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Automatic Ultrasound Monitoring of Blood Pressure during Induced Hypotension

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Accurate measurement of arterial blood pressure is necessary for the safe management of patients undergoing hypotensive anesthesia. Under these conditions sphygmomanometric readings are often inaccurate or unobtainable, and oscillometry is unreliable, especially in obese patients.[1] Therefore, intra-arterial monitoring has frequently been necessary. While this method is accurate, it may be attended by difficulties and patient morbidity. In addition, the procedure is undesirably cumbersome for routine clinical use. For these reasons, the development of an indirect, noninvasive method of blood pressure measurement to provide accurate, easily interpreted, and reproducible results was urgently needed.

This paper describes the results obtained with an automatic ultrasonic Doppler blood pressure monitoring device (AUDM)[§] in patients before and during induced hypotensive anesthesia for radical surgery of the head and neck.

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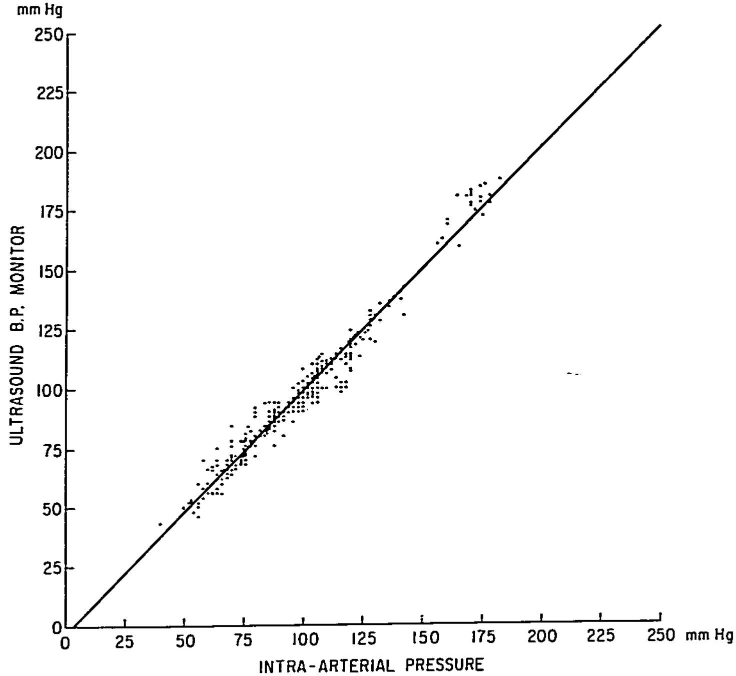

FIG. 1. Scattergram of comparative systolic determinations by ultrasound blood pressure monitor *vs.* contralateral brachial artery pressures. Four hundred and seventy-nine systolic comparisons were made (all points plotted, but many overlap) in 15 patients. Pressures ranged from 42 mm Hg to 190 mm Hg. The correlation coefficient (r) was 0.98, $P < 0.001$. The regression line is shown; its equation is $y = -3.2$ mm Hg $+ 1.0\ x$.

MATERIAL AND METHOD

The principle of ultrasonic kinetoarteriography forms the basis for the monitor.[1-4] A brief description of the method follows. An assembly containing ultrasonic transducers, connected to the monitor, is placed under a standard blood pressure cuff and positioned over the brachial artery. The transducer crystals emit ultrasound toward, and receive reflected waves from, the brachial artery. Doppler frequency shifts in the reflected waves are highly sensitive indicators of arterial wall motion. The monitor automatically inflates the cuff at selected intervals to a preset level above systolic pressure to occlude the artery, and deflates the cuff at a fixed rate. As soon as cuff pressure falls below systolic pressure the artery snaps open at the crest of the systolic pressure rise, then closes again. The rapid motion causes a Doppler frequency shift in the reflected waves, which is detected and activates a relay to indicate the systolic pressure. With each subsequent pulse wave a similar frequency shift is produced, until at the diastolic pressure the artery is no longer occluded. Its rapid motion suddenly disap-

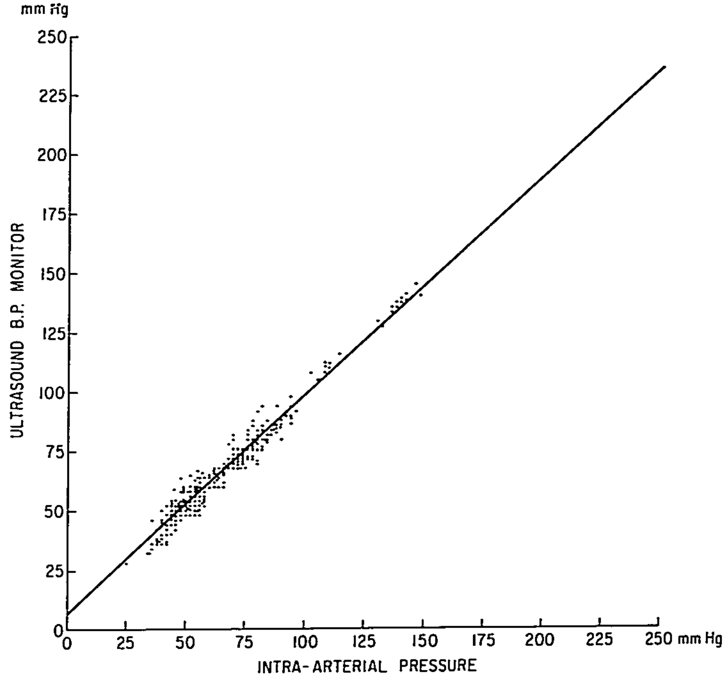

Fig. 2. Scattergram of comparative diastolic pressure determinations by ultrasound blood pressure monitor *vs.* contralateral brachial artery pressures. Four hundred and seventy-nine diastolic comparisons were made (all points plotted, but many overlap) in 15 patients. Pressures ranged from 30 mm Hg to 150 mm Hg. The correlation coefficient (r) was 0.95, $P < 0.001$. The regression line is shown; its equation is $y = 6.1$ mm Hg $+ 0.93\ x$.

pears, and the Doppler shift becomes relatively small. When this condition is detected, the diastolic pressure indicator is held. Thus, the monitor analyzes these signals and automatically displays systolic and diastolic pressures, while pulse-form-analyzing circuits help to discriminate against extraneous motion artefacts.

Fifteen patients without significant cardiovascular or pulmonary disease were scheduled for radical head or neck operations under hypotensive anesthesia. After induction with thiopental and succinyldicholine, the trachea was intubated. Anesthesia was maintained with a mixture of halothane, nitrous oxide, and oxygen, and hypotension was induced with trimethaphan camphorsulfonate (Arfonad). A catheter was introduced into the brachial or radial artery for continuous monitoring of arterial blood pressure by means of a model P37 Statham strain gauge and appropriate amplifiers and recorder. On the contralateral arm a Riva-Rocci cuff and ultrasonic transducer assembly were placed for indirect blood pressure monitoring with the AUDM. The presence or absence of Korotkoff sounds below the

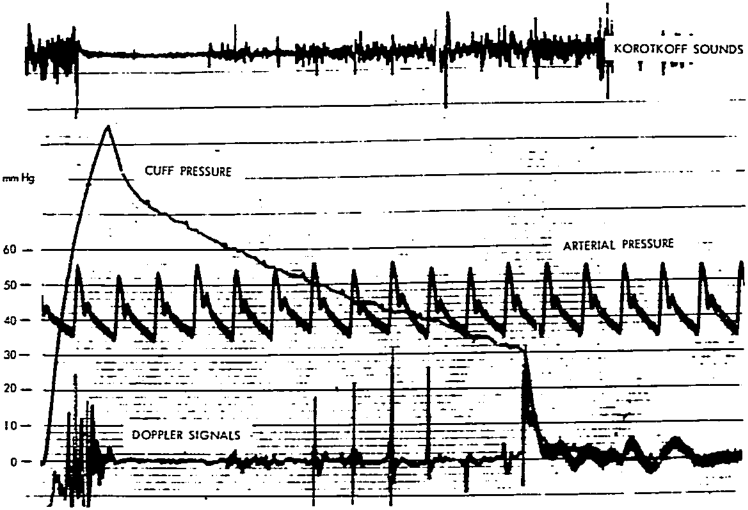

FIG. 3. Absence of Korotkoff sounds and presence of strong Doppler ultrasound signals at low blood pressure levels. At a pressure of 54/34 mm Hg, reached during induced hypotension, Korotkoff sound signals are barely visible on this record; the Doppler ultrasound signals are distinct. Note the appearance of the first Doppler signal as soon as the cuff pressure falls below intra-arterial systolic pressure, and the occurrence of the last Doppler signal when the cuff pressure reaches diastolic pressure.

arm cuff was determined by means of a dynamic microphone and low-frequency amplifier (range 22–220 Hz). Regression analysis, mean difference, and standard deviation of the difference between the two methods were thus determined.

RESULTS

The 15 patients accounted for a total of 479 blood pressure readings, with systolic pressures ranging from 42 mm Hg to 190 mm Hg and diastolic pressures from 30 mm Hg to 145 mm Hg, the higher values representing blood pressures during induction of anesthesia and endotracheal intubation. The mean difference between ultrasonic and intra-arterial systolic pressure readings was −1.7 mm Hg (*i.e.*, the AUDM read lower); the standard deviation of the differences was 4.9 mm Hg. The correlation coefficient was 0.98, $P < 0.001$. For diastolic pressures the mean difference was +1 mm Hg (*i.e.*, the AUDM read higher); the standard deviation of the differences was 4.3 mm Hg, and the correlation coefficient was 0.95, $P < 0.001$. The scattergrams (figs. 1 and 2) show that the data encompass wide pressure ranges. The regression lines indicate a very close linear relationship between the direct and indirect techniques. When hypotensive values, *i.e.*, the 162 readings of intra-arterial systolic pressures equal to or below 80 mm Hg, with their corresponding diastolic pressures, are considered separately, the same conclusions are reached. The mean systolic difference was −0.9 mm Hg, with a standard deviation of the differences of 4.5 mm Hg, and the mean diastolic difference was +1.8 mm Hg, with a standard deviation of the differences of 5.1 mm Hg. The correlation coefficient for systolic pressures was 0.87, and that for diastolic pressures, 0.81. The regression slopes were virtually identical to those calculated from all points.

There were frequent instances when Korotkoff sounds were inaudible, whereas the Doppler signals were quite strong and could be automatically analyzed. An example is shown in figure 3. At an intra-arterial pressure level of 54/34 mm Hg there were distinct Doppler signals but Korotkoff sound impulses were almost indistinguishable from background noise.

Discussion and Conclusion

Difficulties with direct recording of blood pressure are such that they discourage its routine use. In order to supplant the intra-arterial technique, an indirect method must meet rigid criteria. It should be safe and simple to use, and must give reliable readings under various conditions, such as very low pressures, at high ambient noise levels, in obese patients, in patients with irregular pulse rates, and when artefacts due to motion or electrical interference are present.

This study pertains to the accuracy of ultrasonic blood pressure monitoring under conditions of normotension and artificially induced hypotension. Clinical use of the monitor is simple, and it has an ultrasonic energy output of a maximum of 50 mW/cm^2 at a frequency of 2 MHz. With this level of energy output, tissue damage is not expected.[5] Because the intensity of ultrasound is little affected by the distance travelled through soft tissues, blood pressure recording is quite feasible in obese patients. High levels of ambient sound in the audible spectrum cannot interfere with the ultrasonic technique.

The principle of measurement of arterial wall motion by ultrasonic Doppler signals has been described.[6, 7] Poppers,[2, 3] Geddes,[1] and Hochberg and Salomon[4] have reported incorporation of this principle in an automated system. The last authors described its accuracy in typical clinical situations, but they did not explore the specific needs of induced hypotension. They found a systematic difference in diastolic pressures, the AUDM consistently reading 7 mm Hg higher than intra-arterial recording, whereas this study shows a negligible mean difference of 1 mm Hg. However, in terms of systolic pressures, the two studies correlate well.

The AUDM studied has not met all of our criteria. Specifically, it is subject to electrical interference (such as unfiltered electrocautery) and motion artefacts. Logic systems now in development may eliminate the latter. The absence of an arterial cannula for blood sampling has not proved to be a problem, and occasional samples are taken less traumatically with fine-gauge needles.

The requirement for accurate blood pressure measurement in all ranges to be expected during induced hypotension appears to be met adequately by the AUDM. The system parallels and tracks intra-arterial blood pressure changes quite well. It is dependable in patients in whom Korotkoff sounds cannot be recorded because of very low blood pressures. We still use intra-arterial techniques for monitoring when continuous display is needed, as when sudden massive hemorrhage is anticipated. The automatic indirect system is sufficient for routine recording of blood pressure during induced hypotension. In our operating rooms it has replaced intra-arterial monitoring for this purpose.

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