat (mm.) + 0.73 arm size (em.)
Blood Pressure and Circumference of the Arm

Although the simple correlation coefficients implied that blood pressure measured in the ordinary way was higher in subjects with larger arms—as would be expected in view of the observations made by Ragan and Bordley—the association lost significance when the possible influence of other factors was excluded. With constant age, weight, height, and fatness, the partial correlation coefficients for the relations between arm circumference and systolic pressure (+0.097) and between the arm circumference and diastolic pressure (+0.120) were not significant. It must be concluded that arm circumference and blood pressure, as measured in this group of men, were unrelated. An important factor here might be the type of cuff which was used—one with metal braces and clip and not the commoner sleeve type. If the magnitude of any discrepancy between true intra-arterial pressure and observed pressure was directly related to the circumference of the arm the results would imply that the true pressure varied inversely with the size of the arm. This seems unlikely.

The circumference of the arm of men in this study could be predicted reasonably well from the height and weight: arm circumference (cm.) = 179.4 - 2.4 height (in.) + 0.1 weight (lb.) \( r = +0.587 \).

Blood Pressure and Body Fat

Here, too, the simple correlation coefficients indicated a highly significant positive relationship (table 1 and fig. 1). However, when age, height, weight, and size of arm were held constant, the partial correlation coefficients became insignificant \(-0.060\) for the systolic and \(-0.084\) for the diastolic pressure), as illustrated in figure 2.

The insignificant influence of fatness on blood pressure, all other variables being held constant, is also evident from the regression equations mentioned previously.

Serum Cholesterol

The average level of serum cholesterol in this series and the standard deviation were \(214.7 \pm 42.7\) mg. per 100 ml. The cholesterol concentration appeared to be related to age, height, and weight. By the technic of partial correlation the association\(^2\) with height \((+0.091)\), weight \((+0.135)\), and weight/height \((+0.129)\) became unimportant but a significant relationship (to 1 per cent level of probability) with age remained \((+0.264)\). There was no evidence that the cholesterol level was related to the thickness of subcutaneous fat or the blood pressure.

Discussion

Two conclusions to be drawn from the observations made in this study are quite clearcut. The first is that the bigger and heavier a man is, in relation to his height, the higher will be his blood pressure. This is the same as most surveys have concluded. The second conclusion is that the composition of the excess weight is immaterial: it is the over-all bulk that counts, be it muscle or fat. Commonly, of course, it is fat.

To what extent is blood pressure affected by changes in weight? Assuming that the results of this survey can be applied to any one individual whose weight is changing, then the systolic pressure would be expected to rise by 10 mm. Hg and the diastolic by 7 mm. Hg for each increment of 28 pounds in body weight. This assumes there have been no concomitant changes in age, height, or arm circumference. If we take into consideration the average increase in size of arm to be expected with this gain in weight, then the rise in observed systolic and diastolic pressures would be of 12 and 9 mm. Hg respectively. The influence of weight on blood pressure in this group of men is 3 times greater than what has been reported among Norwegians.\(^5\) It is in sharp contrast with the complete lack of relationship between blood pressure and body bulk in natives of New Guinea.\(^6\)

Why should blood pressure increase with body weight? The following argument leads to a rather fanciful, though perhaps plausible, explanation. When weight increases, the bulk of tissue increases and there is an increase in the expenditure of energy and the demand
BLOOD PRESSURE AND OBESITY

for blood. The vascular bed and the cardiac output must increase: cardiac output seems to be related to surface area, which, of course, increases with bulk. But what happens to blood pressure when the augmented cardiac output is forced into an aorta and elastic arterial blood to output must increase in capacity as the body weight rose?

Let us assume that the size of the aorta does not increase. Then, taking average figures for pulse rate and cardiac output we can calculate the expected increase in cardiac stroke volume for any particular increase in body size. In addition, from the volume-pressure characteristics of the human aorta, we can predict the rise in pressure that this extra stroke volume will produce. Thus, for a man who is 30 years of age and 70 inches high the mean pressure would be predicted to rise by 17 mm. Hg when he increased in weight from 140 to 210 pounds. The actual observations in our own series, relating to a weight increase of this order, implied a rise in mean pressure of 21 mm. Hg (that is, from 124/74 to 149/91 mm. Hg for a man having an average arm circumference and fatness). The observed and predicted rises in pressure are not grossly dissimilar.

Finally, what part does cholesterol play in the ill effects of obesity? The results of this study show that the level of serum cholesterol rises with age but is not related to the level of blood pressure, obesity, or body weight. These topics have been discussed elsewhere.

If it is accepted that obesity or, rather, overweight predisposes to the development of coronary artery disease, then the evidence would force us to favor the “blood pressure” rather than the “cholesterol” school in the controversial matter of the pathogenesis of arterial disease. However, it is conceivable that the life-long bathing of arterial walls in serum containing high concentrations of cholesterol—which is a feature of our Western civilization—gradually impairs the volume-elasticity characteristics of the main arterial reservoir. This could be a factor in the association of a rising blood pressure with advancing age and with increasing body weight, both of which are prominent among Australians, whose average serum cholesterol concentration exceeds 200 mg. per cent, but absent among natives of New Guinea whose cholesterol level is only 130 mg. per cent.

The conclusion is that blood pressure is related to weight or bulk of the body, but not to obesity except insofar as it contributes to bulk. To outgrow one’s aorta might be one of the dangers of overeating.

SUMMARY

Measurements were made in 100 men, 20 to 40 years of age, of blood pressure, height, weight, skinfold thicknesses, circumference of the arm, and serum cholesterol.

Analysis showed a positive correlation between blood pressure and body weight, other factors being held constant. Obesity (judged by the thickness of subcutaneous fat) had no apparent influence on blood pressure except insofar as it affected the total body weight. Serum cholesterol concentration was related to age, but not to body weight or obesity.

An increase in body weight of 28 pounds, without any change in arm circumference, was associated with an increase of 10 mm. Hg systolic and 7 mm. Hg diastolic pressure.

The contrast between these results and observations among natives in New Guinea are discussed briefly and a possible explanation is suggested.

ACKNOWLEDGMENT

I am grateful to the Red Cross Blood Transfusion Service for cooperation in this study, to Dr. C. L. Hamblin, of the Department of Humanities, University of New South Wales, for assisting with the mathematical analyses, and to Miss Iris Yee for technical assistance.

SUMMARIO IN INTERLINGUA

Esseva effectuate—in 100 masculos de etates de inter 20 e 40 annos—mesuraciones del presion de sangui, del altor, del peso, del spis-sitate de plicas cutaneae, del circumferentia brachial, e del cholesterol del sero.

Le analyse del datos revelava un correlation positive inter le pression de sanguine e le peso del corpore (con le altere factores tenite a nivellos constante). Obesitate—in tanto que
reflectit in le spissatate del grassia subeuntane-exerceeva nulle apparente influentia super le pression de sanguine, excepte via su effeeto super le total peso corporee. Le concentration del cholesterol seral esseeva relationate al etate del subjectos sed non a lor peso corporee o a lor obesitate.

Un augmento del peso corporee per 28 libras—non accompaniate de un alteration del circumferentia brachial—esseeva associate con un augmento de 10 mm de Hg in le pression systolice e de 7 mm de Hg in le pression diastolice.

Le contrasto inter iste resultatos e observazioni in nativos de Nove Guinea es discutite brevemente. Un explication possibile de iste contrasto es suggeste.

REFERENCES
