Controlled Evaluation of Ultrasonic Measurement of Systolic and Diastolic Blood Pressures in Pediatric Patients

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Accurate monitoring of arterial blood pressure is necessary for the safe anesthetic management of infants and young children. Unfortunately, in this age group blood pressure determination is often difficult.[1-3] Intra-arterial recording, the accepted standard of accuracy, is cumbersome and not without risk. It is therefore not routinely used. Among the indirect methods, the auscultatory technique is frequently inoperable,[2] because Korotkoff sounds are low-energy acoustic phenomena which in children and infants may lie below the threshold of hearing.[4] The palpatory and oscillometric techniques do not allow accurate determination of diastolic pressures.[4] It has been common in our pediatric anesthesiology service that, even when the appropriate-sized cuff and bladder are carefully selected, the indirect methods of blood pressure measurement become virtually useless as soon as the young patient loses heat or blood, experiences vasoconstriction, or receives a relative overdose of anesthetic.[5]

However, under the same adverse conditions no problem is encountered when the blood pressure is monitored by means of ultrasonic arteriokinetography. The pressure values obtained appear to be consistent with the clinical condition of the child.[5] Blood pressures obtained by the ultrasonic and by the auscultatory techniques in patients less than 15 years old reportedly correlate well.[6] Our clinical impression that ultrasonography seems superior to other indirect techniques of blood pressure measurement is in agreement with that of others.[4,6] However, the accuracy of the pressure readings for infants and young children has not been precisely determined, as it has been for adult patients.[7-9]

This paper describes the indirect measurement of systolic and diastolic blood pressures in pediatric patients by ultrasonic arteriokinetography. It evaluates its accuracy and proves its reliability by comparing it with the intra-arterial technique in a study of infants and small children whose blood pressures were anticipated to be difficult to measure by auscultation.

MATERIAL AND METHODS

The principle of ultrasonic blood pressure registration by means of Doppler arteriokinetography has been described,[7] and the incorporation of this technique in an automatic monitor for adult patients has been reported.[8-10] The technique proved especially valuable during episodes of arterial hypotension when the Korotkoff method became unreliable.

In this study, blood pressures of 12 children, ranging in age from 2 weeks to 6 years, were measured a day after they had undergone open-heart surgery. At the time of operation a femoral arterial catheter had been introduced for routine monitoring. Connected to a Statham P37 strain gauge and a Beckman amplifier, it allowed continuous recording of intra-arterial pressures on one channel of a two-channel Brush recorder. These served as a basis for comparison with brachial arterial pressures that were measured simultaneously by ultrasonic arteriokinetography and recorded on the other channel of the Brush recorder. For this technique, an appropriate blood pressure cuff and corresponding ultrasonic transducer were positioned over the brachial artery, with a polyvinylpyrrolidone coupling gel applied between transducer and skin. For patients 21 months of age or older, the cuffs contained bladders whose dimensions ranged

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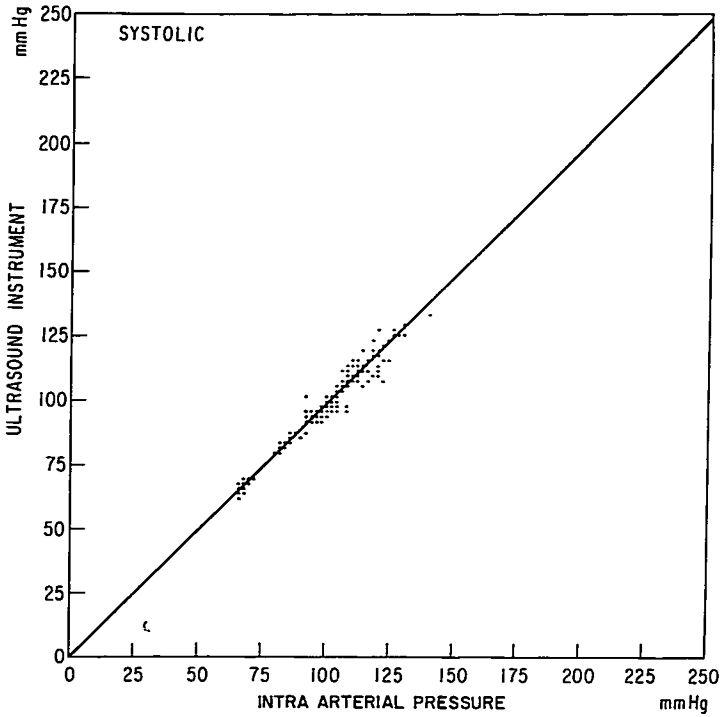

FIG. 1. Scattergram comparing systolic blood pressure readings obtained by ultrasonic arteriokinetography with femoral arterial pressures. Two hundred and seventy-eight systolic comparisons were made in a study of 12 children and infants. (All points are plotted, but many overlap.) Pressures ranged from 65 to 140 mm Hg. The correlation coefficient (r) was 0.98. The regression line is shown; its equation is $y = -0.3 + 0.99\ x$.

from 13.5 × 5.5 cm to 21.5 × 9.5 cm. However, for the four youngest patients, two weeks to four months old, a cuff containing a bladder 10 × 4 cm was applied. The use of several cuff sizes insured that the inflatable bag always covered more than half of the circumference of the arm and that the width of the cuff extended over at least two thirds of the upper arm, the recommended practice for Korotkoff method measurements.[11]

The ultrasound transducer used for children operated at a frequency of 2 MHz, the same frequency found suitable for adults,[7-10] but for the four infants an 8-MHz transducer was used. The higher ultrasonic frequency provided the greater resolution and sensitivity needed to detect the minute arterial wall motion in neonates and infants, whose blood vessels have extremely small diameters. Ultrasonic energy output of either transducer was less than 50 milliwatts/cm^2.

The ultrasonic transducer and blood pressure cuff were connected to an ultrasound

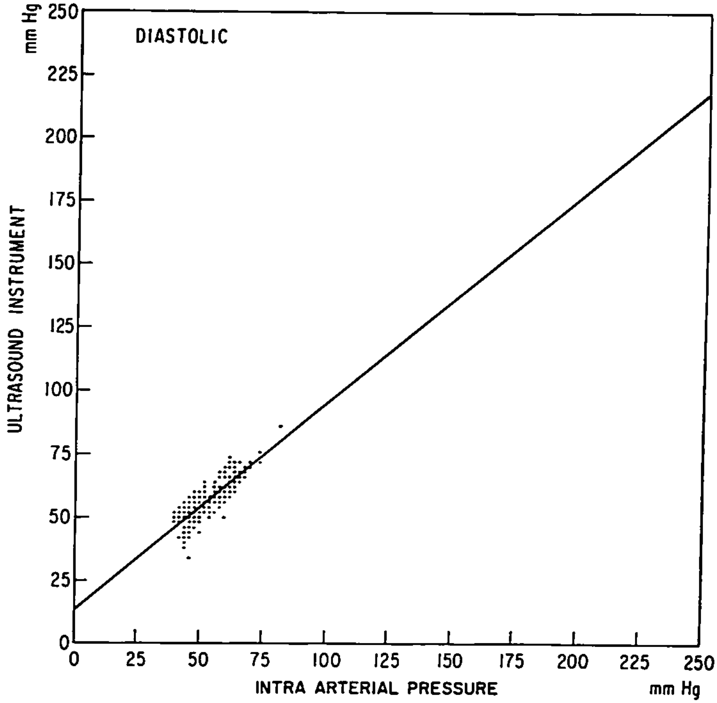

FIG. 2. Scattergram comparing diastolic blood pressure readings obtained by ultrasonic arteriokinetography with femoral arterial pressures. Two hundred and seventy-eight diastolic comparisons were made in a study of 12 children and infants. (All points are plotted, but many overlap.) Pressures ranged from 40 to 80 mm Hg. The correlation coefficient (r) was 0.85. The regression line is shown; its equation is $y = 13 + 0.81\ x$.

Doppler monitor (UDM)† activated only when the cuff was manually inflated. The monitor perceived Doppler frequency shifts in the ultrasonic energy reflected from the brachial artery in motion. It then converted these Doppler impulses into audible signals. The UDM was connected to the second channel of the Brush recorder for registration of the air pressure in the blood pressure bladder, which was calibrated against a mercury manometer.

† Arteriosonde 1010, Roche Medical Electronics Division, Cranbury, N. J.

The operator inflated the cuff above systolic pressure. Slowly deflating it, he listened for the signals indicating Doppler shifts. Upon hearing the first one, he pressed a marker button to indicate the systolic point on the graphic recording of the declining air pressure. Upon identifying the last signal as diastole, he again pressed the marker.

For reasons of objectivity, the study was "blind." Pressures obtained with the UDM were marked without observation of the intra-arterial recording, which was made by a technician. Afterwards, those intra-arterial pressures that were absolutely synchronous with the marked systolic and diastolic points were read.

Concurrent auscultatory blood pressure determination was done or attempted, but only intermittently, because Korotkoff sounds were not always audible.

Results

A total of 278 comparisons of ultrasonic *versus* intra-arterial systolic and diastolic pressures was obtained for the 12 patients. The Doppler shifts were distinctly audible, allowing for easy ultrasonic measurement in all cases. Figures 1 and 2 are scattergrams of the comparisons. Pressures ranged from 65 to 140 mm Hg systolic and from 40 to 80 mm Hg diastolic. The systolic measurements correlated very closely. They were identical in 123 of the 278 comparisons and within 2 mm Hg in another 88 instances. The average UDM pressures were 1 mm Hg below the intra-arterial pressures. The correlation coefficient was 0.98. The standard deviation of the differences was 2.98. The standard deviation from the line of best fit, as shown in figure 1, was also 2.98.

The 278 diastolic measurements obtained with the UDM also demonstrated good agreement with intra-arterial measurements, although not as excellent as that found for the systolic data. Identical values were obtained in 58 of the 278 measurements, and in another 77 comparisons they were within 2 mm Hg of each other. UDM pressures were higher than intra-arterial values by a mean of 3.3 mm Hg. The correlation coefficient was 0.85. The standard deviation of the differences was 4.45. The standard deviation from the line of best fit, as shown in figure 2, was 4.20.

Mathematical comparison of ultrasonic and auscultatory measurements was not feasible. In three of the four infants Korotkoff sounds could not be heard at all. In addition, a 6-year-old child had frequent short periods of hypotension (70–85 mm Hg systolic) during which the Korotkoff sounds became inaudible. When his blood pressure was restored with infusions of isoproterenol auscultatory measurement was possible again. In three other children, it was occasionally difficult to ascertain the diastolic point by auscultation. However, when Korotkoff sounds were distinct, they indicated pressures that were very near those found by ultrasonography.

Discussion

This investigation showed that ultrasonic arteriokinetography possesses greater sensitivity than the Korotkoff method. This was evidenced by the fact that accurate ultrasonic measurement of blood pressures of infants and young children for whom the auscultatory method failed to give useful systolic and diastolic data could always be made. However, when Korotkoff values were measurable, they and the ultrasonic data did not differ substantially from each other.

Comparison of blood pressures obtained by the ultrasonic and intra-arterial methods demonstrated a close agreement that meets clinical requirements very well. Systolic differences were insignificant. Diastolic values correlated less closely. However, the average difference of 3.3 mm Hg is extremely small for any indirect method and would not affect management of the patient.

It is unlikely that the slightly greater differences in diastolic readings can be attributed to inherent differences between femoral and brachial pressures in this young population. On the basis of previous studies, any effect due to the difference between sites of measurement could be expected to be more evident in the systolic values. These, however, correlated extremely well. The probable explanation is that, as with any indirect technique of blood pressure measurement, with ultrasonic arteriokinetography the diastolic point is less clearly defined.[12]

Ultrasonic Doppler instruments designed for flow detection have also been used for blood pressure determination.[13-17] In general, the method has not been adequate in detecting the diastolic point in small children,[13-16] and our experience with a Doppler blood flow detector is consistent with this finding. This is so because the frequency shifts produced by turbulent flow in the arteries of small children are often below the sensitivity threshold of present-day ultrasonic flowmeters. In contrast, when ultrasonic arteriokinetography instruments are used, blood flow signals are filtered out and only the Doppler shifts representing arterial-wall motion are interpreted. Wall motion is perpendicular to the axis of the sound beam, and produces a relatively large Doppler shift.

One factor responsible for the accuracy attained in this study is the careful attention given to the selection of an appropriate cuff and transducer for each patient. A cuff of the proper size provides uniform compression of an adequately large area.[12] Artificially high pressures, 20 to 30 mm Hg in excess of intra-arterial values, could be found in our patients when too small a cuff was used, and erroneously low pressure readings were obtained when an oversized cuff was applied. For the four smallest infants, those from 2 weeks to 4 months old, the cuffs had to be specially made. Existing cuffs were not suitable for this size. Also, it is unlikely that for these infants the indirect measurements would have correlated with the direct values so closely had not a transducer of high ultrasonic frequency, and consequently high resolving power, been employed. However, since penetration of ultrasound is inversely related to frequency (while resolution is directly proportional to frequency), the 2-MHz frequency was used for the other children, 21 months to 6 years old, to enable the sound beam to reach the brachial artery through overlying tissue without having to increase the power output of the apparatus. With a power output of less than 50 milliwatts/cm^2 at frequencies of 2–8 MHz, the UDM is unlikely to produce adverse biologic effects.[18]

The simplicity of the ultrasound technique is such that it enables our nursing, resident and attending staffs to measure blood pressures faster and more easily than is possible by auscultation. In our pediatric unit it has become the method of choice for monitoring nearly all surgical patients.[5] It may represent a major advance in the anesthetic management and intensive care of pediatric patients.

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