PERCUTANEOUS INDWELLING RADIAL-ARTERY CATHETERS FOR MONITORING CARDIOVASCULAR FUNCTION

Prospective Study of the Risk of Thrombosis and Infection

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Abstract Percutaneous central arterial catheterizations were performed at the first radial-artery site in 492 (92 per cent) of 536 insertion attempts in patients in an intensive-care unit. The high success rate was attributed to placement by skilled nurse technicians and use of a simplified catheter device.

The mean duration of catheterization was 3.4 days (range, one to 25 days). With use of a continuous flush system, only five catheters became nonfunctional. Hypotension, use of vasoconstrictive agents and prolonged catheterization were associated with complete arterial occlusion in three study patients who required thrombectomies. Partial occlusions, detected by Doppler ultrasonic flowmeter, occurred in 19.3 per cent.

No local or systemic infections could be definitely related to arterial catheters. Results of 200 arterial catheter-tip cultures were positive in eight cases (4 per cent), but none of these were judged to be a primary source of clinical infection. (N Engl J Med 290:1227-1231, 1974)

INSERTION of indwelling arterial catheters has become an indispensable practice in intensive-care units because it facilitates both monitoring of cardiovascular function and obtaining of frequent arterial-blood samples. Evaluations of complications of a variety of catheters and technics have been reported.[1-5] The most serious complication of arterial catheterization is thrombosis, which occurs in 40 to 60 per cent of cases.[1,3,6,7] The rate of bacterial colonization of indwelling arterial catheters and the risk of associated sepsis have not been reported except for umbilical-artery catheters in infants.[8]

Since 1967 we have performed more than 4000 percutaneous radial-artery catheterizations in a large private community hospital. The present study was undertaken to determine the rate of successful percutaneous insertion of arterial catheters, the complication rates of thrombus formation and bacterial colonization, as well as local and systemic infection, associated with arterial catheters, and the long-term reliability of continuously flushed arterial catheters.

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Methods

From August, 1972, to June, 1973, a prospective study of 536 consecutive central arterial catheterizations performed on 531 patients was conducted in the cardiovascular-thoracic and general-surgery intensive-care units at Latter-day Saints Hospital in Salt Lake City, Utah. During this study 96 per cent of the catheterizations were performed by a specially trained registered nurse with the aid of a technician. Catheterization was done as a convenience on the day before scheduled operations in 87 per cent of the cases. Emergency catheter placement was done in the remaining 13 per cent.

Technic of Arterial Catheterization

Each patient was premedicated with meperidine hydrochloride (50 to 70 mg). Patency of the radial and ulnar arteries was assessed by Allen's test[9] or by Doppler ultrasonic flowmeter (or both). The unshaven wrist was hyperextended (Fig. 1) and a small area over the radial artery was cleansed with an alcohol sponge. A small area on both sides of the radial artery was anesthetized with 1 per cent lidocaine hydrochloride. The needle of the catheter system was then inserted percutaneously into the radial artery (without the use of sterile drapes or gloves) by assessment of the position of the needle and the artery with the fingers and observation of an oscilloscopic display of the arterial pressure. The pressure wave form was monitored while the catheter was being advanced. The tip of the catheter was placed in the subclavian artery by use of the protective conduit of the catheter system to measure distance of insertion. Insertion time — that is, time from skin puncture until the catheter tip was at a central location — was measured to the nearest minute. The needle over-riding the catheter was then withdrawn from the artery to a hub, where it was secured and covered with a plastic needle guard. An antibiotic ointment (Neosporin) from individual packets of 0.9 g (1/32 oz) was applied at the point of arterial entry, and an elastic pressure dressing was applied to control bleeding.

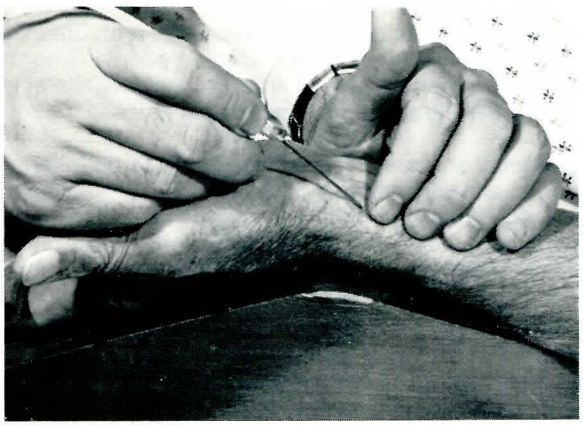

Figure 1. Technic of Percutaneous Radial-Artery-Catheter Insertion with Use of a Specially Constructed Armboard.

The catheter system (Sorenson CAP Intrafuser) permits percutaneous insertion of a 100-cm-long, 1 mm O.D., Teflon catheter through an 18-gauge thin-wall needle. The catheter is prepared for monitoring by filling from a pressurized fluid source through the flush system* (Fig. 2). Physiologic saline with 4 U of heparin per milliliter is pressurized to 300 mm Hg in an air-free plastic bag. The continuous flow of 2 to 3 ml per hour allowed by the flush system through the catheter prevents clotting and consequent loss of catheter function. A rapid-flush valve simplifies filling and flushing the system and permits dynamic response testing of the catheter-transducer system.[10] The limited flow (2 to 3 ml per hour normally and only 5 ml per minute maximum) reduces the risk of cerebral embolization[11] and prevents accidental overinfusion.

*Sorenson Intraflow, Sorenson Research Co., 4387 Atherton Dr., Salt Lake City, Ut.

When the catheter was inserted on the day before surgery, the catheter was filled with concentrated heparin, dead-ended and taped to the patient's arm, after which he was returned to his room. The patients were completely ambulatory and had only minor activity restrictions (e.g., a plastic bag over the area during showers). On the patient's arrival at the surgical suite or intensive-care unit, the catheter was reconnected to the transducer-flush system, and monitoring begun.

Study Protocol

The catheter insertion site was inspected by a member of the study team every second day after insertion for signs of infection or hematoma, and the dressing was changed as needed. Time of each blood gas sample taken through the catheter was recorded. When the catheter was removed, the time and date of removal, the reason for removal and the presence or absence of radial pulse were recorded. The site was inspected by a member of the study team for evidence of local infection. Subsequently, the patient was examined (one to three days after removal of the catheter) by the nursing clinical co-ordinator, and evidence of local infection or hematoma, presence of radial pulse and pain in the hand or wrist were noted. For 280 patients, just before discharge, a Doppler ultrasonic flowmeter was used to classify the characteristics of arterial flow.

In 200 unselected cases, a study-team member cut off the distal 2 to 3 cm of the catheter with sterile scissors when the catheter was removed and cultured the catheter tip in a tube containing 10 ml of sterile trypticase soy broth. Cultures were processed according to standard aerobic bacteriologic technics and were held for seven days before being considered negative.

The hospital record of each patient was reviewed for evidence of positive blood cultures and use of systemic antimicrobial agents. Catheter-tip cultures were not obtained from any of the 38 patients who died, but the hospital records were received by one of us (J.P.B.).

Results

The great majority (495) of the catheters were inserted in patients on a single cardiothoracic service, and the remainder (41) in patients on a general-surgery service. Mean age of the patients was 55 years. There were 371 males and 165 females. Catheters were in place for an average of 3.4 days, with a maximum of 25 days (Table 1). An average of 5.4 blood gas samples per patient were obtained, with one patient having 56 samples drawn.

Percutaneous Insertion

All 531 patients had adequate flow in both radial and ulnar arteries. Insertion time appeared to be a measure of the simplicity of insertion: average insertion time was only 2.8 minutes, with the most frequent duration being only one minute. There was a very high success rate (91.8 per cent) of insertion into the radial artery of choice. An additional 6.7 per cent of the catheters were inserted at a second site, and 1.5 per cent required insertion at a third site (brachial or femoral) and a few by cutdown (0.8 per cent).

In 16 (2.9 per cent) of the patients the catheter could not be advanced centrally to the subclavian artery. Only one patient had an acute reaction to the insertion procedure: bradycardia and hypotension, for which he was given atropine, with subsequent recovery without complication.

In-Use Complications

In no case was there bleeding requiring catheter removal or surgical attention. However, in approxi-

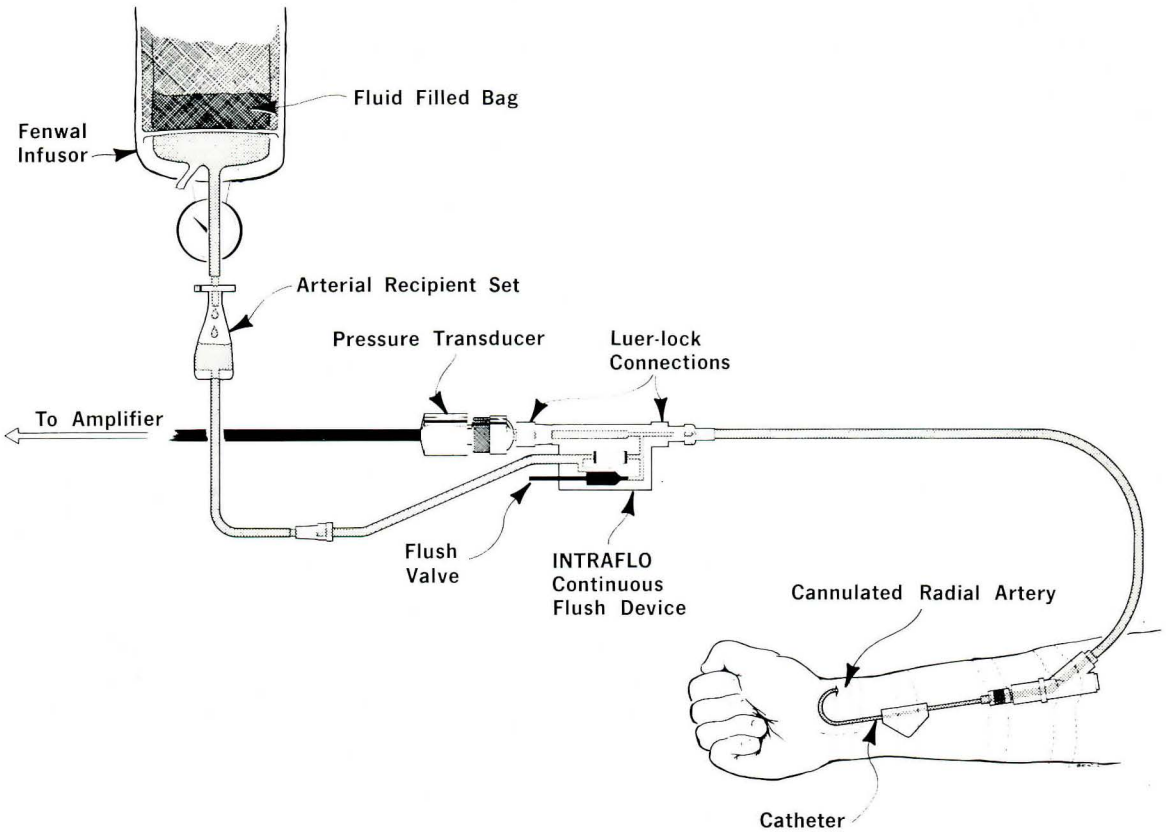

Figure 2. Schematic Diagram of Arterial Catheter, Transducer and Continuous Flush System.

mately 10 per cent of the patients, some of whom were receiving anticoagulants, it was necessary to "sandbag" the insertion site in addition to applying the elastic pressure dressing to prevent clinically important hematoma. The rate of hematoma after removal of the catheters was 9.3 per cent (50 patients). None of the hematomas required surgical attention, and all patients recovered without complication. In one patient the catheter was sheared off while the needle was in the artery, and surgical removal was required, without complication, at the time of scheduled operation.

Table 1. Relevant Features of the Study Population.

Feature	Average	Mode	Minimum	Maximum
Clinical:				
Patient age (yr)	55.3	59	16	91
Insertion time (min)	2.8	1	1	30
Duration of catheterization (days)	3.4	3	1	25
Blood gas samples (no./ patient)	5.4	3	0	56
	No.		*%*	
Insertion success rate:				
1st site	492		91.8	
2d site	36		6.7	
3d site	8		1.5	
Site of entry:				
Percutaneous – total:	532		99.2	
Radial artery	525		97.9	
Brachial artery	3		0.6	
Femoral artery	4		0.7	
Cutdown – total:	4		0.8	
Radial artery	3		0.6	
Femoral artery	1		0.2	

Over the nine-month period only five of the 536 catheters became nonfunctional – three because of clotting and two because they became severely kinked and were severed at the transducer connection.

During the study *none* of the following complications sometimes seen with monitoring arterial catheters were observed: arterial dissection; evidence of trauma to the nerves of the hand or wrist; or excessive bleeding which required transfusion, surgical intervention or medication. In addition, no cases of cerebrovascular accidents were observed that were considered due to the arterial catheter.

Three (0.56 per cent) of the 531 patients required thrombectomies of the radial, ulnar or brachial artery as a result of complete arterial occlusion. In addition, three other patients (not in the study group) during the past 2½ years have required thrombectomies subsequent to arterial catheterization. Five of these six patients had the following in common: catheter in place six or more days; hypotension; and administration of vasoactive agents, with severe peripheral vasoconstriction.

On the basis of these observations, our protocol now requires that patients with these risk factors be reviewed after five days. If the risk of arterial occlusion is

offset by the value of the clinical data provided, the catheter is left in place, or an alternate site (femoral artery) may be selected. Since implementation of this protocol, no thrombectomies have been required in 615 catheterizations.

Follow-up study of 280 insertions with use of a Doppler ultrasonic flowmeter yielded detectable flow reduction in the radial artery in 19.3 per cent (Table 2). Flow was absent in 1.8 per cent, measurable proximal or distal to the insertion site in 4.6 per cent, diminished in 12.9 per cent and normal in 80.7 per cent of the cases.

An unexpected observation was made by follow-up examination of radial-artery flow at the unsuccessful site in patients when a second insertion site was used. Typically, three or four insertion attempts were made at the first site before the operator resorted to the opposite arm. Measurement of flow at the unsuccessful site with use of the ultrasonic flowmeter showed a high rate of diminished flow. The flow measurements were made several days after the artery was traumatized but not entered by the catheter. This observation has resulted in a procedural change requiring immediate success or a cessation of probing during catheter insertion. This finding could be important for patients who require multiple punctures for blood gas sampling where a similar traumatization could occur.

Table 2. Summary of Arterial Occlusions.

Type of Occlusion	No.	%
Complete (536 insertions)	3	0.56
Partial (Doppler study, 280 insertions):		
Radial flow absent	5	1.8
Radial flow measurable proximal or distal to insertion site	13	4.6
Radial flow diminished	36	12.9
Total	54	19.3

Bacterial Colonization and Infection

Catheter tip cultures were positive in eight (4 per cent) of 200 patients. The micro-organisms recovered were *Staphylococcus epidermidis* (two cases), yeast (three), serratia (one), micrococcus (one), and bacillus species (one). None were judged to be clinically serious, although in one case yeast was isolated from a blood culture obtained before the arterial catheter was placed, and later from a central-venous-catheter tip as well as the arterial catheter. In another, sputum cultures, as well as the arterial catheter tip, yielded serratia. No alterations in clinical care were made as a result of the positive-culture reports in any of these cases. Virtually all the patients in the study were receiving systemic antimicrobial agents during the period of arterial catheterization. The average duration of catheterization in those with positive cultures was 5.9 days (vs. 3.7-day average), and seven of the eight patients had arterial lines in place for more than 48 hours.

None of the patients had evidence of local infection or cellulitis at the site of catheter placement.

Catheter-tip cultures were not obtained from 38 patients who died while the catheters were in use. Review of these hospital records showed that the arterial catheters could not be definitely associated with either local or systemic infection in any case and only possibly associated in two cases. Eight deaths occurred during operative procedures, and an additional 10 occurred less than 24 hours after catheter placement. A greater proportion of those patients who died were cared for in the general-surgery intensive-care unit, and their mean age was slightly older (58 years), but the average duration of catheterization (3.1 days) was similar to that of those in whom culture was performed.

Discussion

Central arterial catheterization permits beat-by-beat oscilloscopic display of the pulse contour for determination of blood pressure and heart rate. With the pulse-contour technic developed by Warner,[12-14] beat-by-beat determinations of stroke volume can be made.

The major complication of arterial cannulation for direct arterial-pressure monitoring is thrombus formation. Recent studies[7] indicate that smaller catheter size, relative to the artery, is associated with a lower risk of thrombus formation. The rate of complete and partial thrombosis in our patients (19.3 per cent) is lower than previously reported. We attribute this lower figure to use of a small untapered Teflon catheter (1 mm O.D.), simple, atraumatic catheter insertion technic, and use of a continuous flush system for keeping the catheter tip thrombus free. No amputations have been required as a result of radial-artery cannulation in more than 4000 catheter placements at our hospital.

Our results have shown that the following patients are prime candidates for thrombosis: those who are hypotensive; those receiving vasoactive agents, causing peripheral artery constriction; and those with a duration of catheterization of more than one week.

The high success rate of the catheterization procedure may be attributed to preoperative insertion of most of the catheters under optimal conditions; insertion by a skilled nurse technician who maintains her expertise by daily catheter insertion; and a simplified catheter introduction system.

The continuous-flush system permitted long-term monitoring, with a minimal occurrence of catheter-function loss. All catheter flushing was from a 300 mm Hg air-free pressure system, thereby minimizing upstream flow from the catheter and preventing air embolism or cerebrovascular accidents. Quality of the catheter-transducer system was easily and quickly checked with the flush valve.

Although we were unable to document any clinical infections — either local or systemic — that could be attributed to radial-artery catheterization, our results suggest that arterial catheters should be considered to present risks of infection similar to those of

venous catheters. Serious local infection at the site of arteriotomy has been reported in adult patients,[15] and no difference was found in the rates of contamination of arterial versus venous umbilical catheters in infants.[16] The rate of bacterial colonization of percutaneous venous catheters has been reported to vary from 3.8 per cent in hospitals with specially trained intravenous therapy teams to 34 per cent in a large general hospital without a special team.[17-19] It appears likely that meticulous technic and optimal daily care may reduce the rate of colonization. The fact that the vast majority of the arterial placements reported here were performed by one person under optimal conditions with use of a well designed disposable catheter system may have contributed to the low colonization rate found.

Other factors that may have contributed to the low rate of serious infections include the fact that the majority of these catheters were used for immunologically healthy patients undergoing major surgery, the extensive use of prophylactic systemic antimicrobial agents, and the small size of the catheters employed, as well as the peripheral direction of blood flow.

Nonetheless, the finding that the duration of catheterization was longer in those with positive cultures, as well as the recovery of the same organisms from other sites in two of the eight patients with positive cultures, suggests that arterial catheterization may be a source of infection.

Arterial catheters should be removed as soon as they are no longer necessary; the catheter site probably should be changed, and the catheter tip cultured, in patients who require further monitoring during an infective episode — as has been recommended for venous catheters.[20,21]

Central arterial monitoring catheters can be quickly inserted percutaneously into the radial artery with a high success rate and with an acceptable risk of serious complications. The large number of arterial catheterizations currently performed each year at our hospital indicates the success and reliability of our technic.

We are indebted to the thoracic surgeons who encouraged the study, to Dr. Gilbert Hill for the bacteriologic studies, to Mrs. Margene Withers, R.N., for patient follow-up observation and to Miss Mary Ann Christensen for technical assistance.

References

1. Mortensen JD: Clinical sequelae from arterial needle puncture, cannulation, and incision. Circulation 35:1118-1123, 1967
2. Nejad MS, Klaper MA, Steggerda FR, et al: Clotting on the outer surfaces of vascular catheters. Radiology 91:248-250, 1968
3. Brown AE, Sweeney DB, Lumley J: Percutaneous radial artery cannulation. Anaesthesia 24:532-536, 1969
4. Samaan HA: The hazards of radial artery pressure monitoring. J Cardiovasc Surg 12:342-347, 1971
5. Bartlett RH, Munster AM: An improved technic for prolonged arterial cannulation. N Engl J Med 279:92-93, 1968
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. Tooley WH: What is the risk of an umbilical artery catheter? Pediatrics 50:1-2, 1972
9. 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
10. Gardner RM, Warner HR, Toronto AF, et al: Catheter-flush system for continuous monitoring of central arterial pulse waveform. J Appl Physiol 29:911-913, 1970
11. Lowenstein E, Little JW III, Lo HH: Prevention of cerebral embolization from flushing radial-artery cannulas. N Engl J Med 285:1414-1415, 1971
12. Warner HR: Experiences with computer-based patient monitoring. Anesth Analg (Cleve) 47:453-462, 1968
13. Warner HR, Gardner RM, Toronto AF: Computer-based monitoring of cardiovascular functions in postoperative patients. Circulation 37: Suppl 2:68-74, 1968
14. Graves CL, Stauffer WM, Klein RL, et al: Aortic pulse contour calculation of cardiac output. Anesthesiology 29:580-584, 1968
15. Campion BC, Frye RL, Pluth JR, et al: Arterial complications of retrograde brachial arterial catheterization: a prospective study. Mayo Clin Proc 46:589-592, 1971
16. Krauss AN, Albert RF, Kannan MM: Contamination of umbilical catheters in the newborn infant. J Pediatr 77:965-969, 1970
17. Fuchs PC: Indwelling intravenous polyethylene catheters: factors influencing the risk of microbial colonization and sepsis. JAMA 216:1447-1450, 1971
18. Zinner SH, Denny-Brown BC, Braun P, et al: Risk of infection with intravenous indwelling catheters: effect of application of antibiotic ointment. J Infect Dis 120:616-619, 1969
19. Corso JA, Agostinelli R, Brandriss MW: Maintenance of venous polyethylene catheters to reduce risk of infection. JAMA 210:2075-2077, 1969
20. Control of infections from intravenous infusions. Med Lett Drugs Ther 15:105-107, 1973
21. Maki DG, Goldmann DA, Rhame FS: Infection control in intravenous therapy. Ann Intern Med 79:867-887, 1973

Background Reading

References 6, 7 and 21