1982

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CHARACTERIZATION OF THE OSCILLOMETRIC METHOD FOR MEASURING INDIRECT BLOOD PRESSURE

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(Annals of Biomedical Engineering, Vol. 10(6), pp. 271-280, 1982)

ABSTRACT

In this study, human subjects and dogs were used to determine the ability of the oscillometric method to indicate systolic and diastolic pressure. In the human studies, the auscultatory method was used as the reference. In the animal studies, directly recorded blood pressure was used as the reference. The ability of the sudden increase in cuff pressure oscillations during cuff deflation to indicate systolic pressure was examined and found to overestimate systolic pressure slightly in man, but more in animals. Systolic pressure was encountered when the cuff pressure oscillations were about one half of their maximum amplitude. However, in both man and animals the ratio was not constant; although the range was less in man than in animals. Diastolic pressure was encountered when cuff pressure oscillation amplitude was about 0.8 of the maximal amplitude. This ratio for diastolic pressure was not constant over a range of diastolic pressure. The range of variability was less for man than for the dog.

Key words: Accuracy, Blood pressure, Hypertension, Oscillometric method, Systolic blood pressure, Diastolic blood pressure.

Supported by Grant #HL8947-03; National Heart, Lung, and Blood Institute, Bethesda, Maryland. C.F. Babbs was supported by Career Development Award HL-00587; National Heart, Lung, and Blood Institute, Bethesda, Maryland.

INTRODUCTION

The oscillometric method of measuring blood pressure, which uses the amplitude of cuff pressure oscillation, provides two transitions during cuff deflation: a sudden increase in oscillation amplitude, and a clear maximum amplitude of oscillations. It has been established by Posey et al. (10) and Mauck et al. (9) that the pressure for maximal oscillations corresponds to mean arterial pressure. Verification studies on man have been reported by Ramsey et al. (11) and Yelderman et al. (13).

There are commercially available oscillometric devices that indicate systolic, mean, and diastolic pressure. The criteria for identifying systolic and diastolic pressures from the amplitude of the oscillations are rarely provided. It is known that in some instruments, specified ratios of oscillation amplitude to maximum amplitude are used to identify systolic and diastolic pressure. The study reported herein, involving human and animal subjects, was carried out to characterize the oscillometric method in terms of the location of systolic and diastolic pressure on the spectrum of cuff pressure oscillations seen during cuff deflation.

METHODS AND MATERIALS

Human Subjects

In this study, 43 adult subjects were used, ranging in weight from 51.8 to 98.3 kg and in age from 18 to 59 years. From this group, 23 were selected on the basis of having the correct arm size for the standard 12-cm wide cuff (1). In this group of 23 subjects the ratio of cuff width to arm circumference ranged from 0.36 to 0.46, being within the AHA guidelines (6). Blood pressure was measured on the right arm (at heart level), using the 12-cm cuff, which contained a tiny contact microphone wholly within the air bladder (4). The microphone is a small piezoelectric element (5 x 2 x 2 mm), applied to the inner bladder wall, about one third of the cuff width, measured from the distal edge. The use of this technique permits obtaining very clear, high intensity Korotkoff sounds, which were monitored on a loudspeaker while cuff pressure was being reduced.

cuff pressure, the Korotkoff sounds, and cuff pressure oscillations were recorded simultaneously on a two-channel recorder (Model 2600 Gould, Cleveland, OH). The Korotkoff sounds were bandpass filtered (30-300 Hz) and superimposed on cuff pressure (5). The oscillations in cuff pressure were amplified and band-pass filtered (0.3-30 Hz) and recorded simultaneously, as shown in Figure 1.

The method of obtaining data consisted of placing the subject in the recumbent position for 5 min to obtain a basal state. The cuff was inflated, and then deflated to ensure that it was well seated on the arm. After this preliminary maneuver, three measurements were made on each resting subject. The cuff was inflated quickly to above 200 mmHg, and then deflated at a rate of 3 mmHg per heart beat. When the operator heard the first Korotkoff sound (Phase 1), a mark was placed on the cuff pressure record. When the point of silence (Phase 5) was reached, the cuff pressure record was marked again. Thus, systolic and diastolic pressures were obtained on an acoustic basis; the graphic record served only to identify the instant when phases 1 and 5 occurred.

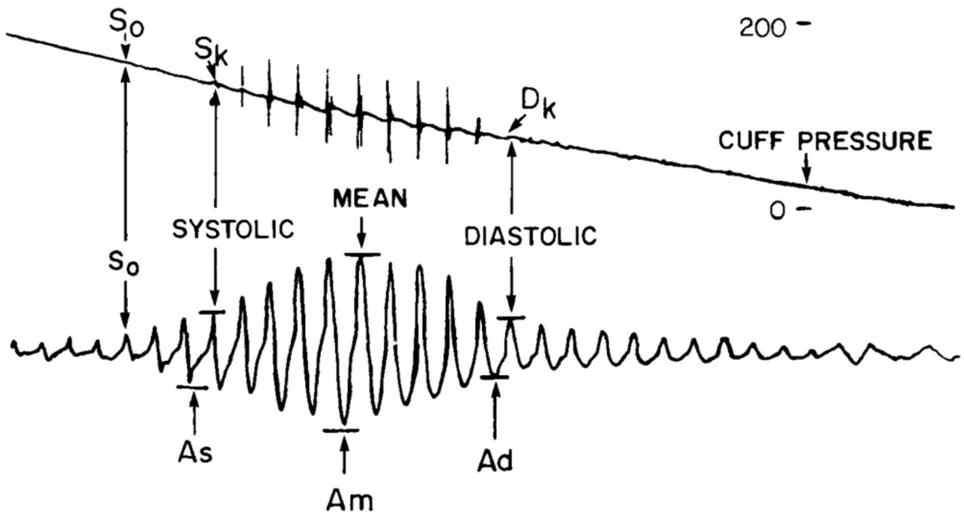

FIGURE 1. Cuff pressure with superimposed Korotkoff sounds and amplified oscillations in cuff pressure. The symbols identify the measurements used to identify systolic and diastolic pressure (see text).

After three measurements were made on each relaxed subject, blood pressure was elevated by stepping in place vigorously for about 2 min. Then the subject adopted a stiff squatting position with the postural-muscles contracted. This maneuver provided a maintained high peripheral resistance for long enough to obtain several measurements of elevated blood pressure.

Referring to Figure 1, four measurements were made: [1] cuff pressure (S_o) where the oscillations suddenly increased during cuff deflation; [2] the amplitude (A_s) of cuff pressure oscillations for auscultatory systolic pressure; [3] the amplitude (A_d) of cuff pressure oscillations for auscultatory (Phase 5) diastolic pressure; [4] the maximal amplitude of cuff pressure oscillations (A_m). From the measured data, the value of S_o (cuff pressure for the sudden increase in cuff pressure oscillations) was compared with auscultatory systolic pressure (S_K). The ratio S_o/S_K was plotted against auscultatory systolic pressure (S_K).

To test the constancy of a point A_s on the cuff pressure oscillations to indicate systolic pressure (S_K), A_s was measured and expressed as a ratio to A_m, cuff pressure for maximal oscillations, i.e., A_s/A_m was plotted versus S_K.

To test the constancy of a point (A_d) on the descending pattern of cuff pressure oscillations to identify diastolic pressure, the ratio of A_d/A_m was plotted versus auscultatory diastolic pressure (A_d).

In order to present the data in an easily-understood manner, the values for S_o/S_K, A_s/A_m and A_d/A_m were classified into ± 5 mmHg intervals. Means and standard deviations were calculated for each data class.

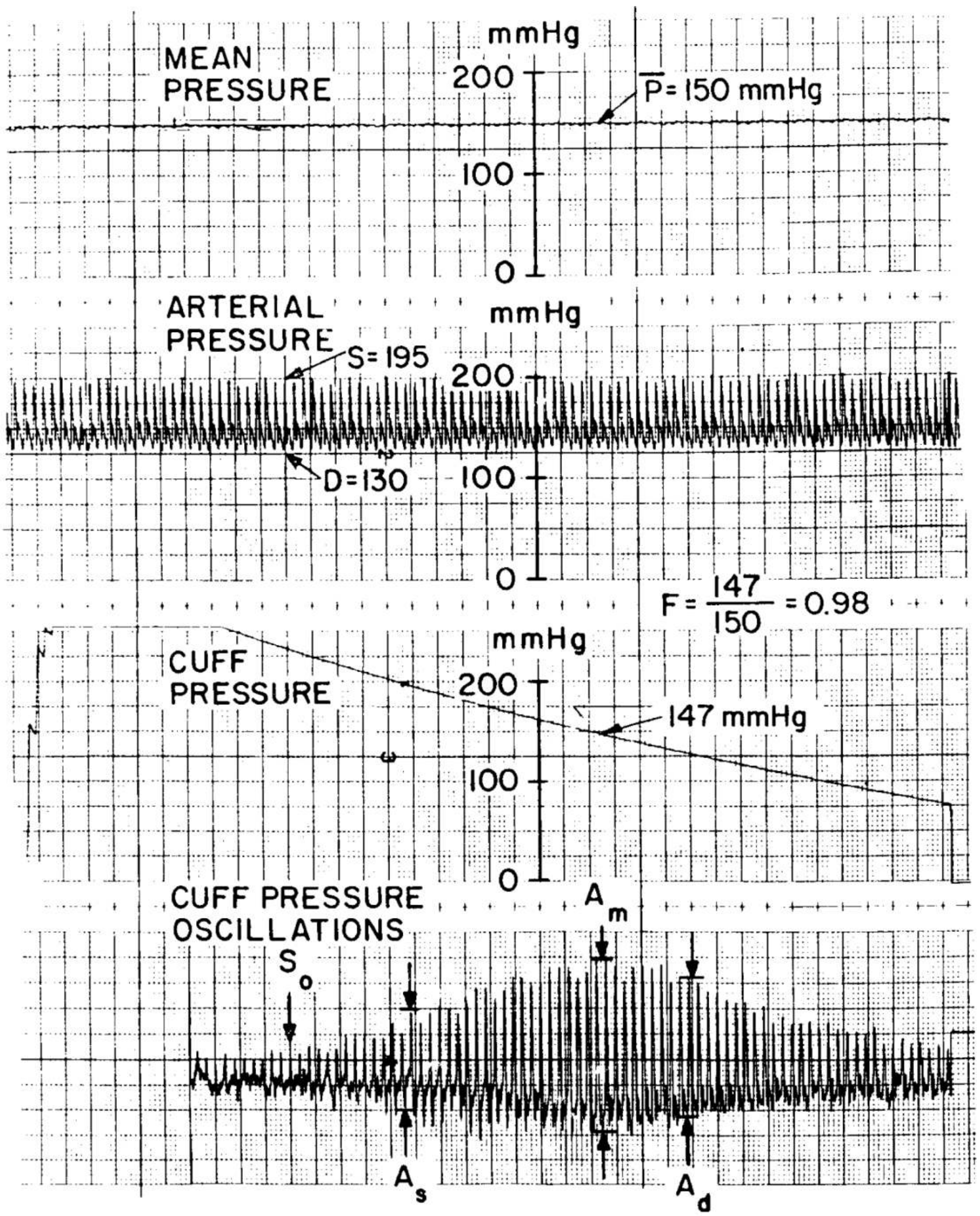

FIGURE 2. Mean arterial pressure, pulsatile arterial pressure, cuff pressure and amplified cuff pressure oscillations. S_o = cuff pressure for sudden increase in cuff pressure oscillations. A_s, A_m and A_d are amplitudes of cuff pressure oscillations at systolic, mean and diastolic pressures, respectively. F is the correction factor (cuff pressure for maximal oscillations divided by true mean arterial pressure P).

Animal Subjects

In this study 13 dogs, ranging in weight from 14 to 32 kg were used. The animals were anesthetized with sodium pentobarbital (30 mg/kg), intubated, and placed in the supine position. The forelimbs were used as the sites for measuring direct and indirect pressures. The brachial artery of one forelimb was catheterized and connected to a pressure transducer (Micro Switch Experimental Model; Micro Switch, Freeport, IL). To the other (shaved) forelimb, a disposable pediatric blood-pressure cuff was applied. Every effort was made to assure that the cuff width was between 33% and 40% of the forelimb circumference, which provided the best correlation between indirect and direct pressure for this limb in the dog (3). If the cuff pressure for maximum oscillations did not coincide with true mean arterial pressure, a scaling factor (F) was used to correct the systolic and diastolic pressures for more accurate comparisons. Usually this factor varied between 0.9 and 1.0. This linear extrapolation is justified on the basis of studies by Geddes et al. (2, 3) and Latshaw et al. (8).

Direct systolic, mean and diastolic arterial pressure, cuff pressure and its amplified oscillations (bandpass filtered 0.3 - 30 Hz), were recorded on a stripchart recorder (Gould; Cleveland, OH). Figure 2 illustrates a typical record.

The procedure consisted of inflating the cuff to well above systolic pressure; then it was deflated quickly: this maneuver seated the cuff. The cuff was then re-inflated quickly to well above systolic pressure and deflated at a rate of about 3 mmHg per heart beat. Cuff pressure for the maximum amplitude of oscillations was identified and compared with true mean arterial pressure. Then the ratio (F) of cuff pressure for maximal oscillations to true mean arterial pressure was calculated. This ratio identified the correctness of fit of the cuff; for a perfect fit F = 1.0. The value of F was used as a scaling factor to multiply true arterial systolic and diastolic pressure to obtain the corrected pressure. The amplitudes of cuff pressure oscillations corresponding to corrected systolic (A_s) and diastolic (A_d) pressure were measured. These amplitudes were expressed as ratios of the amplitude for maximum oscillations (A_m), namely, A_s/A_m and A_d/A_m. As stated previously, one of the goals was to determine if A_s/A_m and A_d/A_m are constant among all animals and in hypotensive and hypertensive states. Similarly, cuff pressure (S_o) for the sudden increase in cuff pressure oscillations was identified and related to corrected systolic pressure and examined for its ability to indicate systolic pressure.

After performing at least five measurements under normotensive conditions, blood pressure was raised incrementally with an intravenous drip of norepinephrine. Five determinations were made at each level of elevated pressure. Then blood pressure was lowered incrementally by intravenous drip of sodium nitroprusside. Again five measurements were made at each hypotensive level. The range of mean blood pressure extended from 30 to 180 mmHg.

The ratio of S_o/S and A_s/A_m was plotted versus corrected diastolic pressure (S). The ratio A_d/A_m was plotted versus corrected diastolic pressure (D). The ratios for all animals for A_s/A_m and A_d/A_m were classified into ± 5 mmHg classes, averaged and plotted versus the corrected systolic and diastolic pressures.

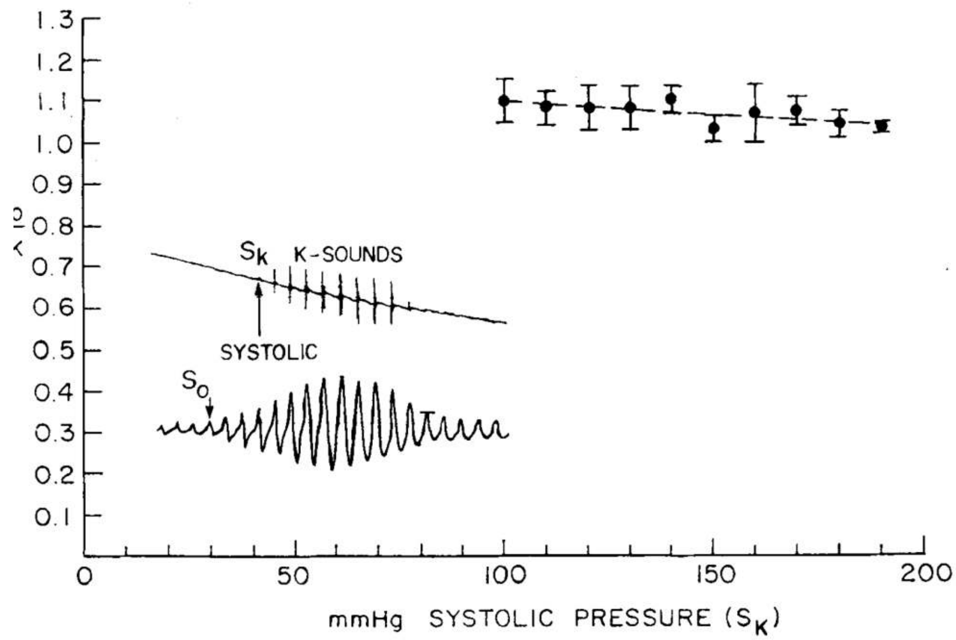

FIGURE 3. The ability of S_o, cuff pressure for a sudden increase in oscillation amplitude, to identify auscultatory systolic pressure (S_K).

RESULTS

Human Subjects

Figure 3 presents the ability of S_o, the cuff pressure, where the amplitude of the oscillations starts to increase markedly, to identify systolic pressure, as judged by the auscultatory method. On the average, the cuff pressure for S_o was 10% to 4% above auscultatory systolic pressure (S_K) over a systolic pressure range extending from 100 to 190 mmHg. At 120 mmHg, S_o overestimated systolic pressure by about 8%.

Figure 4 presents data on the ability of the ratio A_s/A_m to identify systolic pressure, using the auscultatory method as the reference. Note that the ratio decreased from 0.57 to 0.45 over an auscultatory systolic pressure ranging from 100 to 190 mmHg. At 120 mmHg, the ratio was 0.55.

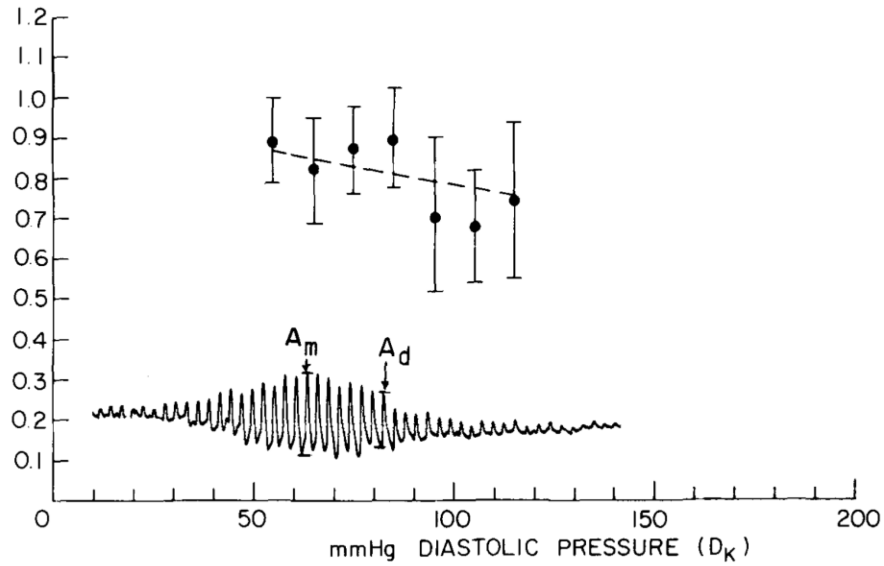

FIGURE 4. The ability of the ratio A_s/A_m to identify auscultatory systolic pressure (S_K).

Figure 5 presents the data on the ability of the ratio A_d/A_m to identify diastolic pressure, as identified by Phase 5 of the auscultatory method. Note that the average ratio decreased from 0.86 to 0.75 over the auscultatory diastolic pressure range from 55 to 115 mmHg. At 80 mmHg the ratio was 0.82.

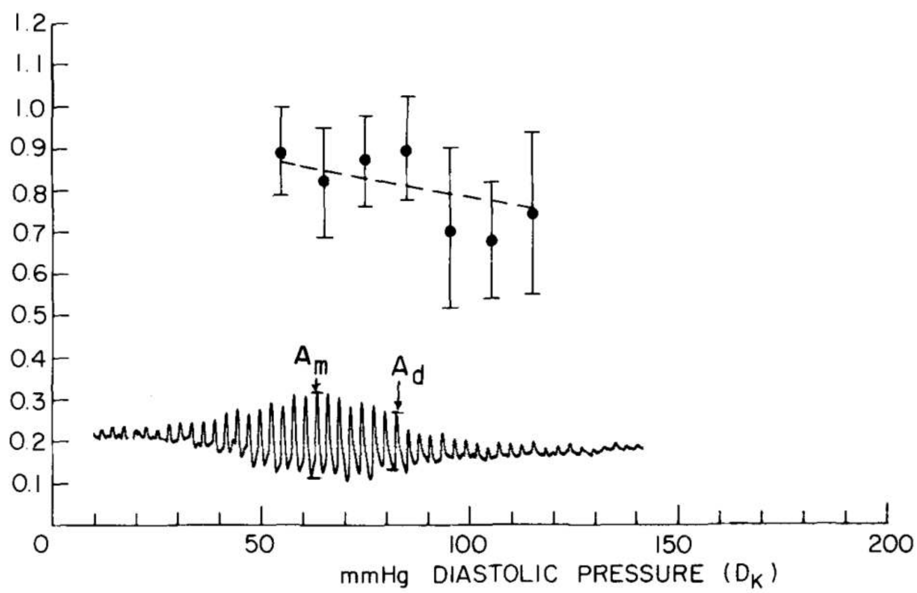

FIGURE 5. The ability of the ratio A_d/A_m to identify auscultatory (Phase 5) diastolic pressure (D_K).

Animal Subjects

Figure 6 illustrates the relationship between S_o (cuff pressure for the sudden increase in cuff pressure oscillations) to direct systolic pressure. Throughout the systolic pressure range (75-235 mmHg), this point overestimated systolic pressure. The overestimation was higher with lower pressure and reached an asymptote at a value about 20% above true systolic pressure.

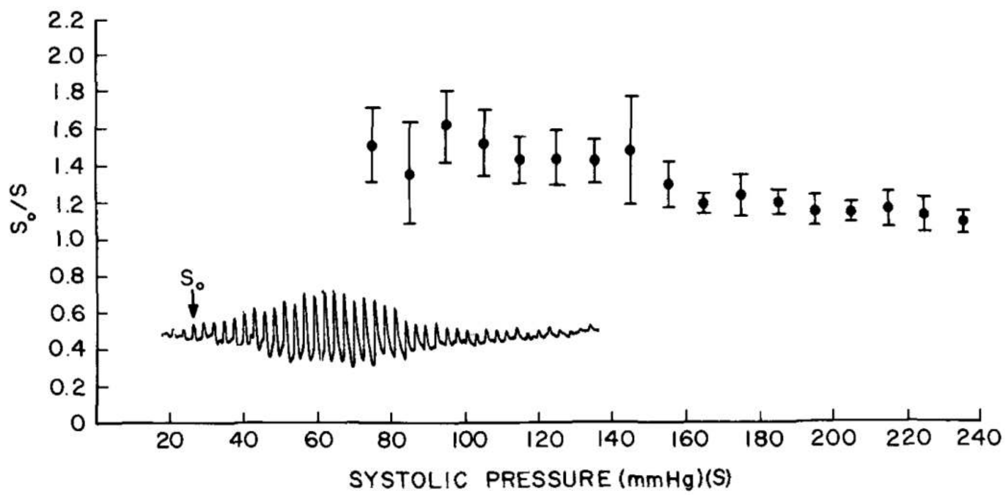

FIGURE 6. The ability of the ratio of S_o (cuff pressure for a sudden increase in oscillation amplitude) to identify systolic pressure (S).

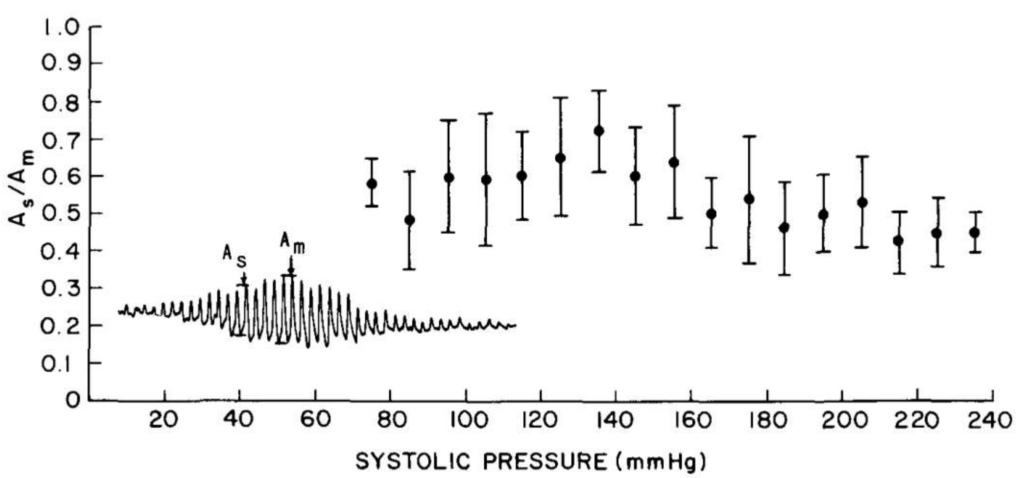

FIGURE 7. The ability of the ratio of A_s (the amplitude of cuff pressure oscillations at systolic pressure) to A_m (the maximum amplitude of cuff pressure oscillations) to identify systolic pressure.

Figure 7 illustrates how the ratio A_s/A_m (the oscillation amplitude at systolic pressure divided by the maximum amplitude at mean pressure) varies with systolic pressure. Throughout the systolic pressure range from 75-235 mmHg, the average ratio varied between 0.73 and 0.45. At 120 mmHg the ratio was 0.62.

Figure 8 illustrates how the ratio A_d/A_m (the amplitude of oscillations at diastolic pressure divided by the maximum amplitude at mean pressure) varied with direct diastolic pressure. Throughout the pressure range studied (35-145 mmHg), the ratio varied between 0.69 and 0.83. At 120 mmHg, the ratio is 0.77.

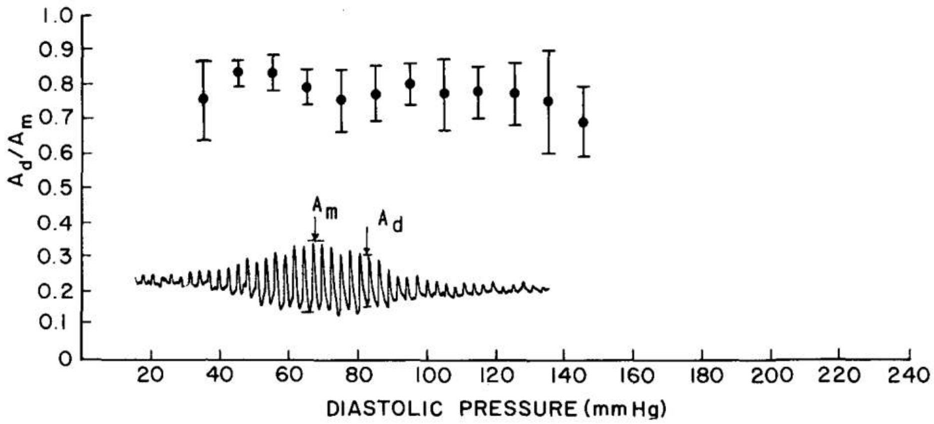

FIGURE 8. The ability of the ratio of A_d (the amplitude of cuff pressure oscillations at diastolic pressure) to A_m (the maximum amplitude of cuff pressure oscillations) to identify diastolic pressure.

Table 1 summarizes the data for the systolic and diastolic criteria for human and animal subjects. The item marked "typical" represents the value for the corresponding normal blood pressure.

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TABLE 1. Characteristics of the oscillometric method of measuring blood pressure.

	Systolic		Diastolic
	S_o/S_k	A_s/A_m	A_d/A_m
Human			
Typical*	1.08	0.55	0.82
Range	1.10-1.04	0.57-0.45	0.86-0.75
	S_o/S	A_s/A_m	A_d/A_m
Dog			
Typical*	1.20	0.62	0.77
Range	1.65-1.20	0.73-0.43	0.69-0.83

*Typical refers to value at normal pressure.

DISCUSSION

From this study involving human and animal subjects, several facts emerge quite clearly. For example, the sudden increase in cuff pressure oscillations that accompanies pulse breakthrough, overestimates systolic pressure in man when the auscultatory method is used as the standard. It also overestimates direct systolic pressure in the animal. It should be pointed out that auscultatory systolic pressure is slightly below true systolic pressure (7, 12); therefore in man S_o may not overestimate arterial systolic pressure by the amount reported herein.

When the amplitude of oscillations is measured during cuff deflation, systolic pressure appears to be encountered when the oscillation amplitude is about one half maximal in both animals and man. As yet there is no theoretical study predicting this relationship. However, this ratio is found not to be independent of systolic pressure, although the variation was less in man than in the dog.

During cuff deflation (below the point of maximal oscillation), diastolic pressure is encountered when the oscillations are about eighty percent of the maximum amplitude. To date, there is no theoretical prediction for this result. In man and in the dog, the ratio was not independent of diastolic pressure; although the range of variation was less in man than in the dog.

Regarding the selection of a fixed ratio of the amplitude of cuff pressure oscillations to maximal amplitude oscillations to identify systolic and diastolic pressure, it is seen that the range for the ratio is bigger for systolic than for diastolic pressure.

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