Measurement of Blood-pressure: Comparison of Intra-arterial and Cuff Values

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In recent years numerous reports have appeared—for example, Pickering (1955)—of discrepancies between arterial blood-pressure measured by an intra-arterial method and by the usual cuff and sphygmomanometer. Part of this discrepancy has been attributed to the effect of arm circumference on arterial pressure measured with a cuff. Corrections based on measurements made by Ragan and Bordley (1941) have been published by Pickering, Roberts and Sowry (1954).

While several workers report good agreement between systolic blood-pressure determined by the intra-arterial and that by the cuff method, there is disagreement over which of the two phases (phase 4, muffling, or phase 5, disappearance) represents the true diastolic pressure.

Ragan and Bordley (1941) state that the pressure represented by sudden muffling (phase 4) of the Korotkoff sounds was usually higher than the intra-arterial pressure. Hamilton, Woodbury, and Harper (1936) found the diastolic pressure to be 9 mm. higher than the intra-arterial pressure when muffling was used as the end-point. Steele (1942) noted that the final cessation of sounds approximated to the intra-arterial diastolic pressure more closely than did muffling. However, Roberts, Smiley, and Manning (1953), using a strain-gauge manometer and an electromanometer (condenser microphone), concluded that muffling of the sounds bears a more constant and close relation to the "true" diastolic pressure. Van Bergen, Weatherhead, Treloar, Dobkin, and Buckley (1954) came to the same conclusion using a standard resistance wire pressure-transducer. The latter workers found that the disappearance of sound grossly underestimated the intra-arterial diastolic blood-pressure.

Recent work (Holland, 1963; Rose, Holland, and Crowley 1964) has shown that blood-pressure measured by a normal sphygmomanometer can be affected by observer bias. The present comparisons of intra-arterial with cuff pressure were made using a London School of Hygiene sphygmomanometer (Holland, 1963) to avoid the possibility of observer bias.

Method

Intra-arterial brachial-artery pressure was measured in the right arm by use of a Hansen (1949) capacitance manometer. This method has been utilized by Sharpey-Schafer (1955) and others in the Department of Medicine, St. Thomas's Hospital, over many years in more than 5,000 individuals. Cuff arterial pressure was measured in the left arm with a standard cuff (12 by 24 cm.) and the London School of Hygiene sphygmomanometer.

Before starting the investigation the blood-pressure of subjects was measured simultaneously in both arms by two observers by connecting two cuffs to a common manometer via a T-junction. In no case was the difference between left and right arms greater than 5 mm. Hg.

Intra-arterial blood-pressure was measured continuously during the course of the experiment. Cuff blood-pressure was measured on three occasions in each individual at intervals of about five minutes. In all calculations reported below the mean of three readings taken was used.

Systolic and both phase 4 (sudden onset of muffling) and phase 5 (complete disappearance of sounds) diastolic pressures were recorded in the left arm. These end-points were signalled electrically on to the intra-arterial record. Intra-arterial systolic and diastolic pressures were read off at these points (Fig. 1).

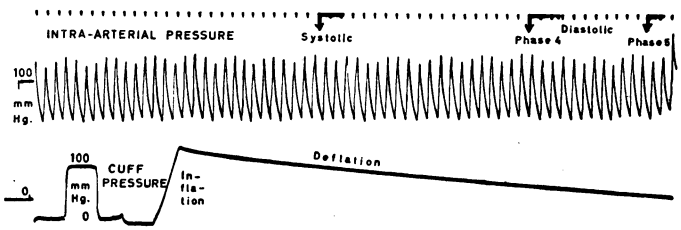

FIG. 1.—Intra-arterial pressure (upper) and pressure within cuff. Note constant speed of inflation and deflation. The arrows mark the signals for systolic and diastolic pressures.

Left mid-arm circumference was measured with a flexible steel tape measure. Skinfold thickness was measured below the angle of the scapula and over the triceps by use of Harpenden skinfold-thickness callipers (Edwards, Hammond, Healy, Tanner, and Whitehouse, 1955).

The 47 subjects (32 male, 15 female) in whom the measurements were made were patients and staff of St. Thomas's Hospital. Table I gives the age distribution and the diseases from which they suffered. All measurements of cuff arterial pressure were made by one observer (W. W. H.).

TABLE I.—*Details of the 47 Individuals Investigated*

Age (years)	No.	Diagnosis	No.
10–19	1	Normal	6
20–29	7	Cardiovascular system	11
30–39	14	Gastro-intestinal	10
40–49	4	Renal system	7
50–59	14	Respiratory system	4
60–69	7	Central nervous system	5
		Other	4

Results

Figs. 2 and 3 show the relation of pressure measured intra-arterially and that measured by cuff. It will be seen that on average both systolic and diastolic pressures measured directly are higher than when measured by the cuff method. The two methods, however, have a very high degree of correlation (coefficient of correlation = 0.95 (systolic), 0.83 (D4), and 0.93 (D5)).

Table II shows that the mean difference between systolic pressure measured by arterial cannula and cuff blood-pressure was 24.6 mm. Hg. For diastolic phase 4 pressure the difference between intra-arterial and cuff blood-pressures was 5.3 mm. and that for diastolic phase 5 was 13.1 mm. Thus the difference between intra-arterial and cuff blood-pressures is less for phase 4 than for phase 5 diastolic but the variance is greater.

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In order to determine whether these differences between intra-arterial and cuff blood-pressures could be due to age, separate correlation and regression coefficients have been calculated for those aged less than 50 and those aged 50 and more (Table III). The differences in the correlation and regression coefficients for these two groups are small and not statistically significant.

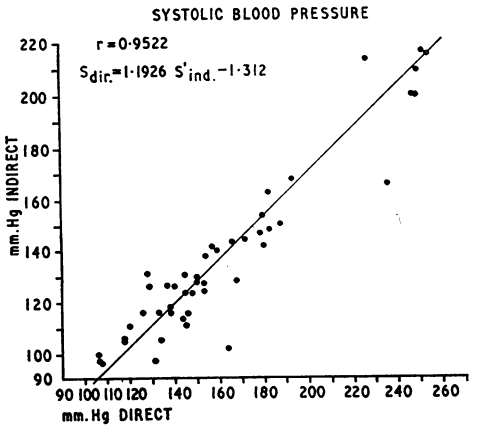

FIG. 2.—Relationship and regression line of intra-arterial and cuff systolic pressures.

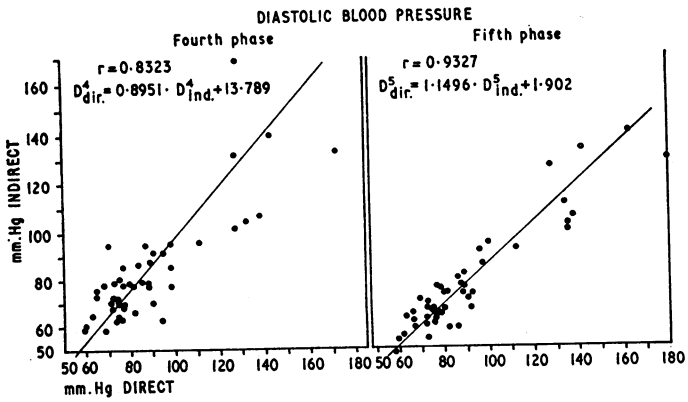

FIG. 3.—Relationship and regression lines of intra-arterial and cuff diastolic pressures.

TABLE II.—*Differences Between Intra-arterial and Cuff Blood-pressures*

Intra-arterial Pressure–Cuff Pressure (mm. Hg)	Systolic	Diastolic 1 (4th Phase)	Diastolic 2 (5th Phase)
+43 – +47	4		1
+38 – +42	4	1	2
+33 – +37	3	2	1
+28 – +32	6	2	3
+23 – +27	7	3	5
+18 – +22	6	3	9
+13 – +17	9	7	10
+8 – +12	5	7	11
+3 – +7	1	11	5
+2 – −2	1	5	
−3 – −7	1	4	
−8 – −12		1	
−13 – −17			
−18 – −22		1	
−23 – −27			
−28 – −32			
Total	47	47	47
Mean difference	+24·6	+5·3	+13·1
Standard deviation	14·0	13·9	9·5

To determine whether the differences between intra-arterial pressure and cuff pressure were dependent on the level of intra-arterial pressure, correlation coefficients have been calculated between the intra-arterial pressure and the difference between intra-arterial and cuff blood-pressures (Table IV). There is little correlation between the difference in intra-arterial systolic pressure and cuff pressure and the level of intra-arterial systolic pressure (coefficient of correlation 0.22). The relation between the level of diastolic fifth-phase blood-pressure and the difference between intra-arterial and cuff diastolic fifth-phase blood-pressures are correlated to a much greater degree (coefficient of correlation = 0.64). The correlation between the level of intra-arterial diastolic fourth-phase blood-pressure and the difference between intra-arterial and cuff diastolic fourth-phase blood-pressures lies between that of the last two.

TABLE III.—*Correlation of Intra-arterial Blood-pressure with Cuff Blood-pressure*

Measurement	Age-Group	Correlation Coefficient	Regression Coefficient and Standard Error of Arterial on Cuff Pressure	
Systolic	< 50 years	+0·90	1·179	±0·115
	50+ years	+0·95	1·194	±0·077
	Total	+0·95	1·193	±0·057
Diastolic (4th phase)	< 50 years	+0·88	1·222	±0·136
	50+ years	+0·81	0·746	±0·123
	Total	+0·83	0·895	±0·089
Diastolic (5th phase)	< 50 years	+0·92	1·249	±0·105
	50+ years	+0·93	1·098	±0·099
	Total	+0·93	1·150	±0·067

TABLE IV.—*Correlation of Intra-arterial Blood-pressure and Difference Between Intra-arterial and Cuff Blood-pressures*

Measurement	Correlation Coefficient
Systolic intra-arterial pressure and difference between systolic intra-arterial and cuff pressures	+0·22*
Diastolic (4th phase) intra-arterial pressure and difference between diastolic (4th phase) intra-arterial and cuff pressures	+0·39†
Diastolic (5th phase) intra-arterial pressure and difference between diastolic (5th phase) intra-arterial and cuff pressures	+0·64‡

* P < 0·1. † P = 0·01–0·001. ‡ P < 0·001.

The question of whether the difference between intra-arterial and cuff blood-pressures could be explained by an effect of arm circumference was investigated by calculating the correlation and regression coefficients between arm circumference and the difference in intra-arterial and cuff blood-pressures. The correlation between the difference in systolic intra-arterial and cuff pressures and arm circumference is barely significant at the 5% level. For diastolic fourth phase and diastolic fifth phase the correlation coefficients are not statistically significant (Table V).

TABLE V

Correlation of Difference between Blood-pressure Measured by Intra-arterial Cannula and Cuff Method and Arm Circumference

Measurement	Correlation Coefficient	Regression Equation of Difference in Pressure (mm. Hg) on Arm Circumference (in.)
Systolic	+0·318*	Y = 3·528x* − 9·27
Diastolic 1	+0·263	Y = 2·911x − 25·56
Diastolic 2	+0·226	Y = 1·696x − 4·14

* P < 0·05.

Correlation of Difference between Blood-pressure Measured by Intra-arterial Cannula and Cuff Method and Skinfold Thickness over Triceps Muscle

Measurement	Correlation Coefficient	Regression Equation of Difference in Pressure (mm. Hg) on Skinfold Thickness (Triceps) (mm.)
Systolic	+0·107	Y = 0·231x + 22·98
Diastolic 1	+0·199	Y = 0·444x − 0·807
Diastolic 2	+0·198	Y = 0·239x − 10·13

Correlation of Difference between Blood-pressure Measured by Intra-arterial Cannula and Cuff Method and Skinfold Thickness over Subscapular Muscle

Measurement	Correlation Coefficient	Regression Equation of Difference in Pressure (mm. Hg) on Skinfold Thickness (Subscapular) (mm.)
Systolic	+0·156	Y = 0·397x + 20·60
Diastolic 1	+0·157	Y = 0·404x − 12·23
Diastolic 2	+0·117	Y = 0·202x + 10·72

A further measure of subcutaneous tissue is provided by the skinfold thickness; this was measured over the triceps and at the angle of the scapula. Table V shows that there is no significant correlation between the difference in cuff and intra-arterial blood-pressures and the skinfold thickness, either over

the triceps muscle or over the subscapular muscle. However, Table VI shows that there is some relation between the arm circumference and the level of intra-arterial blood-pressure, in

TABLE VI.—*Relation of Intra-arterial Blood-pressure (mm. Hg) to Arm Circumference (in.)*

Measurement	Correlation Coefficient	Regression Coefficient and Standard Error of Arterial Blood-pressure on Arm Circumference
Systolic pressure ..	+0·44*	14·15 ± 4·51
Diastolic (5th phase) pressure	+0·43*	8·41 ± 2·69

*P < 0·01.

that the correlation coefficient for intra-arterial blood-pressure and arm circumference is statistically significant. From the equation calculated it may be seen that on average for each increase of 1 in. (2.5 cm.) in arm circumference the intra-arterial blood-pressure rises by 14 mm. Hg systolic and by 8.4 mm. Hg diastolic. The total association between intra-arterial blood-pressure and arm circumference is greater than that for intra-arterial blood-pressure and skinfold thickness over the triceps (coefficient of correlation: systolic = 0.32, diastolic fifth phase = 0.37).

Discussion

Pickering (1955) summarizes comparisons made between direct and indirect methods of measuring blood-pressure; he concludes that indirect methods will underestimate systolic and overestimate diastolic pressure in adults of normal weight, while in the very obese both values will be overestimated. Pickering *et al.* (1954) have utilized the readings made by Ragan and Bordley (1941) for presenting a set of equations for correcting the difference between intra-arterial and cuff blood-pressures for arm circumference. They show that such corrections may be important in differences found in levels of blood-pressure between population groups with different arm circumference.

The present work indicates that, using a Hansen manometer and a method of recording cuff blood-pressure without observer bias, the difference between direct and indirect methods are greater than has been assumed hitherto. It is also shown, however, that both these measures are very highly correlated for systolic and for diastolic pressure. It is confirmed that the differences between direct and indirect methods of blood-pressure are less for the diastolic fourth phase than for the diastolic fifth phase. This was, however, when one observer took all measurements of cuff blood-pressure. No significant relation has been found for the differences between intra-arterial and cuff blood-pressures and arm circumference or for the differences between indirect and direct blood-pressures and skinfold thickness. It has, however, been shown that there is some relation between the differences in indirect and direct blood-pressures and the level of direct blood-pressure, particularly with diastolic blood-pressure, and that the higher the direct blood-pressure the greater is the difference between direct and indirect blood-pressures. In addition, it is demonstrated that there is a correlation between the arm circumference and the level of direct arterial blood-pressure.

The difference in the results of our study compared with those of Ragan and Bordley (1941) may be due to different methods of measurement and selection of subjects. Eleven of Ragan and Bordley's patients had aortic incompetence; only one of ours had these signs. They used a Hamilton manometer and a cuff 13 cm. wide; in addition they had the assistance of a microphone to pick up the auscultatory sounds over the right antecubital fossa and an aneroid manometer to record cuff pressure.

The frequency response of our method and that of others may be different. Hansen (1949) gives full details of the frequency characteristics of the manometer with needles of varying lumen size in arterial-pressure measurements. The No. 25 needle and tubing used in our experiments was also tested and was slightly underdamped; the undamped natural frequency (w_0) was 319 cycles/second, with a driving frequency (w) of 10 the ratio (γ) of $w/w_0 = 0.03$. Thus the amplitude of response of the manometer cannot have been more than 1.02, since β, damping as a fraction of critical damping, was 0.16—that is, the tendency to overshoot is unlikely to have caused an error of more than 2%. This cannot, therefore, explain all the higher pressure found on intra-arterial than on cuff measurement. The Pitot effect of the intra-arterial needle lumen pointing into the stream, and therefore recording arterial end rather than lateral pressure, was not found to have an effect in the brachial artery unless the needle was introduced at a steep angle, which it never was. It is possible that by use of an observer able to exercise bias the level of indirect pressure may have been overestimated.

Different arms were used for the respective measurements in our experiment, and insertion of the needle into the artery may have disturbed the haemodynamics of the limb involved. To avoid this no measurements were taken for several minutes after insertion of the needle. Intra-arterial measurements were recorded for 10 to 20 minutes after the initial insertion, and though the level of pressure fell slightly in both arms over this period of time there was no effect on the difference between the intra-arterial and the cuff pressure. Although for all calculations the mean of the three cuff measurements has been taken in this paper, similar results were obtained when each reading was analysed separately.

The number of observations made in this series of experiments is not very great; it is possible that some relation between arm circumference and the difference in intra-arterial and cuff blood-pressures may have been missed. It is unlikely, however, that this is of such a magnitude that it is of any great importance in comparing levels of blood-pressure in different populations.

Summary

Comparison has been made between direct and indirect arterial blood-pressures in 47 subjects. Direct pressure was measured with the Hansen manometer; indirect pressure was measured by using the London School of Hygiene sphygmomanometer, which decreases observer variation. Indirect and direct blood-pressures are highly correlated. There are, however, differences between arterial and cuff blood-pressures, particularly for systolic pressure. The difference between indirect and direct blood-pressures cannot be accounted for by arm circumference or skinfold thickness. There is some correlation between the difference between direct pressure and indirect pressure and the level of direct pressure. Arm circumference was correlated with diastolic blood-pressure.

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