the mechanism that may have originally contributed to the prolongation of SCh-induced paralysis (*i.e.*, anticholinesterase activity) was later employed as a successful treatment.

In summary, prolonged paralysis from SCh occurred following pyridostigmine reversal of pancuronium-induced neuromuscular blockade. Because of an initial normal response to SCh, the subsequent prolonged paralysis was attributed to residual anticholinesterase effects of the pyridostigmine.

REFERENCES

1. Evans FT, Gray PWS, Lehman H, et al: Sensitivity to succinylcholine in relation to serum cholinesterase. Lancet 1:1229–1230, 1952
2. Argent DE, Dinnick OP, Hobbiger F: Prolonged apnoea after suxamethonium in man. Br J Anaesth 27:24–30, 1955
3. Foldes FF, Swerdlow M, Lipschitz E, et al: Comparison of the respiratory effects of suxamethonium in man. ANESTHESIOLOGY 17: 559–568, 1956
4. Wylie WD, Churchill-Davidson HC: A Practice of Anaesthesia. Chicago, Year Book Medical Publishers, 1966, p 746
5. Bennett EJ, Montgomery SJ, Dalal FY, et al: Pancuronium and the fasciculations of succinylcholine. Anesth Analg (Cleve) 52:892–896, 1973
6. McCaul K, Robinson GD: Suxamethonium "extension" by tetrahydroaminacrine. Br J Anaesth 34:536–542, 1962
7. Thesleff S: An investigation of the muscle-relaxing action of succinylcholine–iodie in man. Acta Physiol Scand 25:348–367, 1952
8. Miller RD, Van Nyhuis LS, Eger EI II, et al: Comparative times to peak effect and durations of action of neostigmine and pyridostigmine. ANESTHESIOLOGY 41:27–33, 1974

Safety of Brachial Arterial Catheters as Monitors in the Intensive Care Unit—Prospective Evaluation with the Doppler Ultrasonic Velocity Detector

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At the University of Iowa, all patients undergoing open-heart surgery are monitored during and after operation with brachial arterial percutaneous cannulas inserted prior to induction of anesthesia. Clinically there has been no significant complication as a result of such cannulations. The purpose of this study was to assess the arterial circulation of the upper extremity prospectively with the aid of the Doppler ultrasonic velocity detector to determine the incidences of subclinical and clinical thromboembolic sequelae of this procedure. We have found Doppler ultrasound to be a sensitive index of asymptomatic arterial obstructive complications following cardiac catheterization via both the femoral[1,2] and brachial[3] arterial routes.

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METHODS AND MATERIALS

From November 1973 to May 1974, 54 patients undergoing open-heart surgery at the University of Iowa Hospitals were studied. There were 36 male and 18 female patients, ranging in age from 6 to 73 years, with a mean of 47 years. Twenty-six patients underwent coronary-artery bypass for ischemic heart disease, 19 patients had correction of acquired

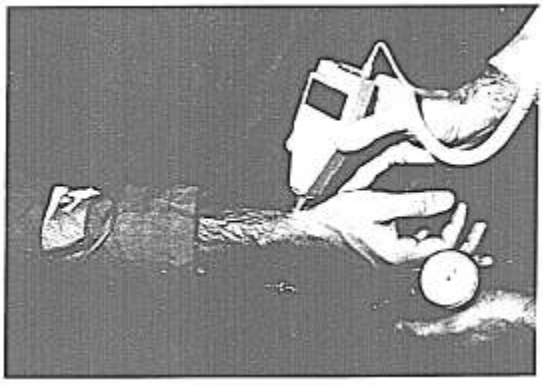

FIG. 1. Technique of measurement of forearm blood pressure utilizing the Doppler velocity detector.

valvular heart disease, and 9 patients had repair of congenital heart defects.

Prior to induction of anesthesia in the operating room, the left antecubital fossa was prepared and draped for the sterile percutaneous introduction of an 18-gauge (20-gauge for children) Teflon cannula[¶] into the left brachial artery. These cannulas were utilized for intraoperative and postoperative arterial pressure monitoring and for obtaining arterial blood for determination of gas tensions. The catheters were continuously flushed with physiologic saline solution containing heparin (2 units/ml) at a rate of 0.03 ml/min.

All patients had daily vascular evaluation of both upper extremities by experienced observers prior to, during, and after removal of the brachial-artery cannulas. Brachial, ulnar, and radial arteries were evaluated for pulse strength, being graded as normal, diminished, or absent. These six arteries were

¶ Longdwell, Becton-Dickinson Company, Rutherford, N.J.

FIG. 2. Technique of modified Allen test utilizing the Doppler velocity detector.

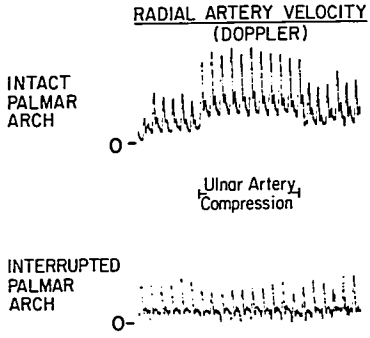

FIG. 3. Radial-artery velocity responses to compression of the ulnar artery with intact (*top*) and interrupted (*bottom*) circulation in the palmar arch.

then examined with a 7.9-megahertz Doppler ultrasonic velocity detector** for the quality of the arterial velocity signal.[3] Velocity signals were graded as normal (multiphasic), abnormal (monophasic), or absent. Abnormal velocity signals correlate with arterial stenosis or occlusion with collateral circulation, while signals are absent with occlusion and poor or absent collateral circulation.

Systolic pressure was measured in the brachial, radial, and ulnar arteries of each arm. For measurement of brachial systolic pressure, a standard pneumatic cuff was placed on the arm and inflated until the Doppler arterial signal obtained from the brachial artery was obliterated. The pneumatic cuff was then slowly deflated until the Doppler arterial signal returned at the brachial systolic pressure. Pressure measurements in the radial and ulnar arteries were similarly determined with the pneumatic cuff on the forearm (Fig. 1). Normally the forearm blood pressure equals or is slightly higher than that in the upper arm.[3] In the presence of arterial obstruction, the radial or ulnar arterial pressure is less than that of the upper arm by an amount proportional to the extent of circulatory impairment. In this study, arterial obstruction was defined as a pressure gradient of 10 mm Hg or more between the upper arm and the forearm.

The integrity of the arterial circulation of the palmar arch can normally be assessed by the Allen test.[4] Inasmuch as false-positive tests have been described, and in order to avoid the inability of the patient to cooperate during and following anesthesia, a modified Allen test was carried out utilizing the Doppler ultrasonic velocity detector. In this test the arterial velocity in either the radial or ulnar artery at the wrist was assessed by Doppler ultrasound before and after compression of the opposite artery (Fig. 2). Normally the arterial velocity increases during compression of the opposite artery (Fig. 3, top). In the presence of an incomplete palmar arch connecting the two circulations, or in the presence of arterial obstruction in the artery being compressed, the arterial velocity does not change significantly during the period of arterial compression (Fig. 3, bottom). This test was carried out on all patients to assess the possible presence of small distal arterial emboli that might not be detected by the usual assessment of the radial, ulnar and brachial circulations.

RESULTS

Prior to cannulation, all patients had normal arterial pulses and velocity signals in the arm. Forearm pressures were equal to or higher than those of arms in all individuals. The average period of brachial arterial cannulation was 1.5 days (range one to three days). Approximately 10 per cent of these patients had periods of low cardiac output and peripheral vasoconstriction during the immediate postoperative periods. Inotropic agents (epinephrine, isoproterenol) were administered as necessary.

In this study, no patient developed Doppler evidence of hemodynamic obstruction of the left brachial artery during the period of cannulation. In the 54 patients studied, there was no evidence of any clinically significant vascular complication related to the catheter as judged by symptoms, persisting major pulse deficits, or signs of ischemia. However, three patients developed Doppler evidence of localized obstruction of an artery in the left forearm (table 1). In none of these patients was

** Ultrasonic stethoscope, Model BF5A, kindly supplied by Medsonics Incorporated, Mountain View, Cal.

TABLE 1. Manifestations of Complications

Onset after Cannulation	Vessel Obstructed	Symptoms	Pulse	Doppler Signal	Arm-Forearm Pressure Gradient (mm Hg)	Doppler Allen Test
One day	Ulnar artery*	None	Absent*	Absent*	120*	Abnormal*
One day	Radial artery	None	Reduced	Abnormal	13	Abnormal
After decannulation	Radial artery	None	Reduced	Abnormal	20	Normal

* Transient, lasting only one day during indwelling cannulation.

the complication attributable to low cardiac output or vasopressor therapy.

One patient had transient obstruction of the left ulnar artery during the period of brachial arterial cannulation. This obstruction was evidenced by a loss of the ulnar pulse and absence of the left ulnar-artery Doppler signal and pressure. However, prior to removal of the catheter, the pulse and signal returned and a normal ulnar arterial pressure returned, remaining normal in the post-cannulation period. Two patients had persistent radial arterial obstruction, one during the period of cannulation and the other after cannula removal. The two patients had diminution of radial pulses, abnormal Doppler signals from the radial arteries, and 13- and a 20-mm Hg systolic pressure gradients, respectively, between the brachial and radial arteries. However, at no time did these patients evidence clinical symptoms or signs of significant ischemia of the hand or forearm. Both had weak but definitely palpable radial pulses in the postoperative period after removal of the catheters. One of these patients had an abnormal Doppler Allen test, whereas the other patient continued to have a normal Allen test despite the radial-artery obstruction.

The remaining 51 patients all maintained normal arterial pulses, arterial velocity signals, and forearm pressures during and after brachial-artery cannulation. No patient has had any arterial insufficiency of the arm during an 18-month period following operation.

DISCUSSION

The prevalence of intensive care units has led to more widespread use of arterial cannulation for pressure monitoring and determinations of arterial blood-gas tensions. Although vessels such as the superficial temporal, dorsalis pedis, femoral, or brachial arteries may be used, the most common method is to utilize an indwelling plastic cannula in either the radial or the ulnar artery. Radial-artery cannulation has been rarely associated with marked ischemia or gangrene of the hand. Nevertheless, the radial artery is often occluded after percutaneous cannulation,[5–7] although recanalization may occur.[8] The rarity of ischemia of the hand is a reflection of the usually excellent collateral circulation from the ulnar artery via the palmar arch. The rare threat of ischemia or gangrene of the hand resulting from radial arterial thrombosis in the absence of arterial continuity of the palmar arch mandates use of the Allen test or the modified Doppler test to identify patients in whom such a risk exists.

There have been few reports of brachial arterial cannulation for monitoring of intensive care patients. The study by Bjork and colleagues[9] revealed a significant risk of angiographic and oscillometric abnormalities of the brachial artery (14 of 25 patients, 56 per cent) with short-term use of such catheters. However, clinically detectable ischemia of the forearm or hand was not reported by those authors, nor have we encountered such complications in our clinical experience with brachial arterial cannulations in more than 1,000 patients during the past three years. The possibility of subclinical arterial complications prompted the present investigation. A prior study revealing a 17 per cent incidence of brachial-artery obstruction following cardiac catheterization,[3] two-thirds of which obstructions were asymptomatic, was further impetus to evaluate more carefully and objectively the arterial circulation after cannulation of the arm.

The present study reveals that the incidence of hemodynamic alterations resulting from the use of an indwelling brachial arterial monitoring cannula is lower than that following cardiac catheterization via this vessel. Of interest is the fact that no patient in this study developed clinical symptoms or signs of significant ischemia, and although two radial-artery obstructions were documented, both patients had pulses in these vessels. The third patient with transient ulnar-artery obstruction may have had an arterial vasospasm that rapidly disappeared during the period of cannulation. The possibility of a small thromboembolus with subsequent fibrinolysis cannot be excluded.

We conclude from this study that percutaneous cannulation with a Teflon brachial-artery cannula is relatively safe and useful for aiding the management of patients in the intensive care unit following open-heart surgery. The two instances of persistent radial-artery obstruction, however, should make one aware of the potential for thromboembolic complications associated with this procedure. That both of these patients were asymptomatic should not lead one to a false sense of security that more serious complications might not develop. We emphasize that meticulous technique in catheter insertion and attentive care and continuous flushing of catheters must be maintained to minimize significant complications. We recognize the clinical safety of radial-artery cannulation and do not wish to recommend brachial arterial cannulation in preference to radial arterial monitoring for those experienced with the latter. However, our data suggest that the incidence of arterial obstruction following brachial arterial cannulation is less than that previously reported on the basis of Doppler evaluation of radial arterial cannulation. Our experience encourages us to continue careful clinical application of this technique to monitor patients in the intensive care unit.

References

1. Barnes RW, Hafermann MD, Petersen J, et al: Noninvasive assessment of altered limb hemodynamics and complications of arterial catheterization. Radiology 107:505–507, 1973
2. Barnes RW, Petersen JL, Krugmire RB Jr, et al: Complications of percutaneous femoral artery catheterization: Prospective evaluation with the Doppler ultrasonic velocity detector. Am J Cardiol 33:259–263, 1974
3. Barnes RW, Petersen JL, Krugmire RB Jr, et al: Complications of brachial artery catheterization: Prospective evaluation with the Doppler ultrasonic velocity detector. Chest 66:363–367, 1974
4. Allen EV: Thromboangiitis obliterans: Methods of diagnosis of chronic occlusive arterial lesions distal to the wrist with illustrative cases. Am J Med Sci 178:237–244, 1929
5. Samaan HA: The hazards of radial artery pressure monitoring. J Cardiovasc Surg 12: 342–347, 1971
6. Bedford RF, Wollman H: Complications of percutaneous radial-artery cannulation: An objective prospective study in man. ANESTHESIOLOGY 38:228–236, 1973
7. Downs JB, Rackstein AD, Klein EF Jr, et al: Hazards of radial-artery catheterization. ANESTHESIOLOGY 38:283–286, 1973
8. Ryan JF, Raines J, Dalton BC, et al: Arterial dynamics of radial artery cannulation. Anesth Analg (Cleve) 52:1017–1025, 1973
9. Bjork L, Enghoff E, Grenvik A, et al: Local circulatory changes following brachial artery catheterization. Vasc Dis 2:283–292, 1965