

relative to higher-vapor-pressure anesthetic vaporizers (halothane). Also, every precaution should be taken to avoid charging a vaporizer with a higher-vapor-pressure liquid than it was designed for. If either of these recommendations is violated, a clinically dangerous situation may rapidly develop.

A Method for Ultrasonic Measurement of Blood Pressure in the Adult Leg

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Measurement of the popliteal blood pressure frequently has clinical significance. In many patients with extensive burns or multiple fractures, and during operations on upper extremities, indirect measurement of the brachial arterial blood pressure is not always feasible. Coarctation of the aorta and aortic-valve insufficiency are associated with disproportionate systolic pressure differences between arm and leg which should be determined to help confirm the diagnosis of either condition. It is advocated that the blood pressures in both the arms and the legs be determined in patients with hypertension or peripheral-artery disease.^{1,2} However, indirect measurement of the systolic and diastolic blood pressures in the leg has heretofore been unsatisfactory. The Korotkoff method is grossly inaccurate,³ the palpatory technique difficult, and the oscillographic approach unreliable.⁴

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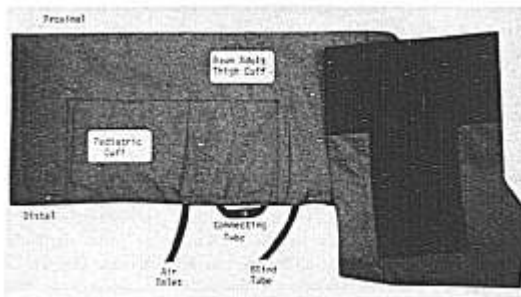
Ultrasonic kinetoarteriography is a new technique of indirect blood pressure measurement. Detection of arterial-wall motion forms its basis. When brachial arterial pressures were determined, it rivaled the intra-arterial technique and exceeded the Korotkoff method in accuracy.^{6,7,8} The aim of the present study was to develop and evaluate ultrasonic kinetoarteriography of the popliteal artery as a method for the measurement of blood pressures in the leg.

MATERIAL AND METHODS

An ultrasonic distance-measuring device was used to determine the depth of the popliteal artery below the skin. All measurements were made in the popliteal fossa of the right leg. The depths ranged from 3.0 to 6.0 cm, with a mean of 4.3 cm, in 17 adults, 20 to 59 years old. In nine children and adolescents, 4 to 13 years of age, the depths ranged from 2.5 to 4.0 cm, and averaged 3.4 cm. This information was necessary for the design of ultrasonic crystals with an appropriate energy focus. Two piezoelectric crystals, one a transmitter and the other a receiver, operating at a frequency of 2 MHz, are sealed separately into a plastic housing. The beam pattern of the transmitting crystal and the signal acceptance aperture of the receiving crystal are of a wide-angle design to provide effective signal reception from the area of the popliteal artery.

§ Ultrasonic Ranging Device (prototype), Roche Medical Electronics Division, Hoffmann-La Roche Inc., Cranbury, New Jersey.

FIG. 1. The twin-bladder blood pressure cuff. A pediatric cuff is sewn inside an adult thigh cuff. The small bladder is inflated first via the air-inlet tube. The outer bladder is subsequently filled via the connecting tube. During deflation the air escapes via the inlet tube, first from the small cuff, then from the large one.



In order to allow precise measurement of blood pressure, an inflatable cuff must provide uniform compression of an area which is 20 per cent wider than the diameter of the limb at the site of measurement.⁹ Owing to the considerable tapering of the upper leg to the popliteal fossa, even the regular thigh cuff cannot evenly compress such a large area, and is therefore not suitable for the determination of popliteal pressure. Based upon anthropometric data on mid and lower thigh circumferences,^{10, 11, 12} a special twin-bladder cuff was designed (fig. 1). It consists of a pediatric blood pressure bladder and cuff sewn inside and parallel to the distal edge of an adult thigh bladder and cuff (19 cm wide and 100 cm long). The air-intake tube leads to the small inner bladder, which in turn is connected to the large outer bladder. The small bladder is inflated first, occupying the void between the outer bladder and the popliteal fossa. As inflation continues, the outer bladder fills from the inner one. Deflation first occurs from the inner bladder through the air-inlet tube. This design insures uniform compression of the lower thigh and popliteal fossa. It also keeps the twin-bladder cuff and the ultrasonic transducer in place during repeated measurements.

The prototype cuff and ultrasonic transducer were used in conjunction with a standard automatic ultrasonic Doppler monitoring device (AUDM),¹³ which has been described.^{5, 6} The ultrasonic transducer was placed over the

popliteal artery, 3 to 5 cm proximal to the center of the popliteal fossa, between the hamstring tendons. A polyvinylpyrrolidone gel applied between the active surface of the transducer and the skin, eliminated the layer of air that would otherwise bar propagation of ultrasonic waves. The cuff was wrapped around the lower thigh, its distal part (i.e., the small bladder) covering the transducer. Cuff and transducer were then connected to the AUDM, whose signal output was registered on one channel of a Brush Mark 220 recorder. The air pressure in the blood pressure cuff was displayed and the perceived Doppler impulses were superimposed on this tracing. The latter indicated the systolic and diastolic points on the tracing of the air pressure.

Following validation studies in three normal subjects to determine pressure ranges and the signal threshold filter for automatic blood pressure sensing, clinical studies comparing AUDM readings with intra-arterial pressures were conducted in 19 patients whose ages ranged from 5 to 74 years. They had undergone open-heart operations one day previously. At that time a femoral-artery catheter for routine monitoring had been placed in each patient. It was now connected to a Statham P-37 strain gauge and Honeywell amplifier for continuous registration of arterial pressure on the second channel of the Brush recorder. Measurements were made only in patients having a palpable posterior tibial or dorsalis pedis pulse to exclude erroneous values that might result from severe arterial obstructive disease.

Mean differences and the standard deviation

† Twin-bladder cuff, popliteal artery ultrasonic transducer, Arteriosonde 1213 and 1216, Roche Medical Electronics Division, Hoffmann-LaRoche Inc., Cranbury, New Jersey.

of the differences were computed for the collected data.

RESULTS

In the 19 patients, a total of 197 comparison measurements were made. Systolic pressures ranged from 84 to 170 mm Hg and diastolic pressures from 32 to 94 mm Hg. The average systolic difference between directly measured femoral pressures and ultrasonically measured popliteal pressures was 3.3 mm Hg, with a standard deviation of the differences of 9.9 mm Hg. The average diastolic difference was 5.1 mm Hg, the standard deviation of the differences being 9.6 mm Hg. The pressures paralleled each other in all cases. All systolic pres-

ures were within 10 mm Hg, and diastolic values within 12 mm Hg, of the corresponding intra-arterial pressures. The ultrasonic reading was higher than the intra-arterial systolic pressure in 12 patients (110 measurements), lower in four (52 measurements), and identical in three (35 measurements). Diastolic pressures determined ultrasonically were higher in 14 subjects (146 measurements), lower in three (35 measurements), and identical in two (16 measurements). Many had arrhythmias, such as atrial fibrillation, bigeminy, or pulsus alternans (fig. 2). Respiration, which was spontaneous at the time of measurement, produced variations in blood pressure ranging from 4 to 24 mm Hg.

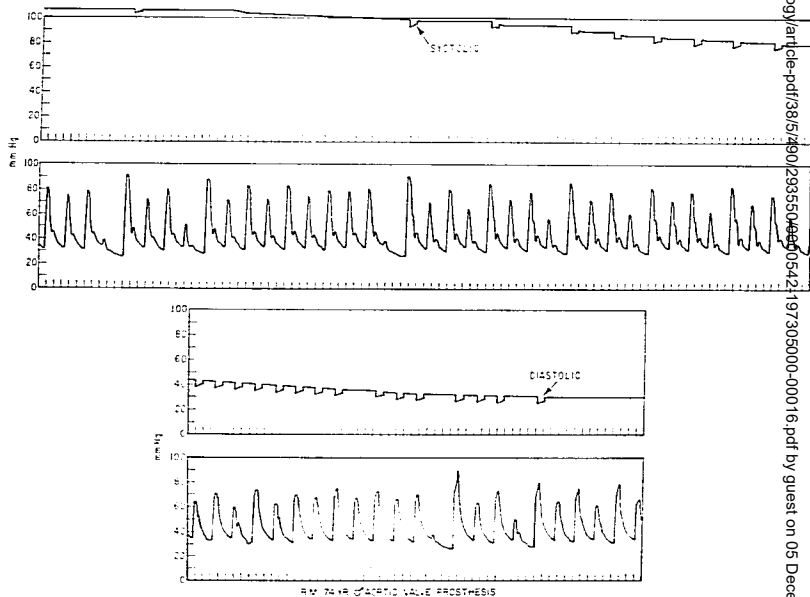


FIG. 2. Simultaneous recording of popliteal pressure and intrafemoral pressure in a patient who underwent replacement of his aortic valve. The upper tracing represents the decreasing air pressure in the blood pressure cuff compressing the popliteal artery. The superimposed notches indicate the occurrence of Doppler frequency shifts in the reflected ultrasound. The lower tracing depicts the femoral arterial pressure waves. Despite an irregular heart rhythm and variations in pressure with each pulse wave, the ultrasonic pressure measurement of 96/28 mm Hg correlates quite well with the intra-arterial pressure of 90/26 mm Hg.

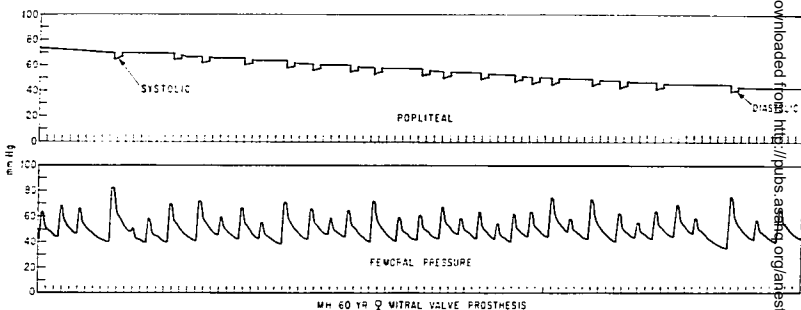


Fig. 3. Simultaneous recording of popliteal and intrafemoral pressures in a patient after mitral-valve replacement. The upper tracing represents the air valve replacement in the blood pressure cuff compressing the popliteal artery, with superimposed notches indicating the occurrence of Doppler frequency shifts in the reflected ultrasound. The femoral arterial pressure, recorded in the lower tracing, shows great irregularity. A sudden intra-arterial pressure peak is the cause of an erratic ultrasonic Doppler signal. Correlation between popliteal and femoral blood pressures, 70/40 vs. 82/35 mm Hg, appears poor. However, further study of the record shows that, with the exception of the sudden peak, femoral systolic pressures indeed hovered around 70 mm Hg.

DISCUSSION

Ultrasonic measurements showed that the popliteal artery lies considerably deeper below the skin than does the brachial artery. This is why a transducer with a different focus is necessary for effective signal reception.

The intra-arterial and the Doppler ultrasound techniques are in clinically acceptable agreement in the measurement of the blood pressure in the leg. Serial comparison of the values obtained with the two methods showed a near-constant difference for most readings in each individual, indicating that the ultrasound method responds consistently to physiologic changes.

In interpreting the recorded differences, one must consider two factors, the patient population, and the method of measurement. Cardiac status was generally poor in most of the patients; blood pressure was labile, and abnormal intra-arterial waveforms were usually present. They produced the occasional erratic pressure values recorded by the AUDM (fig. 3). For example, a patient with pulsus alternans or atrial fibrillation may have unusually strong pulse waves greatly exceeding the average pressure. If the air pressure in the cuff has already decreased below this abnormal

pressure and has not yet reached a level corresponding to the average systolic value, the reading indicated by the monitor is far below the intra-arterial pressure existing at that particular instant. Since for these patients even continuous intra-arterial registration requires some averaging of values, it is important that with an intermittent technique several pressure readings be obtained at short intervals.

Factors relating to the method of measurement include the limitations in accuracy of calibration for each system, and more important, the physiologic pressure differences that exist at different sites of measurement.⁸

The average differences observed in this study are comparable to those reported previously when ultrasonically measured brachial pressures were compared with intra-arterial values,⁷ although the standard deviation of the differences is a few mm Hg higher. The differences are well within the limits for the Korotkoff and Riva-Rocci methods of measurement.^{13, 14}

With the development of a twin-bladder cuff and a transducer with a deep energy focus, ultrasonic kinetography of the popliteal artery has become a simple method of indirect blood pressure measurement with clinically adequate

accuracy. It can serve as a routine technique when the arm cannot be used, or whenever the blood pressure in the leg must also be determined.

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Tracheostomy Obstruction Secondary to a T-Adapter

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T-adapters or T-tubes are frequently used by inhalation therapy and intensive care personnel. They are designed to deliver humidified, oxygen-enriched gases to a patient with an endotracheal or tracheostomy tube. This communication reports a potentially lethal defect in a disposable T-adapter.

REPORT OF A CASE

A 37-year-old Caucasian man had Stage II-A Hodgkin's disease, which was diagnosed in January 1968. Initial treatment consisted of radiation ther-

apy to the cervical, axillary, and mediastinal nodal areas (dose = 4,000 rads). After irradiation, he developed bilateral pleural effusions which necessitated periodic thoracentesis. No evidence of Hodgkin's disease was found either in the pleural fluid or by pleural biopsy. Because of increasing shortness of breath and an entrapped right lower lobe, a right thoracotomy was performed. A thick fibrous peel was removed from the right lower lobe and from the chest wall. Postoperatively, the patient needed prolonged intubation and respiratory support. His endotracheal tube cuff was deflated for 5-10 minutes every two hours, during which time the tube was attached to a T-adapter (fig. 1). A tracheostomy was performed on the twelfth postoperative day. By the twentieth postoperative day, the patient tolerated 30 minutes of every two hours off the respirator on the T-adapter. At 4:00 AM on that day, the T-adapter fell on the floor and was changed.

At noon, the patient was not tolerating being on the T-tube very well and was able to talk around

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