BLOOD PRESSURE DETERMINATION IN THE NEWBORN WITH A PHOTOSPHYGMOMETER

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Physicians who deal with infants and small children have long sought for a reliable clinical method of blood pressure determination which would be applicable to their patients. The methods currently in use are, for the most part, clumsy and unreliable.[4] In the techniques of auscultation, palpation, and the flush method, the errors of human interpretation are great. Accurate auscultation of the neonatal Korotkow sounds is virtually impossible without the use of a Fox Localizer or similar instrument.[41] Placement of such a localizer is difficult to maintain in active infants. Most observers have found palpation unsatisfactory in infants. The fact that some observers[11, 14, 25, 36, 42, 44, 47] have reported successful use of this method only serves to prove the great variability of results that could be expected if it were widely used. In simple terms, some could feel an infant's pulse but the majority could not. With the flush method rapid serial determinations cannot be performed and often the end point is not sharply delineated. It is therefore not practical for use in the practice of surgery.

Electric Impedence Plethysmography and the Infratonsystem of Keuth[27] involve the use of bulky, complicated, and expensive apparatus. Oscillometry, as defined by Ashworth[4] is perhaps one of the better existing clinical methods of infant blood pressure measurement, but it will always retain problems of an inherent technical nature. The oscillations often appear and disappear gradually with no sharp end point for either systolic or diastolic pressures.[34]

Since arterial cut downs for blood pressure measurement are not routine, direct pressure measurement can only be made in a pulsating umbilical cord.[32, 37] The use of this technique, therefore, is limited to the immediate post-partum period. Even at that time it is difficult to correlate cord pressures with direct arterial pressures inside the infant because of the damping effects of the contracting cord. This error is compounded by the fact that cord contraction may begin at varying times after birth and progress at different rates in individual patients. It is, therefore, all but impossible to ascertain the effect of cord-contraction damping on pressure readings at any given instant.

The measurement of arterial blood pressure in infants and small children presents special problems. Infants have a normal clutching reflex which causes them to maintain their forearms flexed upon their arms so as to keep their hands near their faces. This complicates any indirect system employing a cuff on the upper arm. The small extremities are difficult to fit with a cuff of proper length and width for obtaining the accurate and reliable pressures. In infants there are great variations in peripheral blood pressure induced by straining and crying. A newborn baby's small heart with its rapid rate necessarily has a small stroke volume and hence produces a weak peripheral pulse.

Of all the above problems the most crucial one is the need for a satisfactory clinical method of detecting this feeble peripheral, neonatal pulse. We believe that the photosphygmometer adequately answers this need. This is a report of a sensitive, photoelectric, pulse detection system which we have employed in the measurement of systolic arterial blood pressure in 26 infants shortly after birth and in 100 infants in the first week of life.

Received from the Department of Anesthesiology, University of Virginia Hospital, Charlottesville, Virginia, and accepted for publication December 14, 1960.

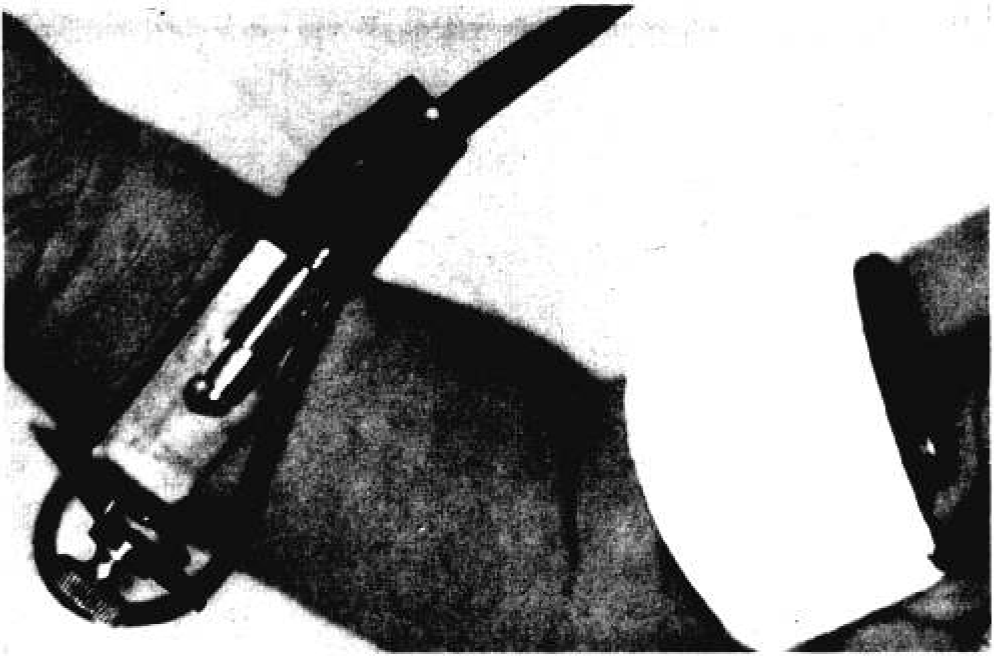

Fig. 1. The pickup is shown applied to the forearm with the rubber cuff affixed on the upper arm by a strip of adhesive tape.

Method of Detection *

A small, low intensity light source is placed on one side of the infant's forearm. The light after transilluminating the forearm is detected on the opposite side by a small crystal photoelectric cell (figs. 1 and 2). With each cardiac cycle the pulse wave increases the density of the portion of the extremity and thus reduces the light transmission through it. The variation in light intensity is detected by the photoelectric cell

* Circuit diagrams, parts lists and technical aspects of the construction and operation of the photosphygmometer were previously discussed by Mr. Robert E. Robinson III and Dr. Douglas W. Eastwood in Anesthesiology 20: 704, 1959.

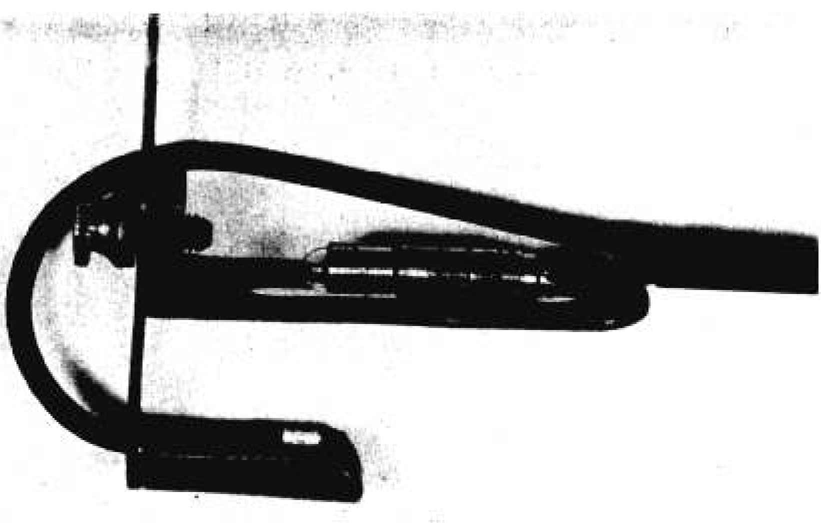

Fig. 2. The photosphygmometer pickup enlarged to show details of construction.

and relayed by small wires to a compact transistorized amplifier. The amplified signals are used to drive a ballistic meter for visual signal monitoring and at the same time to produce a tone for audio monitoring.

The complete photosphygmometer is compact and portable, measuring 2 × 5½ × 7 inches, and is relatively simple and inexpensive. In our hands it has performed excellent service in everyday clinical use.

Blood Pressure Cuff

A standard 2.5 × 6 cm. infant rubber cuff bladder was applied to the anatomical anterior surface of the arm, as recommended for infants up to one year of age by the American Heart Association.[46] In no case did the bladder completely encircle the arm. The bladder was fixed to the arm with one-inch adhesive tape as suggested by Wolff.[47] Pressure was supplied to the cuff from the rubber bulb of a Tycos aneroid hand manometer. This manometer was previously checked against a mercury column and found to be reliable in the pressure ranges expected to be encountered.

Recording System

The recording system was necessary only for the documentation of experimental data. For the clinical measurement of blood pressure only the photosphygmometer pickup and amplifier box together with a cuff and a manometer would be required.

The signals from the photosphygmometer pickup and the cuff pressure were recorded on a Grass Four Channel Polygraph Recorder. The cuff pressure was displayed by connecting a Statham Transducer into the tubing between the manometer and the cuff by means of a Y connector. With the apparatus thus arranged, the systolic pressures of the infants were obtained by inflating the cuff above systolic pressure and slowly lowering it. The point of appearance of pulse waves on the second channel indicated systolic pressure (fig. 3). When the audio signal became rhythmical, indicating pulsations at the wrist, the systolic pressure was read from the manometer dial. The pressure recording pen of the polygraph was calibrated before each determination.

Subjects

The studies embraced three phases. In phase I, photosphygmometer blood pressure determinations were made on 26 normal infants as soon as possible after birth. The average time lapse between birth of the infants and the first determinations was 5.3 ± 4.3 minutes. In all cases the cord was clamped immediately after birth. The infants were then placed in a resuscitation box where the determinations were made. All infants were evaluated in the first minute after birth by the method of Apgar.[5] Length, weight, sex, mode of delivery, and length of gestation of the infants were also noted. Data from the mothers included parity, length of the first and second stages of labor, the type and amount of anesthesia, and any abnormalities, such as toxemia.

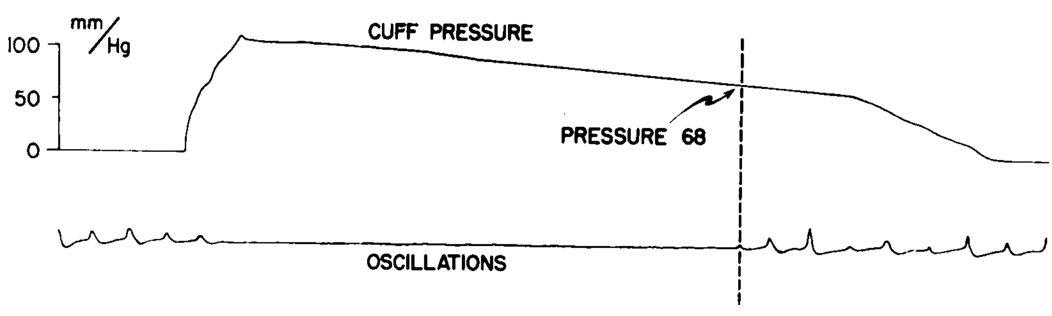

Fig. 3. A typical polygraph tracing of a blood pressure determination using the photosphygmometer. As the cuff is inflated the oscillations of the pulse in the forearm disappear. The point of reappearance of the oscillations, as the cuff pressure is slowly lowered, is read as the systolic pressure.

In phase II, pressure measurements were made on 100 normal infants ranging in age from one to seven days. The technique employed was the same as in phase I. Three determinations of blood pressure were made on each of the 100 infants, giving a total of 300 readings.

Both Schaffer and Wigger's groups have stated that the 2.5 cm. cuff bladder must be placed directly over the artery if the bladder is too short to completely encircle the arm.[41, 46] Therefore, to determine the variation in pressure due to applications of the bladder slightly to either side of the arm, the following study was done. In the first 50 babies the cuff was applied to the center of the anterior surface of the arm for the first pressure determination. The cuff was then removed before the second reading and reapplied approximately 45 degrees lateral to the midline. After the second reading the cuff was removed and rotated to a position approximately 45 degrees medial to the midline, and the third reading was taken.

Observation from the second group of 50 babies were with the cuff carefully applied to the anterior midline of the arm and left in place for all three determinations. The age and sex of each infant were recorded.

In phase III, the pressure readings obtained with the photosphygmometer were compared with intra-arterial pressures. The method used in phase III was identical with that used in phases I and II with the addition of direct intra-arterial readings. The cuff (the size of which had to be varied to fit the different sized patients) and the photosphygmometer pickup were applied to the right arm. The intra-arterial cannula was placed in the left brachial artery, the cannula consisting of a 20 gauge needle attached through a 12-inch length of heavy polyethylene tubing to a Statham Electrical Pressure Transducer. With the equipment thus arranged, cuff pressure, direct brachial artery pressure, and the waves from the photosphygmometer could be recorded simultaneously. In this way indirect readings on the right brachial artery were compared to direct pressures from the left brachial artery.

Results

Phase I. The average of six determinations of systolic brachial arterial blood pressure in each of 26 normal infants as measured with the photosphygmometer 5.3 ± 4.3 minutes after birth was 72 mm. $\pm$ 12 mm. of mercury. The lowest average individual pressure was 48 mm. of mercury, and the highest average individual pressure was 93 mm. of mercury. Since the large standard deviation of 12 mm. of mercury reflects the variability of blood pressures in *different* individual infants rather than the reliability of the method for a series of determinations in any one infant, we therefore calculated separately a mean for the six measurements on each infant. A standard deviation (SD) about these means was then determined for each infant. The average of these individual SD values for the group of 26 infants was 5 mm. of mercury.

Apgar classification[5] of the 26 infants failed to reveal a correlation with the blood pressure. The only one of the five Apgar variables that showed any constant relation to blood pressure was the heart rate. Two of the 26 infants had heart rates of less than 100 per minute. Their pressures were significantly elevated. Average heart rate for the group was 120 beats per minute.

Weight of the infants was the only other variable in our study which proved to have an apparent correlation with blood pressure. There was an average rise of 1 mm. of mercury for every 100 grams of birth weight between 2,500 and 4,000 grams. The slope of this rise was statistically significant at the .05 level by the t test (fig. 4).

There was no predictable correlation of blood pressure with length of the infants, sex, or length of gestation (three of the infants believed to have been born one month prematurely had blood pressures above the mean for the group).

Three infants delivered by forceps extraction did not have significant alterations of their blood pressures as compared to those spontaneously delivered. Neither type nor duration of maternal anesthesia showed any predictable correlation with blood pressure in the infants.

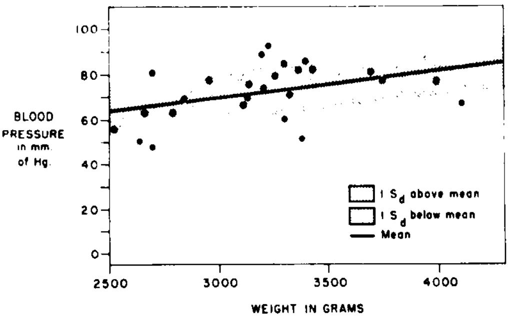

FIG. 4. The above graphically demonstrates the relationship between the systolic blood pressures of 26 normal, newborn infants and their birth weights.

No significant difference was noted in infant blood pressure associated with increased parity of the mothers, length of the first two stages of labor or the presence of maternal toxemia.

Phase II. The combined average of three systolic blood pressure determinations in each of 50 infants, aged one to seven days, in whom the cuff was repositioned between readings was 68 mm. ± 11 mm. of mercury. The mean individual SD was 5 mm. of mercury.

The average systolic blood pressure of the group of 50 infants, aged one to four days, in whom the cuff was carefully positioned in the midline of the arm and left in place for all three determinations was 72 ± 14 mm. of mercury. Here the average individual SD was 3 mm. of mercury.

Thus the combined average of the systolic blood pressures of 100 babies sampled at random in the first week of life without regard for the cuff position on the arm was 70 ± 12 mm. of mercury with an average individual SD of 4 mm. of mercury.

There was no significant difference in the systolic pressures of males versus females in the first week of life.

Phase III. Twenty-two directly measured intra-arterial pressures were compared with a like number of simultaneously measured indirect pressure readings obtained with the photosphygmometer. The average difference between the direct and indirect readings was only 2 mm. of mercury ± 1 SD of 3 mm. of mercury. In eleven of the 22 sets of readings the direct and indirect readings were identical.

TABLE 1

VALUES OBTAINED FOR SYSTOLIC PRESSURE OF INFANTS IN THE FIRST FOUR DAYS OF LIFE

Cases (No.)	Age in Days	Pressure in mm. Hg
17	1	72
34	2	69
35	3	70
12	4	68

DISCUSSION AND COMMENTS

Our results have been compared with previous reports of infant blood pressure measurements (table 2).

A number of observers who measured newborn systolic pressure have also followed their subjects for variable periods of time after birth. Table 3 summarizes some of their results which may be compared with our results from phase II (table 1). Our results were 10–15 mm. of mercury higher than most previous reports of systolic pressures in the newborn. The findings of Salmi [40] and Young and Holland [49] are closest to agreement with the figures we obtained.

We believe the only disadvantage of our method to be the necessity of owning a photosphygmometer—an instrument costing about $100.00 to purchase or construct.

We have seen no burns on infants' arms resulting from contact with the pickup pictured in figures 1 and 3. An earlier model pickup with the light source imbedded in rubber did cause a minor burn on an infant's forearm.

Previous observers have noted the great lability and variation of a newborn baby's blood pressure within short periods of time.[14, 16, 24, 31, 32, 41, 48] We observed on one occasion a newborn infant with a pressure of 98 mm. of mercury while crying and straining. As we continued to make serial pressure measurements he stopped crying and relaxed. His systolic pressure decreased to 52 mm. of mercury in less than three minutes.

TABLE 2

PREVIOUS REPORTS OF INFANT BLOOD PRESSURE MEASUREMENT

Author and Reference	Method	No. of Cases	Pressure in mm. of Hg	Type	Age of Infant
Adams, F. H.[3]	Catheter in right heart	8 normals	32–66	Systolic	Up to 35 hours
Ashworth, A. M.[4]	Glass capillary oscillometer using two cuffs	20 normals	62–116	Systolic	At birth
Balard, P.[6]	Pachon oscillometer		55/35	Syst./Diast.	Newborn
Bowman, J. E.[10]	Pachon oscillometer	100	55/38	Syst./Diast.	Newborn
Brash, A. A.[11]	6-cm. cuff, palpation of radial pulse	50 toxemic 100 normals	48.3 55.4	Systolic Systolic	First day life First day life
Browne, F. J. and Dodds, G. H.[12]	Riva Rocci, auscultation	3 toxemic 6 normals	75.3 73.0	Systolic Systolic	0.9 hours 2–18 days postpartum
Cook, H. W.[14]	Riva Rocci, palpation of radial pulse		75–90	Systolic	In first 6 months
Fordtran, F. J. Killinger, W. A. Newsom, W. T.[15]	Glass capillary oscillometer	70	50–120	Systolic	Newborn
Forfar and Kibel[16]	Flush method	513	59.5 60.5 63 87	Systolic Systolic Systolic Systolic	0–12 hours 13–24 hours 0–3.5 days 6–11 days
Haselhorst, G.[23]	Direct umbilical	8	68–110	Systolic	At birth
Holland, W. W. and Young, I. M.[25]	Riva Rocci, palpation of brachial artery	54 14	69 93 53	Systolic Systolic Systolic	At birth 6 months At birth with fetal anoxia
Ikeda, K.[26]		589	60.6	Systolic	First day of life
Keuth, U.	"Infratonsystem" (microphone connected to ECG)	40	118/75	Syst./Diast.	3 weeks–5 months
Londe, S.[28]	Oscillometery	78 prematures	58–88	Systolic	First day of life
Neu[30]	Gärtner's tonometer		90	Systolic	In newborn
Nyberg and Westin[23]	Direct umbilical	20	88/54	Syst./Diast.	Within 1 minute after birth
Oppenheimer and Bauchwitz[33]	Riva Rocci		60/80	Systolic	In newborn
Popoff[32]	Riva Rocci		40–70	Systolic	Term infants
Reinhold and Michael[35]	Flush method	5 4	50.4 56.2	Systolic Systolic	First day of life First day of life
Reis and Chaloupka[36]	Riva Rocci, palpation of radial pulse	100	43	Systolic	First day of life

TABLE 2—*Continued*

Author and Reference	Method	No. of Cases	Pressure in mm. of Hg	Type	Age of Infant
Ribemont, A.[37]	Direct umbilical		64.8	Systolic	At birth
Rucker and Connell[39]	Single-bag oscillometry	52	55/40	Syst./Diast.	First day of life
Salmi, T.[40]	Riva Rocci, auscultation	38	46/28	Syst./Diast.	First day of life
Schaffer, A. I.[41]	Impedence plethysmography	24	52–102	Systolic	First day of life
Seitz and Becker[42]	Riva Rocci, palpation of radial pulse		43	Systolic	First day
Smith[44]	2.5-cm. cuff, Riva Rocci, palpation		70–80	Systolic	At birth
Sullivan and Kobayshi[13]	Flush method		90.4	Systolic	At birth
Sladkoff[32]	Gärtner's tonometer		61	Systolic	First day of life
Trump, J.[50]	Gärtner's tonometer		60–90	Systolic	At birth
Utheim, K.	Riva Rocci, auscultation on leg		80–100 55–85	Syst./Diast.	Infants over 1 month
Wolff, L. V.[47]	Riva Rocci, palpation of radial pulse	60	62 74	Systolic Systolic	3–7 days At 6 months
Woodburry, Robinow and Hamilton[48]	Direct umbilical with hypodermic manometer	24	80/46	Syst./Diast.	At birth
Vierordt[40,42]	Riva Rocci		111	Systolic	Newborns
Young, I. and Holland, W. W.[49]	Riva Rocci, palpation of brachial artery	71	60–70 65–80.5	Systolic Systolic	3–5 days At 10 days

TABLE 3

THE AVERAGE SYSTOLIC BLOOD PRESSURES IN MILLIMETERS OF MERCURY FOR INFANTS IN THE FIRST TEN DAYS OF LIFE AS REPORTED BY TEN AUTHORS

Author and Reference	1st day of life	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Sietz and Becker[12]	43	48	58	56	58					66
Ballard[6]	55	60	60	65	65					75
Rucker and Connell[39]	55	58	54	58	69	63	61	63	63	64
Wolff[47]			(62—mean for 3rd to 7th day)							
Bowman[10]	55	60	60	62						
Forfar and Kibel[16]	(63—mean for first 3 days)					(87—mean for 6th–11th day)				
Reinhold and Michael[35]	49.5	51	51							
Salmi[40]	46	64	70	75	78	79	81	86		
Reis and Chaloupka[36]	43	48	55	59	63	66	70	73	75	78
Young and Holland[19]			(60–70—mean for 3rd–5th days)							65–80

SUMMARY

An electronic system consisting of a light source, a small crystal photoelectric cell, an amplifier and a signal indicator has been used for detection of the pulse in infants and small children. The children's forearms were placed between the light source and the photo-cell and were transilluminated, since the density of the tissue mass fluctuated with the pulse, the signal from the photo-cell altered with each pulse wave. The output of the photo-cell was amplified and used to activate a ballistic meter for visual signal monitoring and a tone for audio monitoring. This pulse detection system was used with a standard one-inch blood pressure cuff on the arm to provide an accurate and reliable method for determining systolic blood pressure.

Systolic arterial blood pressure was measured in 26 infants shortly after birth and in 100 infants in the first week of life. The average systolic pressure for the infants just after birth was 72 mm. of mercury. Average pressure varied between 68 and 72 mm. of mercury for the first four days of life though individual readings varied between 48 mm. and 93 mm. of mercury. The instrument gave readings which varied within a standard deviation of 5 mm. of mercury in individual subjects. The accuracy of the blood pressure values obtained with the photosphygmometer was compared with a series of simultaneously directly measured intra-arterial pressures. The average difference between the direct and indirect readings was 2 mm. of mercury.

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LOCAL ANESTHETICS Most inhaled anesthetics are inert; local anesthetics are not. Local anesthetics have active groups and act by polar association. The blockade produced by conventional local anesthetics probably results from the biochemical changes caused by the drug on the lipoprotein film at the surface of the plasma membrane. Local anesthetics stabilize the membrane, and thereby the changes in permeability necessary for propagation of an impulse from zone to zone are unable to occur. Truly reversible local anesthetic drugs alone seldom produce a block lasting more than 2½ to 3 hours. Other agents used for producing long lasting anesthesia do so by causing neurolysis and transient or even permanent damage to nerve fibers. (*Adriani, J.: Clinical Pharmacology of Local Anesthetics, Clin. Pharmacol. Ther. 1: 645 (Sept.-Oct.) 1960.*)

LOCAL ANESTHETIC The effects of systemically administered analgesic agents upon peripheral nerves have been studied in dogs by stimulation of tooth pulp nerves. The dogs were anesthetized with pentobarbital, the trachea was cannulated and the blood pressure was recorded from the femoral artery. The inferor alveolar nerve was isolated, cut at the central end, and immersed in warm mineral oil. Action potentials in these nerve fibers were recorded. Mechanical, thermal and electrical stimuli were applied to the canine and molar teeth. Local anesthetics (procaine and lidocaine) decreased the excitability of the pulpal nerves to electrical and thermal stimulation of the tooth and decreased the mechanically sensitive neurons of the tooth tissue. These effects resulted from an elevation of threshold for excitation and not the result of an inability of the nerve to generate or propagate impulses. Morphine sulfate had no consistent effect upon the dental nerves and receptors. (*Wagers, P. W., and Smith, C. M.: Responses in Dental Nerves of Dogs to Tooth Stimulation and the Effects of Systemically Administered Procaine, Lidocaine and Morphine, J. Pharmacol. Exp. Ther. 130: 89 (Sept.) 1960.*)

SYMPATHETIC BLOCK In deciding the advisability of sympathectomy for patients with arterial insufficiency of the lower extremities not suitable for direct vessel operation, no importance was placed on the response to a paravertebral lumbar sympathetic block. Occasionally a continuous block over a period ranging from a few days to a week was valuable, in that if no relief of pain occurred or if a small area of gangrene progressed in spite of the prolonged sympathetic block, amputation was recommended instead of sympathectomy. (*Morety, W.: Surgical Management of Chronic Arterial Insufficiency of Lower Extremities, J. Int. Coll. Surg. 34: 169 (Aug.) 1960.*)