Anesthesiology
50:253–256, 1979

Indirect Measurement of Mean Blood Pressure in the Anesthetized Patient

MARK YELDERMAN, M.D.,* AND ALLEN K. REAM, M.D.†

Reliable blood pressure determination is a necessity in the management of the anesthetized patient. Noninvasive methods utilizing occlusive techniques are usually employed because of their low risk and simplicity. However, invasive techniques are presumed to be more accurate, and permit continuous measurement so that short-term variations, as with respiration, can be averaged.[1–3]

The Korotkoff technique, first reported in 1905,[4] continues to be the clinically preferred noninvasive technique. Interest in a noninvasive technique of measuring *mean* blood pressure has arisen, perhaps because the *mean* is frequently recorded when invasive techniques are used. In this study, values of invasively and noninvasively determined mean pressure measured simultaneously are compared. However, our data do not resolve the controversy as to whether *mean* pressure is more or less valuable than systolic/diastolic pressure in influencing patient management.

Noninvasive measurement of mean pressure makes use of a principle first reported by Marey.[5] Using a liquid-filled occluding chamber around an artery, he found that intra-arterial pulsations were transmitted to the liquid in the chamber. Subsequent investigators attempted to define the relationship between the amplitude of the externally measured pressure oscillation and the pressure within the vessel.

Several investigators suggested that the occlusive pressure yielding maximum oscillation was very close to diastolic pressure.[6–9] Subsequently, it was suggested that maximum oscillation occurred above diastolic pressure, perhaps above mean pressure.[10] Two separate groups, using liquid-filled [11] and air-filled[12] chambers, independently reported that the minimum occlusive pressure for maximum oscillation was equal to mean arterial pressure. This conclusion was supported in more sophisticated studies, examining both isolated arterial segments and intact arteries in extremities encircled by compressible air bladders.[13,14] Unfortunately, none of these studies report data permitting statistical analysis of the accuracy and reliability of the reported correlation. All of the reported techniques were technically difficult.

We used special computer-assisted instrumentation for validation of the indirect technique presented. However, a commercial instrument that automatically determines mean blood pressure using this technique is now available.‡ A description of its mode of operation and an evaluation of its clinical accuracy are presented in a separate paper.[15]

METHODS

Nineteen patients undergoing open-heart surgery at Stanford University Hospital were studied. Blood pressure determinations were made throughout the entire procedure, so long as pulsatile pressure was observed. The typical mean pressure was 80 torr, with a range of 45 to 125 torr. During most of the period of study, ventilation was controlled.

An 18-gauge cannula was inserted percutaneously into the randomly selected right or left radial artery and liquid-coupled via 4 feet of noncompliant tubing to a pressure transducer located at mid-heart level. A 12- or 13-cm cuff was applied to the opposite arm with the cuff bladder centered over the brachial artery. The cuff bladder was in turn coupled to a pressure transducer and automated inflator. Both transducers were calibrated using a mercury manometer.

For each of approximately 30 determinations for each patient, the cuff was rapidly inflated to suprasystolic pressure and deflated in decrements of 3–6 torr over 45 seconds to infradiastolic pressure. Both transducer outputs were digitized (intra-arterial at 50 hertz and the cuff transducer at 25 hertz) and stored on magnetic tape for subsequent evaluation.

Baseline cuff pressure for each interval between cuff decrements was defined as the cuff pressure without superimposed oscillations. For each indirect determination of mean pressure, the average magnitude of oscillation of cuff pressure at each value of baseline cuff pressure was calculated. Indirect mean arterial pressure was defined as the minimum baseline cuff pressure at which maximum cuff pressure oscillation occurred. Direct mean intra-arterial pressure was obtained by averaging the intra-arterial pressure over the period of three sequential baseline intervals. The period was selected so that the second interval contained the minimum baseline cuff pressure for

* Fellow in Anesthesia.
† Assistant Professor of Anesthesia.
Received from Stanford University School of Medicine, Stanford, California 94304. Accepted for publication July 15, 1978.
Address reprint requests to Dr. Yelderman.

‡ Dinamap, Applied Medical Research Corporation, 5041 West Cypress Street Tampa, Florida 33607.

0003-3022/79/0300/0253 $00.70

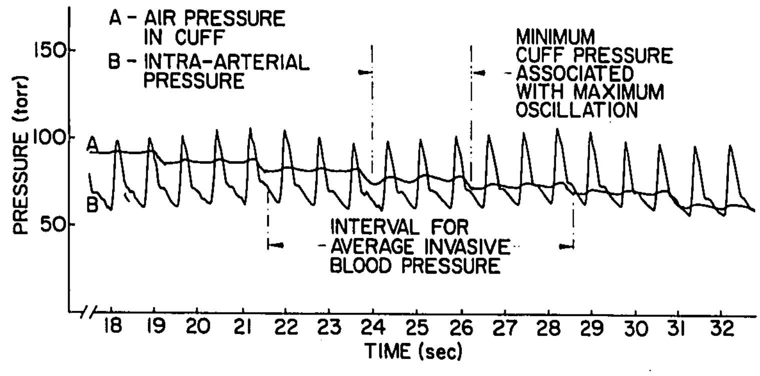

FIG. 1. A selected example of actual recordings used to estimate mean pressure via the indirect technique, and to calculate simultaneous mean arterial pressure. *A*, air pressure within the blood pressure cuff. *B*, Direct arterial pressure. The interval over which arterial pressure was averaged for comparison is marked. See text.

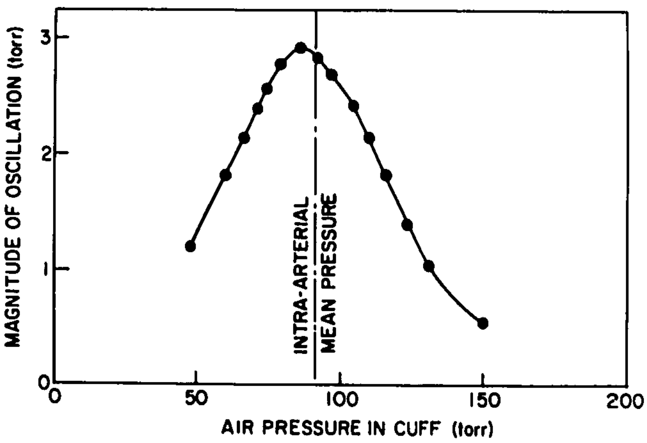

FIG. 2. An average of several values of mean arterial pressure determined by the indirect technique. The amplitude of oscillation of cuff pressure is plotted against cuff pressure. True mean arterial pressure is shown for comparison.

maximum oscillation. These periods of arterial averaging ranged from 8 to 12 seconds and contained a discrete number of complete heart cycles. Figure 1 shows a typical interval for one determination.

An average of several typical determinations is plotted in figure 2, showing the variation in amplitude of cuff pressure oscillation as a function of baseline cuff pressure. The average arterial pressure near the point of maximum oscillation is shown for reference.

Figure 3 illustrates a typical patient record showing paired determinations.

RESULTS

Mean error for the pooled data from all 19 patients was 1.40 torr, with a standard deviation of 6.22 torr. Error was defined as estimated value minus direct value. The results for individual patients and the pooled data are shown in table 1.

A practical bound for specifying maximum error is the absolute value of mean error plus two standard deviations ($|\bar{\epsilon}| \pm 2\sigma_\epsilon$).[16] This assures that less than 5 per cent of all measurements will have error greater than this bound if the errors are normally distributed; a requirement which our data satisfied. For the values presented above, this bound is 14 torr.

We also used regression analysis to estimate the minimum error for an instrument calibrated to an individual patient. The most likely value of the error for a given measurement and the standard deviation of the estimate about the regression line were calculated for each patient. These results are summarized in table 1. The mean standard deviation $S_{y,x}$ was 5.08, with a standard deviation from this value of 1.52. By analogy with the discussion just presented, 97 per cent of patients will have a standard deviation about their regression line less than $S_{y,x} = 5 + 2(1.5) = 8$ torr and the error bound will be less than $2S_{y,x} = 16$ torr. This is not an obvious improvement in accuracy from that obtained above using pooled data.

However, such an approach is not clinically practical even if error bounds are reduced, since it is necessary to make a large number of paired measurements over a wide range of values of blood pressure in the individual patient in order to derive this calibration line. Furthermore, we have no guarantee that the calibration line would be unchanged in a subsequent encounter with the same patient.

DISCUSSION

The pooled data suggest that the estimate of mean arterial pressure based on minimum cuff pressure for maximum cuff pressure oscillation is within 1.4 torr, close to the accuracy limit of the pressure transducers

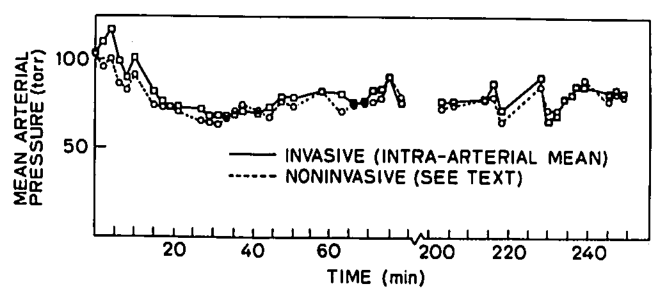

FIG. 3. Values of mean pressure determined by direct and indirect techniques for an individual patient. The missing segment occurred during cardiopulmonary bypass. Note that *typical* error in individual measurements is less than half the error bound of 14 torr, and more than 95 per cent of all errors are less than 14 torr—agreeing with the definition of the bound.

and amplifiers used for measurement. However, this result is an average value over many determinations. It is misleading when used to estimate error in most clinical applications.

The clinician typically bases therapeutic decisions on one, or at most, a few, blood pressure determination(s). Thus, he is not primarily interested in the error associated with the average of a large number of determinations, but rather in the error associated with a single determination. Our data show that the error for a single determination is less than 14 torr, or less than 17 per cent of average pressure. More than half of the single determinations will have errors less than half this bound.

The magnitude of the decrements in cuff pressure (3–6 torr) induced a minimal error in the variance (σ_ϵ^2). Shepherd's correction[17] indicates that if no variations had been introduced by cuff pressure decrements, σ_ϵ would have been 6.05 instead of 6.19. $\bar{\epsilon}$ would not have changed.

We randomized the arm used for reference measurement to minimize mean error. The statistics for the two groups of patients are summarized in table 2. The differences between the two groups were not statistically significant, suggesting negligible influence of right versus left arm reference.

TABLE 1. Correlation Coefficients (r), Standard Deviation of Estimate on the Linear Regression ($S_{y,x}$), and Mean Error of the Estimate ($\bar{\epsilon}$) and Standard Deviation of the Error (σ_ϵ) for Each Patient

	Correlation Coefficient (r)	Standard Deviation ($S_{y,x}$)	Error: Mean ($\bar{\epsilon}$)	Error: Standard Deviation (σ_ϵ)
Patient 1	.86	5.47	3.05	5.65
Patient 2	.94	4.06	−9.15	10.31
Patient 3	.85	5.63	−0.23	5.34
Patient 4	.85	5.74	−3.01	6.60
Patient 5	.78	7.15	−2.01	7.39
Patient 6	.94	4.36	−1.74	4.93
Patient 7	.94	2.04	−5.07	6.09
Patient 8	.75	4.72	1.30	4.92
Patient 9	.92	3.78	1.32	3.58
Patient 10	.88	6.27	6.56	7.93
Patient 11	.80	4.16	4.54	5.55
Patient 12	.74	5.34	3.65	9.40
Patient 13	.79	6.08	4.44	7.17
Patient 14	.93	2.38	1.91	2.67
Patient 15	.92	4.25	5.31	6.27
Patient 16	.93	8.48	6.36	9.77
Patient 17	.93	5.41	2.02	5.45
Patient 18	.70	5.97	7.16	8.72
Patient 19	.89	5.17	4.61	6.49
Pooled results	.87	6.19	1.40	6.22

$\epsilon \triangleq$ estimated value − true value

= indirect measurement − direct arterial measurement.

TABLE 2. Results for Patients with Direct Pressure Measured in the Right Arm versus the Left Arm*

	R	$S_{y,x}$	$\bar{\epsilon}$	σ_ϵ
Reference right arm	.91	5.61	3.44	6.21
Reference left arm	.83	6.36	−.48	6.5
Pooled data	.87	6.19	1.40	6.22

* In each case, indirect pressure was measured in the opposite arm to permit simultaneous comparison. Differences between the two groups are not statistically significant. (The symbols are defined in table 1.)

In a well-designed study, Van Bergen compared direct determinations of systolic and diastolic blood pressure with indirect ausculatory and oscillometric techniques.[1] The data are presented in graphic form, permitting a reasonable estimate of error bounds by the criteria cited above. The error in estimation of mean systolic pressure by auscultation was approximately ±20 per cent, (decreasing to approximately ±15 per cent with regression analysis of pooled data). The error in estimation using the oscillometric technique was similar but slightly smaller.

The estimate of mean diastolic pressure (the better estimator of mean pressure) was approximately ±30 per cent (decreasing to approximately ±15 per cent with regression analysis of pooled data).

Berliner's data[18] suggest similar error bounds, despite modest differences in technique. No study that suggests tighter error bounds could be found.

What conclusions can be drawn from these observations? We suspect that most clinicians will be uncomfortable in thinking of error bounds for single determinations as large as those cited here, partly because most studies report mean error over many determinations (for our data, less than 1.5 per cent of average blood pressure). An error bound for a single determination of ±17 per cent seems quite large in comparison. However, we submit that single-measurement analysis is most appropriate when the clinical application requires individual measurements. The error with this technique is smaller than that associated with the Korotkoff technique. Unlike the Korotkoff technique, error can be substantially reduced by averaging a few sequential determinations because mean error is so small.

These data suggest that indirect measurement of mean blood pressure by the proposed technique is likely to be more accurate than measurement of systolic and diastolic pressures, using oscillometric or Korotkoff techniques, and considerably more accurate than estimation of mean blood pressure using oscillometric or Korotkoff techniques. Many potential sources of variation remain inadequately understood and controlled.[19-21] Nonetheless, determination of mean blood pressure using noninvasive techniques appears clinically feasible and useful.

The authors gratefully acknowledge the assistance of B. William Brown, Professor of Biostatistics, and J. Halpern, Programmer, Department of Biostatistics.

REFERENCES

1. Van Bergen FH, Weatherhead DS, Treloar AE, et al: Comparison of indirect and direct methods of measuring arterial blood pressure. Circulation 10:481-490, 1954
2. Geddes LA: The Direct and Indirect Measurement of Blood Pressure. Chicago, Year Book Medical Publishers, 1970
3. Whitcher C: Blood pressure measurement, Techniques in Clinical Physiology. Edited by Belville JW, Weaver CS. London, Macmillan, 1969, pp 85-124
4. Korotkoff NS: On the subject of methods of determining blood pressure. Bull Imperial Medical Academy, St. Petersburg 11:365, 1905
5. Marey EJ: Pression et vitesse du sang, Physiologique Experimental. Volume 2. Paris, G. Masson, 1876
6. Roy CS, Adami JG: The heart beat and pulse-wave. Practitioner 45:20, 1890
7. Howell WH, Brush CE: A critical note upon clinical methods of measuring blood pressure. Boston Med Surgi J, 145:146-151, 1901
8. Erlanger J: A new instrument for determining the minimum and maximum blood pressure in man. John Hopkins Hosp Rep 12:53, 1904
9. Erlanger J: Studies in blood pressure estimation by indirect methods. Am J Physiol 55:84-158, 1921
10. Brooks C, Luckhardt A: The chief physical mechanisms concerned in clinical methods of measuring blood pressure. Am J Physiol 40:49-74, 1916
11. Pachon V, Fabre R: Sur le critere de la pression minima dans la methode oscillometrique. C Rendus Soc Biol 84:871, 1921
12. Gley P, Gomez DM: La détermination des pressions moyenne et minima par la méthode oscillometrique. Presse Med 39:284, 1931
13. Posey JA, Geddes LA: The meaning of the point of maximum oscillations in cuff pressure in the indirect measurement of blood pressure. Part I. Cardiovasc Res Cen Bul 8:15-25, 1969
14. Geddes LA, Moore AG, Garner H, et al: The indirect measurement of mean blood pressure in the horse. Southwest Veterinarian 23:289-294, 1970
15. Yelderman M, Ream AD: A microprocessor based automated noninvasive blood pressure device for the anesthetized patient. Proceedings of the San Diego Biomedical Symposium 17:57-64. New York, Academic Press, 1978
16. Robinson DJ, Ream AK, Corbin SD, et al: Quality control of a computer based physiologic monitoring system. Proceedings of the San Diego Biomedical Symposium 16:233-242. New York, Academic Press, 1977
17. Armitage P: Statistical Methods in Medical Research. New York, John Wiley and Sons, 1971, p 43
18. Berliner K, Fujiy H, Lee DH, et al: The accuracy of blood pressure determinations, a comparison of direct and indirect measurements. Cardiologia 37:118-128, 1960
19. Geddes LA: The importance of cuff width in measurement of blood pressure indirectly. Cardiovasc Res Cen Bul 14: 69-79, 1976
20. King GE: The errors in clinical measurement of blood pressure in obesity. Clin Sci 32:223-237, 1967
21. Irvine RO: The influence of arm and cuff size on the measurement of blood pressure. NZ Med J 67:279-283 1968

Anesthesiology
50:256-258, 1979

A Modified Doppler Flow Detector Probe—An Aid to Percutaneous Radial Arterial Cannulation in Infants and Small Children

H. M. CHINYANGA, M.SC., M.D., F.R.C.P.(C),* AND J. M. SMITH, PH.D., P.ENG.†

Cannulation of the radial artery has become routine for monitoring blood pressure and obtaining blood samples during major surgical procedures and intensive care.[1] The artery to be cannulated is located by palpation or, when this is difficult, is exposed by a cutdown and the catheter introduced under direct vision. The chances of successful percutaneous cannulation decrease with decreasing age and/or size of the patient.

This paper describes a technique we developed that has increased the success rate of percutaneous cannulation of the radial artery in infants and small children, and thus reduced the need for arterial cutdowns.

MATERIALS AND METHODS

The use of Doppler ultrasound for blood flow detection is well established.[2] The technique described here utilizes a commercially available instrument‡ used in conjunction with a modified probe. The crystal dimensions of the standard probe are such

* Staff Anaesthesiologist.
† Director, Department of Medical Engineering.
Received from the Departments of Anaesthesiology and Medical Engineering, The Hospital for Sick Children, 555 University Avenue, Toronto, Ontario Canada M5G 1X8. Accepted for publication July 22, 1978.
Address reprint requests to Dr. Chinyanga.

‡ Ultrasonic Doppler flow detector, Model 811, Parks Electronics Laboratory, Beaverton, Oregon.