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On the Safety of Radial Artery Cannulation

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The frequency of complications following radial artery cannulation for monitoring purposes was determined in 1,699 cardiovascular surgical patients and in 83 patients in whom cannulation was performed in another artery after failure at the radial site. Patients were examined and radial artery flow determined by a Doppler technique 1 day and 7 days after decannulation. Although partial or complete radial artery occlusion after decannulation occurred in more than 25% of the patients, no ischemic damage to the hand or disability occurred in any patient. Neither duration of cannulation nor the size or material of the cannulas were determinants of abnormal flow. Abnormal flow was significantly related to female sex, the presence of hematoma, and to the use of extracorporeal circulation. The radial arteries of 16 patients whose results of Allen's test were abnormal were cannulated and no abnormal flow or ischemia followed. In 22 patients, the ulnar artery was cannulated after multiple punctures of the ipsilateral radial artery and no ischemia followed. We conclude that in the absence of peripheral vascular disease, the Allen's test is not a predictor of ischemia of the hand during or after radial artery cannulation, that when decreased or absent radial artery flow follows cannulation it is of no clinical consequence, and that radial artery cannulation is a low-risk high-benefit monitoring technique that deserves wide clinical use. (Key words: Artery: radial, Allen's test. Complications. Monitoring: blood pressure).

ALTHOUGH PERMANENT ISCHEMIC damage of the hand after radial artery cannulation is rare, anesthesiologists are concerned with potential ischemic damage resulting from radial artery occlusion during or after cannulation. Investigations of the incidence of radial artery occlusion have implicated duration of cannulation,[1,2] size of cannula,[3-5] composition of the cannula,[3,6] and several patient characteristics[5,7,8] as predisposing factors. In these investigations, patients having an Allen's test with abnormal results for patency of the palmar arches were excluded in the belief that the risk of ischemic damage of the hand was too great to permit cannulation.

For at least 2 decades, cardiovascular surgical patients of the Texas Heart Institute have been monitored by radial artery cannulation without routine performance of an Allen's test. During this period the only patients who suffered ischemic damage to the hand were those suffering multiple particulate emboli arising from within the heart and those with prolonged low cardiac output requiring high doses of vasopressors for protracted periods. In both situations ischemic damage occurred in extremities that were not cannulated as well as in the one that was cannulated. We continue to cannulate routinely the radial artery using cannulas of different sizes and materials with or without a prior Allen's test and using techniques that vary with the preference of each anesthesiologist. This mix of materials and methods in a large number of patients within a single institution provided a unique opportunity to evaluate not only the incidence of radial artery occlusion but also the clinical significance of thrombosis when it occurs, the value of the Allen's test in predicting thrombosis and ischemia, and, secondarily, to look for factors which predispose to thrombosis.

Methods

During a 4-month period (February 1, 1981, to May 31, 1981) all adult patients of the Texas Heart Institute scheduled for elective operations requiring radial artery cannulation for intraoperative monitoring were included in this study. Only pediatric patients, patients having emergency operations, and those not requiring direct blood pressure monitoring were excluded. An additional 83 patients were excluded because the brachial (61 patients) or ulnar (22 patients) artery was cannulated after numerous attempts failed to cannulate the radial artery. Patients who expired before decannulation were also excluded. No patients with vascular disease of the arms, *e.g.*, Raynaud's or thromboangitis obliterans, were operated upon during this period. Complete histories and follow-up data were thus obtained from 1,699 patients after radial artery cannulation, a sample representing more than 80% of the patients operated upon during this period.

All cannulations were performed in the operating room without gloves or draping and after skin preparation with alcohol swab only. Cannulas were taped but not sutured in place and no topical antibiotic was applied, although all patients routinely received systemic broad spectrum antibiotics in the perioperative period. Cannulas were inserted by anesthesia trainees (78%) and staff anesthesiologists (22%). Four different cannulas were used, 18 ga and 20 ga tapered polypropylene (Medicut) and 18 ga and 20 ga nontapered teflon (Cathlon). The operator elected the type and size of cannula, the technique of transfixion or direct insertion, and whether to perform an Allen's test. The Allen's test, when done, was performed according to the technique modified by Bedford[1,4] and the results were considered

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abnormal if the time for reappearance of blood in the hand, including distal digits and thenar eminence, exceeded 15 s. The artery was cannulated whether or not the test results were abnormal. During operation and for most patients following operation, the cannulas were manually flushed intermittently with saline containing heparin (4 U/ml). Others were flushed continuously at 3 ml/h during the postoperative period only. At the time of decannulation, the site was manually compressed until no bleeding occurred.

For each patient, age, sex, diagnosis, operation, and site of any recently performed diagnostic catheterization were recorded. Hypertension was considered present when recorded as a specific diagnosis or when the patient was being treated with antihypertensive drugs. Vascular disease was considered present when symptoms of ischemia were present or physical evidence of obstruction or aneurysm had been demonstrated in some circulation other than the coronary. Details of arterial cannulation were recorded immediately after, including the number of times the artery was punctured and whether a hematoma was present. Data recorded in the perioperative period included the use of vasopressors by infusion, the use of intraaortic balloon counterpulsation, and the occurrence of circulatory collapse requiring cardiopulmonary resuscitation in the first 24 hours after operation.

Except for patients released from the hospital less than 1 week after arterial decannulation, all patients were interviewed and examined by one investigator (C.A.) 1 day (early) and 7 days after removal of the cannula except for approximately 300 patients discharged from the hospital before the seventh day and examined as early as the fourth day (late). Data recorded at the time of examination included 1) infection at site, 2) hematoma at site, 3) abnormality of skin color of hand and patient perception of skin color, 4) sensory abnormality of the hand, 5) patients' estimate of disability of hand, 6) the presence and fullness of radial pulse, and 7) arterial flow estimated by Doppler ultrasonic flow meter (Parks Electronic Laboratory—Model 841). Flow was evaluated at the site of cannulation, proximal and distal to it with and without manual occlusion of the ulnar artery. An area of complete or partial radial artery occlusion was considered present if the sound of flow over the puncture site was absent or obviously reduced relative to the normal proximal vessel. If reduced flow was present, the possibility that it represented ulnar collateral flow was excluded by repeating the observations during manual occlusion of the ulnar artery. The term abnormal flow includes both partially and completely occluded vessels.

In analysis of these data, the group with early abnormal flow was considered separately from those with late abnormal flow, because abnormal flow did not occur in some patients until the late examination. When relevant, both early and late data are presented. In addition, data of the group with reduced flow (partial occlusion) were analyzed separately and combined with the data of the absent flow (complete occlusion) group for both early and late observations. Analysis for predisposing factors revealed no significant differences among these various subgroups. Unless otherwise identified, the data presented, therefore, are those of combined partial and complete occlusion at the early observation period.

The statistical significance of observed differences in incidence was determined by chi-square analysis corrected for continuity.

TABLE 1. Some Characteristics of 1,699 Patients Having Radial Artery Cannulation

	Percentage
Male	79.8
Operation	
Coronary artery bypass (CAB)	63.4
Non-CAB with ECC*	21.4
No ECC*	15.2
Hypertension	40.6
Vascular Disease	19.4

* ECC-Extracorporeal circulation.

Results

Almost two-thirds of the patients studied underwent coronary artery bypass operations, accounting for the high incidence of men and hypertension (table 1). Abnormal flow in the radial artery occurred in 21.2% of patients 1 day (early) after decannulation (table 2). By 4–7 days (late), almost two-thirds of these were found to have normal flow. By this time, however, 6.5% of arteries with previously normal flow had become completely (2.8%) or partially (3.7%) occluded. Palpation of pulses was less reliable than flow estimation and consistently underestimated the incidence of occlusion. A pulse was palpated, even though diminished, in 61% of arteries that were shown to be completely occluded by flow measurement and a normal pulse was found in 14% of partially occluded arteries.

Changes in skin color occurred in 10 patients, eight with pallor over the thenar eminence and two with mottling over the volar surface of the forearm. Four of the former and both of the latter (six of the 10) had normal radial artery flow early after decannulation. At the late examination, pallor of the thenar eminence persisted in three patients, two of whom continued to have normal radial flow. Skin color was normal in all patients within 12 days of operation.

TABLE 2. Complications of Radial Artery Cannulation

	Early (%)	Late (%)
Abnormal flow	21.2	13.8
Absent flow	8.1	5.7
Reduced flow	13.1	8.1
Abnormal pulse	14.8	11.1
Hematoma	12.0	12.7
Infection	0	0.06
Abnormal skin color	0.6	0.3
Sensory abnormality	0.3	0.06

All four patients who had sensory abnormalities had some numbness of the posterior thumb, and three of these had partial radial artery occlusion. At the time of discharge from the hospital, radial artery flow and sensation were normal in all patients except one who had persisting numbness despite normal flow. The only suggestion of infection occurred in one patient at the late examination and consisted of erythema at the puncture site unassociated with tenderness or adenitis.

The incidence of abnormal radial artery flow was not related to the duration of cannulation (table 3) nor to the size or material of the cannula (table 4). Because each physician selected his own cannula, our institutional preference for the 20 ga tapered polypropylene is apparent. The frequency of abnormal flow at early and late examinations did not vary significantly with cannula size or material. There were also no significant differences between groups combined for cannula size (18 ga *vs.* 20 ga) or material (polypropylene *vs.* teflon). The larger cannulas were not more difficult to use in terms of the frequency of arterial punctures. Hematoma, another index of trauma, was present early in 12.1% of patients and equally distributed among cannula types. Abnormal flow was twice as common when hematoma was present (41.1% *vs.* 18.5%; $P < 0.005$) but not more common after multiple arterial punctures as compared with single punctures.

Of factors examined that might predispose to abnormal flow, only female sex had a significantly higher incidence (table 5). In 1,699 patients, 20.5% were female, 40.6% had hypertension, 93.0% of arteries were transfixed, and 76.8% of cannulas were flushed manually. Patients whose operations required extracorporeal circulation (84.8%) had a significantly higher incidence of abnormal flow. The incidence of abnormal radial artery flow in patients who had noncoronary vascular disease was lower than the incidence in those who did not (14.2% *vs.* 22.3%). This difference was not significant when corrected for the use of extracorporeal circulation. No perioperative event that might have predisposed to abnormal flow proved to be significantly related (table 6).

In 204 patients, the radial artery was cannulated in the same arm in which the brachial artery had been used within 7 days for coronary angiography. Abnormal flow occurred in 17.4% of this group, compared with 22.1% for the opposite arm ($P < 0.25$). All significant predictors of early abnormal flow also predicted late abnormal flow and no early nonpredictors proved to be predictors in data for late abnormal flow.

The 83 patients in whom radial artery cannulation failed and subsequently an ulnar or brachial artery was cannulated were not included in the study but were followed. Of these, nine (10.8%) had abnormal radial artery flow at early observation, with seven showing complete occlusion. Puncture of the radial arteries and cannulation of the ulnar arteries of the same hand occurred in 22 patients and was followed by partial occlusion of one and complete occlusion of three radial arteries (an incidence of 18%) but no occlusion in any of the 22 ulnar arteries. None of these 83 patients had any of the other complications listed in table 2 develop.

The Allen's test was performed on 411 patients (24.2% of the sample) and was considered abnormal (greater than 15 s) in 16 patients (3.9%). None of these 16 patients had signs of ischemia develop during cannulation, and none had abnormal radial artery flow or skin or sensory changes develop after decannulation.

Discussion

The primary purpose of this study was to examine the safety of radial artery cannulation as used for blood pressure monitoring and only secondarily to search for factors predisposing to arterial thrombosis. The study

TABLE 3. Relationship of Duration of Cannulation to Abnormal Radial Artery Flow after Decannulation

	Duration of Cannulation (Hours)				
	12	12–24	24–36	36–48	48
Number of patients	66	1,033	408	105	87
Percentage of patients at this duration with abnormal flow early*	25.3	23.3	19.2	16.0	16.2
Percentage of patients at this duration with abnormal flow late*	11.9	14.6	12.5	12.3	12.7

* The ratio of absent flow to reduced flow was consistently 1:2 in all subgroups.

was well suited to this purpose because it was prospective, consisted almost entirely of patients with some cardiovascular disease, was not limited in variety of cannulas and techniques, disregarded the results of the Allen's test, and permitted most (78%) cannulations to be performed by relatively inexperienced physicians. With the possible exception of the exclusion of emergency surgical patients, these aspects of the study tended to elicit rather than prevent complications of cannulation, the worst scenario.

Among the 1,699 patients who had radial artery cannulation and the 83 patients in whom cannulation failed, no patient, when interviewed and examined late after decannulation, was aware of any disability related to the hand or forearm of the cannulated artery. Although approximately 25% of these patients suffered partial or complete occlusion of the radial artery with and without hematoma at some time after decannulation, no permanent ischemic damage to the hand or forearm occurred, and there were no clinical consequences of arterial thrombosis when it occurred. This outcome is not at odds with the results of other prospective studies, which when combined included more than 2,300 patients,[1-10] none of whom suffered permanent ischemic damage. In one report of 1,000 patients,[10] two radial arteries were explored surgically, one for embolus and the other for reasons not stated.

Despite this apparent safety of radial artery cannulation, there are reports of catastrophic results requiring digit or even forearm amputation following radial artery cannulation. Alleged contributory causes in these reports include emboli originating in the heart,[11-13] excessive trauma from very large or long catheters,[13-15] prolonged circulatory failure with vasoconstrictor administration,[13,15-17] Raynaud's disease,[16] and hyperlipoproteinemia.[17] In our own experience of more than 20 years, ischemia of the hand during or after radial artery cannulation occurred only in patients who had multiple emboli or prolonged circulatory failure with high-dose vasopressor therapy and ischemia was always present in more than one extremity. In this study, short-term circulatory failure or vasopressor administration did not increase the incidence of abnormal radial artery flow (table 5), and certainly hyperlipoproteinemia was present, although unmeasured, in a large proportion of our population who had coronary artery disease. It would seem that ischemic damage following radial artery cannulation might be anticipated only in patients who had severe vascular disease of the cannulated extremity, severe generalized ischemia of prolonged low flow states and high dose vasopressor therapy, particulate embolization from the central circulation, and trauma to a significant length of the artery as by cut-down and ligation.[13,14] It is significant that in no report of tissue necrosis after radial artery cannulation did the area of necrosis arise from or remain limited to the tissue uniquely dependent on radial artery blood flow.

In this regard, the value of the Allen's test in predicting potential ischemic damage after cannulation requires reappraisal, because several reports of tissue necrosis occurred in patients whose Allen's tests had normal results.[15,17,18] The original test described in 1929 was for the purpose of evaluating palmar collateral circulation in thromboangitis obliterans.[19] Although its date of introduction to anesthetic practice is obscure, modifications have been described as early as 1973,[1,20]

TABLE 4. Relation of Cannula Type to Abnormal Radial Artery Flow, Trauma, and Hematoma Formation

	Polypropylene 18 ga	Polypropylene 20 ga	Teflon 18 ga	Teflon 20 ga
Number of patients	129	1456	27	87
Abnormal flow early (%)	22.5	20.4	30	28
Abnormal flow late (%)	19.5	13.2	7	18
Multiple arterial punctures (%)	19.4	22.0	25	33*
Hematoma early (%)	11.6	12.0	25	10

* Significantly different from 18 ga and 20 ga polypropylene ($P < 0.05$).

TABLE 5. Potential Predisposing Factors to Abnormal Flow after Radial Artery Cannulation

Factor	Incidence of Abnormal Flow		Significance
Sex	Male (1351)* 20.2	Female (348) 27.1	$P < 0.01$
Hypertension	Present (690) 20.0	Absent (1,009) 22.6	$P > 0.25$
Vessel puncture	Transfix (1,580) 21.4	Direct (119) 24.5	$P > 0.30$
Flush technique	Manual (1,305) 21.7	Continuous (394) 19.6	$P > 0.40$
Extracorporeal circulation	Present (1,441) 22.7	Absent (258) 12.2	$P < 0.008$

* Parentheses contain number of patients with attribute.

TABLE 6. Potential Perioperative Complications Predisposing to Abnormal Flow after Radial Artery Cannulation

Complications	Abnormal Flow in Patients			Significance
	Number of Patients	With Complication (%)	Without Complication (%)	
Vasopressor infusion	294	17.5	22.0	$P < 0.09$
Circulatory collapse	10	9.1	21.3	$P < 0.54$
Intraaortic balloon	17	5.9	21.4	$P < 0.21$

and further refined by graded responses of normal, less than normal, and absent collateral circulation.[1,4,5,21–25] Although arteries with less than normal responses have been cannulated without ischemic sequelae, the value of the absent collateral circulation response in predicting ischemic damage after cannulation never was tested. Most reports estimate the incidence of absent ulnar collateral circulation at 3–5% of the population. One investigator, using a more sensitive technique, reported a frequency of 10.4% in a group whose mean age was 56 years.[25] In our study, the Allen's test was performed in 411 patients, and, as others found, ulnar collateral circulation was absent in 4% (16 patients). After radial artery cannulation of these 16 patients, none had ischemia during or abnormality of radial flow after cannulation. Projecting this 4% incidence to our entire population (1,699 patients), 68 patients with absent ulnar collateral circulation were cannulated without suffering ischemic damage of the hand. It would seem that the Allen's test is not useful as a predictor of ischemia in the absence of vascular disease.

There is a body of surgical information that tends to support this lack of predictive value in patients with normal vessels. Following war trauma[26] and civilian trauma,[27] ligation of radial, ulnar, and brachial arteries was not followed by ischemic loss of tissue. Several weeks after microvascular repair of radial and ulnar arteries after trauma, arteriography revealed a high incidence of occlusion of one or both vessels without distal vascular insufficiency.[28,29] These authors postulate that these arteries thrombose after repair *only if there is adequate collateral circulation,* which could explain the absence of any abnormal flow in our 16 patients who had Allen's tests with abnormal results and the absence of ischemia in the estimated 68 patients in this study without adequate ulnar communication.

A secondary objective of this study was to search for factors predisposing to arterial thrombosis after cannulation. Our results support and fail to support factors identified in other studies. Bedford and Wollman published the first prospective analysis of complications of radial artery cannulation in 105 patients.[1] They described pallor of the thenar eminence in four patients, digital emboli in two, and transient ischemia over the catheter tip in 14, probably related to flushing the cannula at high pressure.[30] All these changes resolved during the period of observation. Complete occlusion of the radial artery occurred in 40 patients and was correlated with duration of cannulation. Subsequent studies confirmed duration of cannulation as a predisposing factor[2] and implicated others including type of catheter[3,6–8] hematoma formation,[5] low cardiac output,[5] and female sex.[5,8,31] In the only study of a large number of cannulations,[10] the incidence of abnormal radial artery flow early after decannulation was 24.3% in 1,000 patients, an incidence similar to ours. Despite the relatively large number of patients studied, we were unable to confirm duration of cannulation as a predisposing factor, nor the size or material of the cannula, nor a number of other variables we recorded. In our study, the incidence of abnormal flow was significantly higher in women and in patients undergoing operations with extracorporeal circulation, for either of which we have no ready explanation. The presence of hematoma also increased the incidence of abnormal flow probably by the mechanism of external compression.

Our data, the largest prospective study of the risk of radial artery cannulation yet undertaken, permit several conclusions: 1) we were unable to identify any risk of serious ischemic complications; 2) the risk of partial or complete occlusion of the radial artery after cannulation was high, more than 25%, but there were no important clinical consequences of thrombosis; 3) we found no compelling evidence to recommend or reject any catheter or technique of cannulation; 4) the Allen's test was not predictive of ischemic damage after cannulation and may not even correlate with abnormal flow; and 5) radial artery cannulation is a low-risk high-benefit method of patient monitoring that deserves wide clinical use.

References

1. Bedford RF, Wollman H: Complications of percutaneous radial artery cannulation: An objective prospective study in man. ANESTHESIOLOGY 38:228–236, 1973
2. Evans PJD, Kerr JH: Arterial occlusion after cannulation. Br Med J 3:197–199, 1975
3. Downs JB, Rackstein AD, Klein EF Jr, Hawkins IF Jr: Hazards of radial artery catheterization. ANESTHESIOLOGY 38:283–286, 1973
4. Bedford RF: Radial artery function following percutaneous cannulation with 18 and 20 gauge catheters. ANESTHESIOLOGY 37:37–39, 1977
5. Davis FM, Stewart JM: Radial artery cannulation. A prospective study in patients undergoing cardiac surgery. Br J Anaesth 52:41–47, 1980
6. Bedford RF: Percutaneous radial-artery cannulation—increased safety using teflon catheters. ANESTHESIOLOGY 42:219–222, 1975
7. Mortensen JD: Clinical sequelae from arterial needle puncture, cannulation and incision. Circulation 35:1118–1123, 1967
8. Kim JM, Ara Kawa K, Bliss J: Arterial cannulation: Factors in the development of occlusion. Anesth Analg (Cleve) 54:836–841, 1975
9. Jones RM, Hill AB, Nahrwold ML, Bolles RE: The effect of method of radial artery cannulation on post cannulation blood flow and thrombus formation. ANESTHESIOLOGY 55:76–78, 1981
10. Mandel M, Dauchot PJ: Radial artery cannulation in 1,000 patients: Precautions and complications. J Hand Surg 2:482–485, 1977
11. Michaelson ED, Walsh RE: Osler's node—a complication of prolonged arterial cannulation. N Engl J Med 283:472–473, 1970

12. Mathews JI, Gibbons RB: Embolization complicating radial artery puncture. Ann Intern Med 75:87–88, 1971
13. Samaan HA: The hazards of radial artery pressure monitoring. J Cardiovasc Surg 12:342–347, 1971
14. Bartlett RH, Munster AM: An improved technic for prolonged arterial cannulation. N Engl J Med 279:92–93, 1968
15. Baker RJ, Chunprapaph B, Nyhus LM: Severe ischemia of the hand following radial artery catheterization. Surgery 80:449–457, 1976
16. Katz AM, Birnbaum M, Moylan J, Pellet J: Gangrene of the hand and forearm: A complication of radial artery cannulation. Crit Care Med 2:270–272, 1974
17. Cannon BW, Meshier WT: Extremity amputation following radial artery cannulation in a patient with hyperlipoproteinemia Type V. ANESTHESIOLOGY 56:222–223, 1982
18. Mangano DT, Hickey RF: Ischemic injury following uncomplicated radial artery catheterization. Anesth Analg (Cleve) 58:55–57, 1979
19. Allen EV: Thromboangitis obliterans: Methods of diagnosis of chronic occlusive arterial lesions distal to the wrist with illustrative cases. Am J Med Sci 178:237–244, 1929
20. Ryan JF, Raines J, Dalton BC, Mathieu A: Altered dynamics of radial artery cannulation. Anesth Analg (Cleve) 52:1017–1023, 1973
21. Gelberman RH, Blasingame JP: The timed Allen's test. J Trauma 21:477–479, 1981
22. Husum B, Berthelsen P: Allen's test and systolic arterial pressure in the thumb. Br J Anaesth 53:635–637, 1981
23. Mozersky DJ, Buckley CJ, Hagood CO Jr, Capps WF Jr, Dannemiller FJ: Ultrasonic evaluation of the palmar circulation—a useful adjunct to radial artery cannulation. Am J Surg 126:810–812, 1973
24. Husum B, Palm T: Arterial dominance in the hand. Br J Anaesth 50:913–915, 1978
25. Husum B, Palm T: Before cannulation of the radial artery: collateral arterial supply evaluated by strain-gauge plethysmography. Acta Anaesthesiol Scand 24:412–414, 1980
26. Zipperman HH: Acute arterial injuries in the Korean War. Ann Surg 139:1–8, 1954
27. Morris GC Jr, Beall AC Jr, Roof WR, DeBakey ME: Surgical experience with 220 acute arterial injuries in civilian practice. Am J Surg 99:775–781, 1960
28. Boswick J: Injuries of the radial and ulnar arteries. J Bone Joint Surg 49(A):582, 1967
29. Gelberman RH, Nunley JA, Koman LA, et al. The result of radial and ulnar arterial repair in the forearm. J Bone Joint Surg 64(A):383–387, 1982
30. Wyatt R, Glaves I, Cooper DJ: Proximal skin necrosis after radial artery cannulation. Lancet 1:1135–1138, 1974
31. Bedford RF: Wrist circumference predicts the risk of radial arterial occlusion after cannulation. ANESTHESIOLOGY 48:377–378, 1979