ARTERIAL PRESSURE AND ARM CIRCUMFERENCE

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The relation between sphygmomanometer reading and arm circumference is of more than academic interest. It has obvious implications in the field of population studies in that arm circumference varies with sex, age, weight, and physical demands of occupation, while, at the clinical level, whether or not a man is accepted for life insurance or for an occupation such as crane or lorry driving may turn on an estimate of his arterial pressure made with a sphygmomanometer. Yet evidence about the relationship remains inconclusive and confusing.

Ragan and Bordley (1941) compared, for 51 subjects, the direct measurement of arterial pressure taken in one arm by the intra-arterial method of Hamilton with the indirect measurement of pressure taken simultaneously in the other arm by a standard mercury sphygmomanometer. They found that there was a tendency for indirect readings to be lower than intra-arterial readings for subjects with thin arms and higher for subjects with thick arms. But their data which did not include body weight, were derived from a small, mixed (male and female), and very unrepresentative sample. (Some of the subjects were suffering from hypertension, others had syphilitic aortitis, and their ages ranged from 19 to 60 years). Excluding thirteen subjects with aortic regurgitation or aortitis, Pickering, Roberts, and Sowry (1954) used the same data to draw up a Table of Corrections for arm circumference to be applied to sphygmomanometer readings. They admitted that the corrections might be misleading when used on individual readings, but claimed that they were well worth making for the comparison of large groups and then proceeded to apply them to their own data. Others have since followed their example (Miall and Oldham, 1955).

More recently, however, Holland and Humerfelt (1964) have failed to demonstrate any relationship between arm circumference and the difference

between simultaneously taken direct and indirect measurements of arterial pressure, although they did find a positive correlation between arm circumference and the direct intra-arterial readings. But their report is incomplete, in view of the fact that it does not take body weight into account; for arm circumference is highly correlated with weight, and weight itself is known to be related to indirect readings of arterial pressure (Bøe, Humerfelt, and Wedervang, 1957; Society of Actuaries, 1959).

In an analysis of data on physique, occupation, and indirect readings of arterial pressure in a population of more than 5,000 employed men between the ages of 15 and 69 years, Lowe (1964) has confirmed that, for a given age, sphygmomanometer readings increase with body weight and that weight and arm circumference are highly correlated. When he corrected for weight, he found that the effect of arm circumference upon pressure reading was negligible and he concluded that the greater part, perhaps all, of the observed relationship between arm circumference and sphygmomanometer reading was attributable to the close association between arm circumference and weight. His conclusion can be criticized, however, on the ground that it is based on the combined readings of twelve different observers, for he had already shown (Lowe and McKeown, 1962) that the observers differed widely in the level at which they recorded systolic and diastolic pressure measurements in comparable populations. In what follows some of the same data are subjected to a more rigorous analysis to meet this objection.

MATERIAL AND METHODS

In March, 1960, twelve medically qualified observers recorded the arterial pressure of 5,239 men as they attended a mobile mass radiography unit

which was visiting their firm. Using mercury sphygmomanometers with standard cuffs, they read systolic pressure as the point at which sounds first appeared and diastolic pressure as the point at which they became muffled. The men were weighed without coats, waistcoats, and shoes, and their arm circumference was taken at the mid point of the right arm, with the arm hanging loosely by the side (Lowe and McKeown, 1962).

The analysis which follows is concerned only with men aged 45 to 69 years and is limited to data collected by those five observers who each examined more than 150 men in that age range. By means of an electronic computer, multiple regression analysis of systolic pressure on age, weight, and arm circumference was applied within each of the five observers and the procedure was repeated for diastolic pressure. The abbreviated Doolittle technique (Anderson and Bancroft, 1952) was used to solve the variance, covariance matrix. This method gives the progressive reduction in the sum of squares attributable to the variable concerned after adjusting for the previous variable or variables (e.g. the sum of squares for weight adjusted for age, and for arm circumference adjusted for both age and weight). The approach was first to consider in respect of systolic and diastolic pressure readings:

- If information on age by itself was of value;
- If weight added any more information;
- If arm circumference contributed anything further not contained in (a) and (b).

The analysis was then repeated, taking the variables in the order: age; arm circumference; and weight.

RESULTS

The five samples of men examined by the five medical observers (Table I) were very similar in respect of age and arm circumference and reasonably comparable in respect of weight. (The men in Observer E's sample were somewhat heavier than in the other samples). But the levels at which the observers read systolic and diastolic pressures were

strikingly different. Mean systolic pressure varied from 127.3 (Observer A) to 143.5 (Observer E), a range of 16.2 mm. Variation between the observers in their reading of diastolic pressure was much less, ranging from 81.2 (Observer B) to 83.9 (Observer C), a difference between the extremes of only 2.7 mm. As shown in previous publications (Lowe and McKeown, 1962; Lowe, 1964), there appeared to be no relationship between the level at which an observer read systolic pressure and the level at which he might be expected to read diastolic pressure. For example, Observer A recorded the lowest mean systolic pressure (127.3) and one of the highest mean diastolic pressures (83.8).

Table II (opposite) gives the zero order correlations between the five variables (systolic and diastolic pressures, age, weight, and arm circumference) for each of the five samples. If consistency as well as statistical significance is taken into account, the data display a clear though complex pattern.

First, the correlations of age with both systolic and diastolic pressure are positive for each of the five observers, and within each observer the correlation of age is higher with systolic than with diastolic pressure.

Secondly, the correlations of weight with both systolic and diastolic pressure are all positive (with the exception of systolic pressure read by Observer A), but in contrast to the relationship with age, the correlation is in every case lower for systolic than for the corresponding diastolic pressure.

Thirdly, for these middle-aged and elderly men, the correlations of age with both weight and arm circumference are uniformly negative (except in the case of Observer D); so that any adjustment for age will increase the first order correlations between pressure and weight or arm circumference.

Finally, and most important, arm circumference and body weight are themselves highly correlated (the correlation ranges from +0.6058 for Observer A to +0.8345 for Observer C); and, since for each observer the correlation between weight and

TABLE I
MEAN AND STANDARD DEVIATION OF SYSTOLIC AND DIASTOLIC BLOOD PRESSURE, AGE, BODY WEIGHT AND ARM CIRCUMFERENCE AS READ BY FIVE OBSERVERS

Variable	Observer				
	A	B	C	D	E
Systolic Pressure (mm.)	127.3 ± 17.7	137.9 ± 23.7	140.4 ± 23.6	141.7 ± 26.6	143.5 ± 25.1
Diastolic Pressure (mm.)	83.8 ± 12.8	81.2 ± 11.6	83.9 ± 13.5	81.8 ± 12.8	81.8 ± 13.2
Age (yrs)	53.8 ± 5.7	54.8 ± 5.8	54.1 ± 5.8	53.8 ± 5.7	53.4 ± 5.7
Weight (lb.)	157.6 ± 24.0	157.1 ± 22.4	159.0 ± 25.0	157.6 ± 24.0	162.4 ± 26.2
Arm Circumference (cm.)	28.3 ± 2.3	28.0 ± 2.3	28.5 ± 2.5	28.3 ± 2.3	28.7 ± 2.5
Size of Sample	159	199	232	206	210

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TABLE II

ZERO ORDER CORRELATION COEFFICIENTS BETWEEN SYSTOLIC PRESSURE, DIASTOLIC PRESSURE, AGE, BODY WEIGHT, AND ARM CIRCUMFERENCE

Observer	Variable	Variable				
		Systolic	Diastolic	Age	Weight	Arm
A	Systolic	1	·6337*	·2405*	·0715	·0918
	Diastolic		1	·0290	·0187	·0316
	Age			1	·1311	·2178*
	Weight				1	·6058*
	Arm					1
B	Systolic	1	·6516*	·2307*	·1476*	·0537
	Diastolic		1	·0908	·2332*	·1872
	Age			1	·0049	·1285
	Weight				1	·7842*
	Arm					1
C	Systolic	1	·6832*	·2040*	·0651	·0003
	Diastolic		1	·1118	·1125	·0422
	Age			1	·2208*	·3056*
	Weight				1	·8345*
	Arm					1
D	Systolic	1	·8388*	·3533*	·0842	·0399
	Diastolic		1	·2351*	·1856*	·1435*
	Age			1	·0323	·0233
	Weight				1	·8214*
	Arm					1
E	Systolic	1	·7307*	·1821*	·3844*	·2967*
	Diastolic		1	·0612	·4352*	·3525*
	Age			1	·1146	·1657*
	Weight				1	·8157*
	Arm					1

*All results significant at the conventional 5 per cent. level are starred in this and subsequent Tables.

pressure is consistently higher than the corresponding correlation between arm circumference and pressure

(with the one exception of diastolic pressure as read by Observer A), it seems likely that the association between arm circumference and pressure is an indirect one, due to the high correlation between arm circumference and weight.

This is confirmed by the regression analysis within each observer for systolic and diastolic pressures on age, weight, and arm circumference. When the independent variables are considered in the order age, weight, and arm circumference, it is seen that for systolic pressure (Table III) age is a significant predictor for all five observers (line 2). The additional information provided by weight is of significance only for Observers B and E (line 4), while any further information provided by arm circumference is of no significance for any observer (line 5).

On the other hand, for diastolic pressure (Table IV, overleaf) age is a substantial predictor only for Observer D (line 2) but weight is of significance for all observers except A (line 4). And, once again, the additional information provided by arm circumference is trivial (line 5).

When the independent variables are considered in the order age, arm circumference, and weight (Tables III and IV, lines 6 and 7), it is seen that weight still makes a significant reduction to the sum of squares even after the effect of age and arm circumference has been removed. This again indicates

TABLE III

REGRESSION ANALYSIS OF SYSTOLIC PRESSURE ON AGE, BODY WEIGHT, AND ARM CIRCUMFERENCE

Line No.	Source of Variation	Observer A			Observer B			Observer C			Observer D			Observer E		
		d.f.	SS	F	d.f.	SS	F	d.f.	SS	F	d.f.	SS	F	d.f.	SS	F
1	Total	158	49717†		198	110939		231	128299		205	145208		209	131775	
2	Age	1	2874	9·53*	1	5917	11·28*	1	5331	10·04*	1	18157	29·06*	1	4376	8·38*
3	Body Weight and Arm Circumference after Age	2	101	<1	2	2782	2·65	2	1949	1·83	2	830	<1	2	21934	21·41
4	Body Weight after Age	1	81	<1	1	2454	4·68*	1	1633	3·08	1	771	1·24	1	21933	42·84*
5	Arm Circumference after Age and Body Weight	1	20	<1	1	328	<1	1	316	<1	1	59	<1	1	1	<1
6	Arm Circumference after Age	1	80	<1	1	786	1·49	1	546	1·03	1	341	<1	1	14486	28·24*
7	Body Weight after Age and Arm Circumference	1	21	<1	1	1996	3·80	1	1403	2·64	1	489	<1	1	7448	14·54*
8	Deviations from Regression	155	46742		195	102240		228	121019		202	126221		206	105466	
9	Mean Square		301·6			524·3			530·8			624·8			512	

†Age is considered in code: 45-49=1; 50-54=2; etc. d.f.=Degrees of Freedom: SS=Sum of Squares:

$$F = \frac{\text{Mean square of corresponding variable or variables}}{\text{Mean square of deviations from regression}}$$

TABLE IV
REGRESSION ANALYSIS OF DIASTOLIC PRESSURE ON AGE, BODY WEIGHT, AND ARM CIRCUMFERENCE

Line No.	Source of Variation	Observer A			Observer B			Observer C			Observer D			Observer E		
		d.f.	SS	F	d.f.	SS	F	d.f.	SS	F	d.f.	SS	F	d.f.	SS	F
1	Total	158	15461		198	26660		231	41872		205	33837		209	36375	
2	Age	1	13	<1	1	220	1.71	1	523	2.94	1	1874	12.25*	1	137	<1
3	Body Weight and Arm Circumference	2	23	<1	2	1474	5.75*	2	999	2.80	2	1075	3.52	2	7213	25.59*
4	Body Weight Alone	1	8	<1	1	1456	11.37*	1	829	4.66*	1	1074	7.02*	1	7209	51.16*
5	Arm Circumference after Body Weight	1	15	<1	1	18	<1	1	170	<1	1	1	<1	1	4	<1
6	Arm Circumference Alone	1	13	<1	1	1073	8.38*	1	270	1.52	1	753	4.92*	1	4922	34.93*
7	Body Weight after Arm Circumference	1	10	<1	1	403	3.15	1	729	4.10*	1	322	2.10	1	2291	16.29*
8	Deviations from Regression	155	15425		195	24966		227	40350		202	30888		206	29025	
9	Mean Square		99.5			128			177.8			152.9			140.9	

†Age is considered in code: 45-49 = 1; 50-54 = 2; etc. d.f. = Degrees of Freedom: SS = Sum of Squares:

$$F = \frac{\text{Mean square of corresponding variable or variables}}{\text{Mean square of deviations from regression}}$$

that, of the two variables weight and arm circumference, only weight is of any importance.

In Table V partial regression coefficients for systolic and diastolic pressure in respect of age and weight are given separately for each observer. (Arm circumference has been deleted because our analysis shows that in the presence of body weight it is unnecessary.) Clearly the observers differed not only in respect of the level at which they read systolic and diastolic pressure in comparable populations, but also in respect of their measurement of the trend of pressure with age and weight. (The regression surfaces of systolic and diastolic pressure on age and weight were, for the five observers, significantly non-parallel). However, as approximate indices of those trends, it can be assumed that in a population of men over the age of 45 years there will be a mean increase of about 1 mm. in systolic pressure for each additional year of life and an increase of about 1 mm. in diastolic pressure for every 10 lb. increment in body weight. It must be emphasized that these estimates apply only to the cross-sectional pattern

of arterial pressure in the general population of men who have survived to and are still working at ages above 45 years. Mortality is directly related to weight and arterial pressure (Society of Actuaries, 1959), so it cannot be assumed that as individual men age or put on weight their pressures will increase in the same way.

DISCUSSION

Our analysis indicates that, of the three variables considered (age, body weight, and arm circumference), only age and body weight appear to be significant predictors for sphygmomanometer readings of systolic and diastolic arterial pressure. Age has a more pronounced effect on systolic than on diastolic pressure, while diastolic pressure is relatively more sensitive to differences in body weight. It should be borne in mind, however, that even when these two variables are taken together they account for less than 10 per cent. of the total variation.

It seems quite clear that the influence of arm circumference upon sphygmomanometer readings is

TABLE V
MEAN AND PARTIAL REGRESSION COEFFICIENTS FOR SYSTOLIC AND DIASTOLIC PRESSURES IN RESPECT OF AGE AND WEIGHT

Observer	Systolic			Diastolic		
	Mean (mm.)	b_1 mm. per 5 years	b_2 mm. per lb.	Mean (mm.)	b_1 mm. per 5 years	b_2 mm. per lb.
A	127.3	3.57*	-.03	83.8	.27	.01
B	137.9	4.67*	.16*	81.2	.91	.12*
C	140.4	4.61*	.11	83.9	1.65	.08*
D	141.7	8.16*	.08	81.8	2.57*	.10*
E	143.5	5.05*	.39*	81.8	1.30	.23*

indirect only and is due to its high correlation with body weight. In effect, therefore, any attempt to "correct" sphygmomanometer pressure readings for arm circumference (Pickering and others 1954; Miall and Oldham, 1955) will eliminate the important influence of body weight. But there still seems to be need for further research on the inter-relation between indirect and intra-arterial measurements of blood pressure and arm circumference and weight.

Observer differences in the reading of arterial pressure are so great, not only in respect of the level at which pressure is read but also in respect of its trend with age and weight, that between-survey differences are as likely to be due to differences between observers as to differences between the populations observed. For internal comparisons, investigations carried out by one observer have a clear advantage. But for between-survey comparisons, five or more observers are probably necessary, and the statistical analysis will need to be carried out for each observer separately.

SUMMARY

From a regression analysis of data on systolic and diastolic pressures and age, weight, and arm circumference collected by five different observers in a population of employed men aged 45 to 69 years, it appears that the reported relationship between arm circumference and sphygmomanometer reading is an indirect one, and is due to the high correlation

between arm circumference and body weight. It appears, therefore, that to correct sphygmomanometer readings for arm circumference is probably to eliminate the effect of body weight.

The data in this paper were collected when Prof. C. R. Lowe was a member of the Department of Social Medicine, University of Birmingham. It is with pleasure that he acknowledges his indebtedness to Prof. T. McKeown for his advice and support and to the General Electric Company Ltd for permission to interview and examine their employees. Mr T. Khosla wishes to thank the Department of Physics, University College, Cardiff, for granting him access to their electronic computer and the Welsh Hospital Board for access to their tabulators.

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