Aortography and Peripheral Arteriography:

An Analysis of Results in a University Medical Center *

JOHN H. FOSTER, M.D., DUNCAN A. KILLEN, M.D.

*From the Department of Surgery, Vanderbilt University School of Medicine,
Vanderbilt University Hospital and Thayer Veterans Administration
Hospital, Nashville, Tennessee*

AORTOGRAPHY and peripheral arteriography have been employed as diagnostic procedures for over 30 years. In 1923, Brooks introduced aqueous sodium iodide as a contrast medium for arteriography.[8] Dos Santos employed aqueous sodium iodide to perform the first translumbar aortograms in 1929.[14, 15] The advances in vascular surgery of the past decade have been paralleled by a demand for better preoperative evaluation. Vascular surgeons have employed aortography and peripheral arteriography with increasing frequency over the past ten years. The numerous reports in the literature of arteriography have stressed either complications or special technics, with little reference to the incidence of success or failure of the diagnostic procedure.[1, 2, 9, 11, 12, 16, 24, 29, 31, 32, 35, 44] The purpose of this report is to present a critical and comprehensive survey of the available material at Vanderbilt University Hospital and Thayer Veterans Administration Hospital.

Method

All aortograms and peripheral arteriograms (excluding cerebral arteriograms) performed from 1950 through 1957 were reviewed. The record of each patient was carefully reviewed as to clinical history, physical findings and indications for arteriogram. Each arteriogram was analyzed as regards anesthesia, dye employed, injection technic, radiological technic, interpretation of films, post-arteriogram course and subsequent operative findings. Each set of roentgenograms available was reviewed and correlated with the findings recorded in the patient's record.

Results

Each procedure could be classified as a thoracic aortogram, abdominal aortogram or peripheral arteriogram (Table 1). Demonstration of the femoral arterial system by abdominal aortography was not counted as a separate femoral arteriogram. Angiocardiograms for the purpose of demonstrating the thoracic aorta were not included among the thoracic aortograms.

Thoracic Aortography: A total of 25 thoracic aortograms were performed on 24 patients, ranging in age from five weeks to 62 years. Ten of the patients were infants under two and one-half years of age. The indications for thoracic aortography are recorded in Table 2. The indication for which the aortogram was performed does not necessarily mean the suspected lesion was found; some of these patients were found to have normal thoracic aortae.

Of the 25 thoracic aortograms performed, 18 yielded diagnostic roentgenograms (Table 3). The term *diagnostic* is employed to mean that the films could be interpreted to demonstrate conclusively the suspected

pathology or a normal aorta definitely without the suspected lesion. Five different technics were employed to inject dye into the thoracic aorta. Direct needle injection into the common carotid artery, which was exposed under local or general anesthesia, was the most commonly employed method (Fig. 1–3). This method was used in seven infants and nine adults. The failure to achieve a diagnostic aortogram in two cases by the transcarotid route was attributable to tissue extravasation of the dye due to an improperly placed needle. Retrograde catheters were employed to inject dye into the thoracic aorta via the brachial, femoral and subclavian arteries. The transventricular thoracic aortogram was the only percutaneous injection in the group. Failure to obtain diagnostic results with thoracic aortography is analyzed in Table 4. Those failures attributed to inadequate contrast may be due to inadequate amount or concentration of dye, timing of exposures, rate of injection, or faulty x-ray technic. Urokon 70 per cent was the dye most commonly used; Hypaque 50 per cent has been employed recently in the infant group. The dosage was 0.75 cc. per Kg. in children and 30 to 50 cc. in adults. In two cases, a second injection of dye was carried out. Manual injection of dye and rapid serial x-ray exposures were used in all the thoracic aortograms. In the transcarotid aortograms, distal occlusion of the carotid artery was practiced; however, the opposite carotid artery and/or the vertebral arteries were opacified in eight

TABLE 1. *Aortagrams and Peripheral Arteriograms Vanderbilt University Medical Center 1950–57*

Procedures	Number	Patients
Thoracic aortogram	25	24
Abdominal aortogram	127	117
Peripheral arteriogram	81	63
Total	233	204

TABLE 2. *Indications for Thoracic Aortography*

Indications	Number
Coarctation of aorta	8
Patent ductus arteriosus	7
Aneurysm	3
Arteriovenous fistula	3
Vascular ring	2
Aortic insufficiency	1
Occlusive disease of subclavian artery	1
Total	25

instances. The coronary arteries were visualized in two instances.

Abdominal Aortography: A total of 127 translumbar aortograms were performed on 117 patients ranging from one to 76 years of age. There were approximately 30 per cent of the patients in each of the fifth, sixth and seventh decades of life. There were 110 males and seven females.

Anesthesia: Three types of anesthesia were employed: local (35 per cent), spinal (50 per cent) and general anesthesia (15 per cent). General anesthesia was usually intravenous sodium thiopental. In the early years covered by this study, spinal anesthesia was commonly used; however, the current practice is to use local anesthesia for insertion of the needle into the aorta and intravenous seconal just prior to injection of the dye into the aorta.

Technic of Abdominal Aortogram: The following is an outline of the technic generally employed in the performance of translumbar abdominal aortogram in this series. With the patient in the prone position, a long, No. 18 needle is inserted four finger's breadths to the left of the spinous processes and three finger's breadths below the twelfth rib. The needle is directed towards the vertebral bodies and slightly cephalad. When the vertebral body is encountered, the needle is slightly redirected to slip just in front of the vertebral body and into the abdominal aorta, usually at
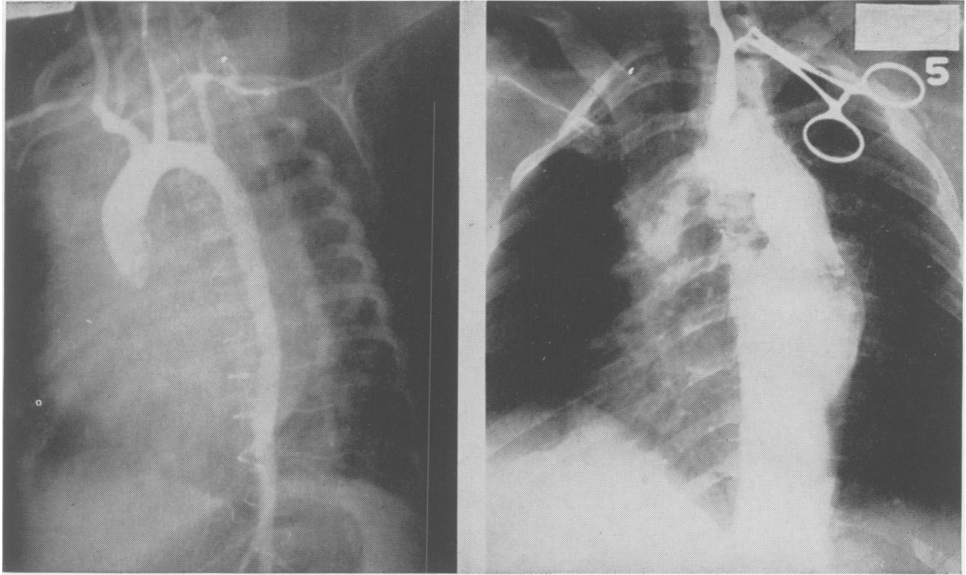
FIG. 1. (left). Transcarotid thoracic arotogram in an infant 3½ months of age employing Hypaque 50%, 0.75 cc./kilogram, revealing normal aorta.

FIG. 2. (right). Transcarotid thoracic aortogram demonstrating an arteriosclerotic aneurysm of the descending thoracic aorta.

the level of the first lumbar vertebra. It is the current practice to use a single needle, but in 75 per cent of the cases of this series, a second needle was inserted into the aorta. Through the two needles, a total of 25 cc. of 70 per cent dye is injected rapidly into the aorta, and a series of eight x-ray films are exposed rapidly (0.03 to 0.1 second) at half second or one second intervals as the dye is injected. The injection requires about two seconds. In 83 per cent of the abdominal aortograms, 70 per cent Urokon was the dye employed, but recently 50 per cent Hypaque has been used.

A single roentgenogram was exposed in 25 per cent of the aortograms, and the remainder involved the serial x-ray exposures as described above. Patients have been tested for sensitivity to the dye by an intravenous test dose. It was possible to determine the roentgenographic location of the needle or needles in 69 of the abdominal aortograms as depicted in Figure 4.

Results of Abdominal Aortograms: In 127 abdominal aortograms, 89 (70 per cent) yielded diagnostic roentgenograms (Table 5) (Fig. 5, 6). There were 14 complications, two were serious major compli-

TABLE 3. *Technic and Results of Thoracic Aortography*

Site of Entry	Number	Diagnostic	Complications
Carotid artery	16	14	1
Brachial artery	5	1	0
Femoral artery	2	2	0
Subclavian artery	1	1	1
Left ventricle	1	0	0
Total	25	18 (72%)	2

TABLE 4. *Analysis of Thoracic Aortogram Failures*

Site of Entry	Number	Cause
Carotid artery	2	Both 2° tissue extravasation
Brachial artery	4	All 2° inadequate contrast
Left ventricle	1	Injection into pulmonary artery
Total	7 (28%)	

cations, the remainder transient and minor complications. Complications will be described in more detail subsequently.

An important factor in obtaining a diagnostic aortogram in this series was the x-ray technic employed (Table 6) (Fig. 7). The aortograms in which the x-ray technic is listed as unknown represent cases in which the roentgenograms were not available for review. The causes of aortogram failure are listed in Table 7. In many of the successful serial exposure aortograms, any one of the exposures would have been judged a failure.

In a comparison of two needle aortogram versus single needle technic, the incidence of diagnostic results was 69 per cent and 60 per cent respectively.

The roentgenograms available were analysed for visceral arterial opacification incident to abdominal aortography.[34] The following vessels were visualized in the percentages indicated: renal arteries—40
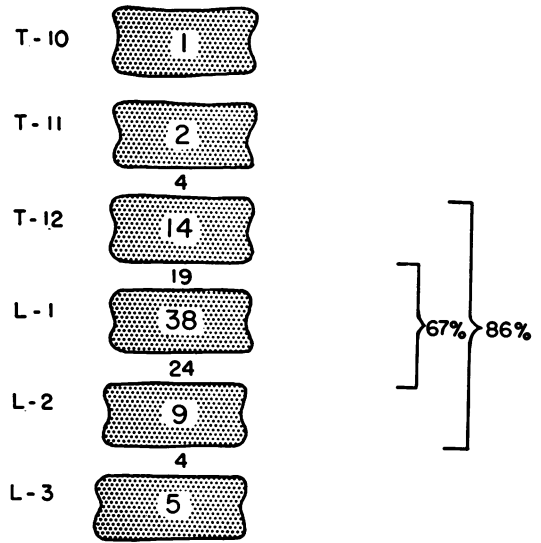
FIG. 4. Translumbar abdominal aortography, roentgenographic location of 120 needle tips in 69 aortograms.

FIG. 3. Transcarotid thoracic aortogram in an adult demonstrating a coarctation of the aorta.

per cent splenic artery—31 per cent, superior mesenteric artery—45 per cent, hepatic artery—23 per cent and inferior mesenteric artery—33 per cent.

Peripheral Arteriography: A total of 81 peripheral arteriograms (excluding cerebral arteriograms) were performed on 63 patients. There were 56 males and seven females ranging in age from 20 to 81 years. Eighty per cent of the patients were between 40 and 70 years of age. There were 77 femoral arteriograms, three popliteal arteriograms and one brachial arteriogram. The examination yielded diagnostic results in 61 per cent of the procedures (Table 8) (Fig. 8–10). There was one minor complication and two major complications, these followed percutaneous femoral arteriography. Over 80 per cent of the peripheral arteriograms were performed by the percutaneous route. Operative and percutaneous arteriograms met with roughly the same degree of success (Table 9). The relationship between diagnostic results and x-ray technic is recorded in Table 10. Fail-
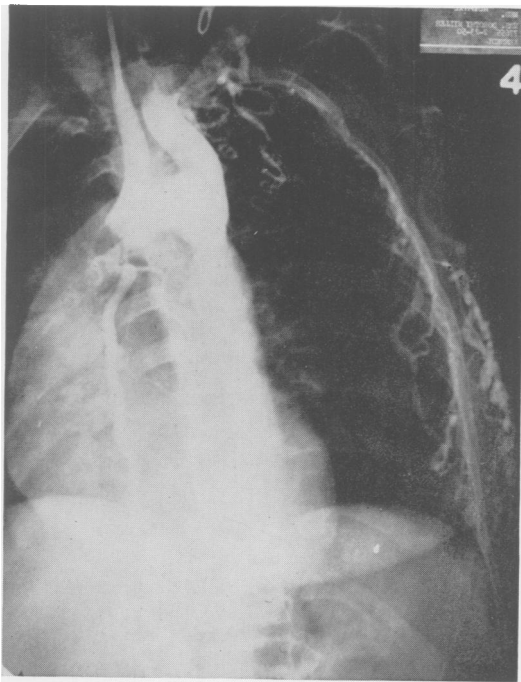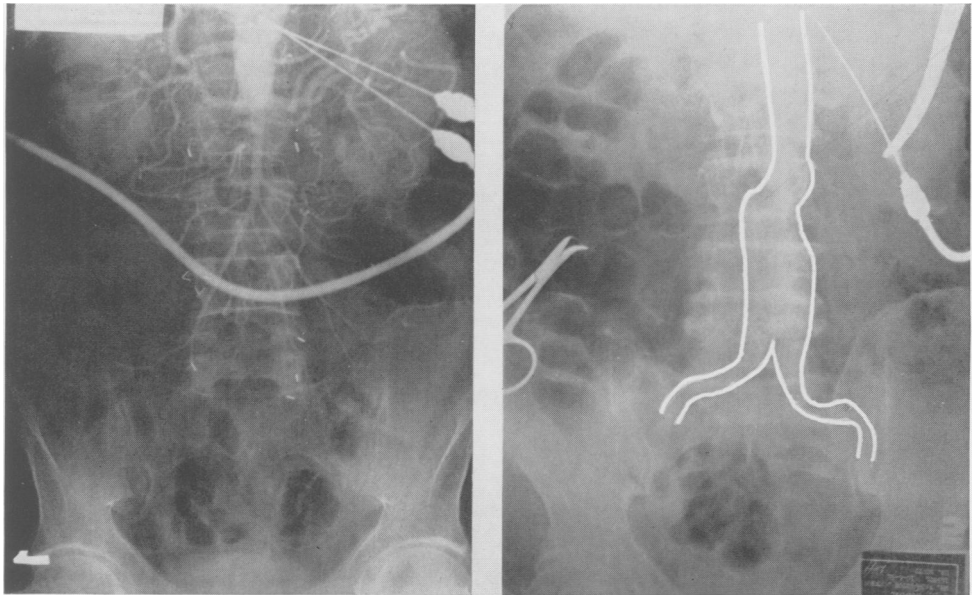
FIG. 5. (left). Two-needle translumbar aortogram demonstrating complete obstruction of the aorta just below the renal arteries, LeRiche syndrome. Note opacification of the visceral arteries.

FIG. 6. (right). Abdominal aortogram (retouched) demonstrating central channel in arteriosclerotic aneurysm. Laminated clot prevents opacification of the entire aneurysm.

ures are listed in Table 11. Nine of the 11 failures due to inadequate contrast were associated with a single x-ray exposure. *In the femoral arteriograms, 28 complete arteriosclerotic blocks were found of which 24 were demonstrated to be segmental blocks with collateral filling of the distal artery* (Fig. 11). The percutaneous arteriograms have generally been performed with local anesthesia, 15 cc. of 30 per cent Urokon being used. Recently 50 per cent Hypaque has been the radiopaque dye employed.

Summary of Results of Aortograms and Arteriograms

In the eight-year period 1950 through 1957 there were 233 aortograms and peripheral arteriograms performed (Table 12). The number of procedures performed in each year of the study are depicted in Figure 12. The difference in the number of procedures performed in 1957 as opposed to procedures in 1956 reflects a reduction in abdominal aortography, 55 in 1956 and four in 1957.

Complications of Aortography and Peripheral Arteriography

In the 233 arteriographic procedures performed, there were 19 complications encountered (Table 13).

Minor Complications: Thoracic aortography was complicated by two minor incidents. The first was a Horner's syndrome secondary to a transcarotid aortogram during which there was extravasation of dye

TABLE 5. *Indications for and Results of Abdominal Aortography*

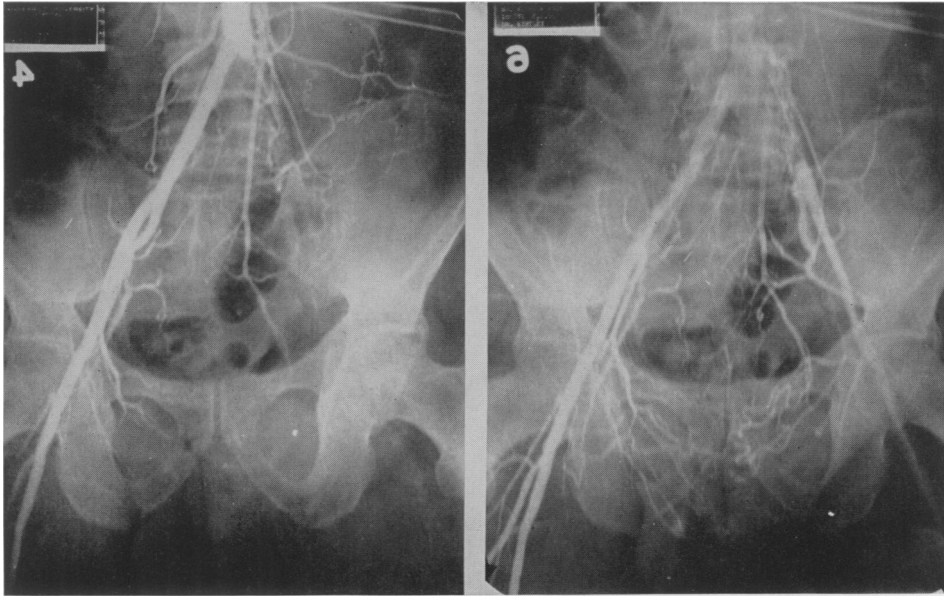| Indications	Number	Diagnostic	Complications
Arteriosclerotic occlusive disease	80	53 (66%)	7
Aneurysm	27	22 (81%)	3
Renal disease	15	9 (60%)	4
Arteriovenous fistula	2	2 (100%)	0
Graft followup	3	3 (100%)	0
Total	127	89 (70%)	14

FIG. 7. (A-left), (B-right). Abdominal aortogram revealing segmental occlusion of left common iliac artery. Collateral filling of distal iliac and femoral vessels demonstrated by serial x-ray exposures.

in the para-carotid tissues. The second complication followed a trans-subclavian thoracic aortogram employing two injections of dye. The ipsilateral arm developed acute ischemia. This was promptly relieved by stellate ganglion block and heparinization.

Peripheral arteriography was complicated by one minor incident, a transient generalized urticaria following a femoral

TABLE 6. Roentgenographic Technic of Abdominal Aortography

Technic	Number	Diagnostic	Failures
Single exposure	33	18 (54%)	15 (13 inadequate contrast)
Serial exposure	88	67 (76%)	21 (10 inadequate contrast)
Unknown	6	4 (67%)	2 (2 inadequate contrast)
Total	127	89 (70%)	38 (30%)

TABLE 7. Analysis of Abdominal Aortogram Failures

Cause	Number
Inadequate contrast	25
Tubing leak	4
Tissue extravasation	8
Poor x-ray technic	1
Total	38 (30%)

TABLE 8. Indications for and Result of Peripheral Arteriography

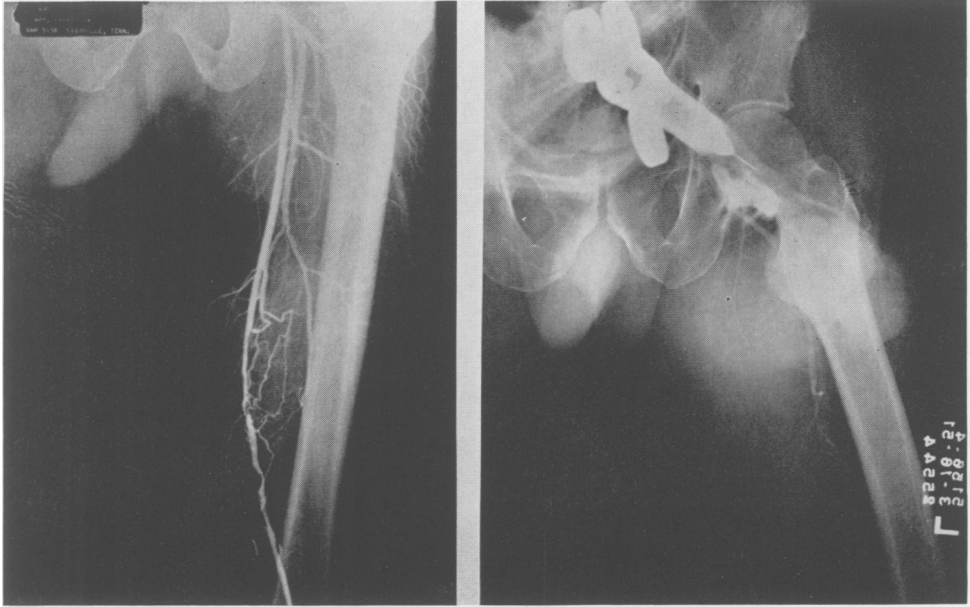| Indications	Number	Diagnostic	Complications
Occlusive disease	64	39 (61%)	2
Aneurysm	9	8 (89%)	1
Arteriovenous fistula	4	2 (50%)	0
Graft followup	4	3 (75%)	0
Total	81	52 (64%)	3

FIG. 8. (left). Operative femoral arteriogram revealing arteriosclerotic disease but a patent arterial system. Note the profunda and superficial femoral arteries and extensive collateral channels.

FIG. 9. (right). Percutaneous femoral arteriogram with opacification of large aneurysm of femoral artery.

arteriogram. The remaining 12 minor complications followed translumbar abdominal aortogram. These were all transient and relatively insignificant incidents. Gross
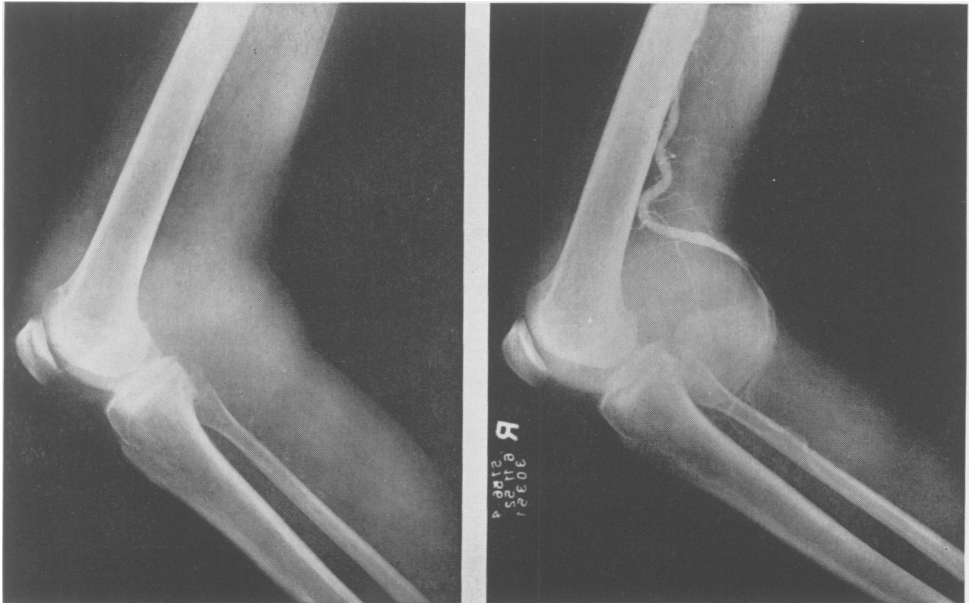

FIG. 10. Aneurysm of popliteal artery. (A-left) Scout roentgenogram showing large mass in popliteal fossa. (B-right) Percutaneous femoral arteriogram demonstrating artery entering aneurysm and opacification of nonclotted portion of aneurysm.

TABLE 9. *Injection Technic and Results of Peripheral Arteriograms*

Technique		Diag-nostic	Compli-cations
Percutaneous	67	44 (66%)	3
Operative	14	8 (57%)	0
Total	81	52 (64%)	3

TABLE 10. *Radiologic Technic and Results of Peripheral Arteriography*

X-Ray Technique	Number	Second Injections	Diag-nostic
Serial exposure	17	0	13 (76%)
Single exposure	60	7	38 (63%)
Unknown	4	0	1 (25%)
Total	81	7	52 (64%)

TABLE 11. *Analysis of Peripheral Arteriogram Failures*

Cause of Failure	Number
Extravasation	11
Poor x-ray technic	4
Injection of femoral vein	2
Movement of patient	1
Inadequate contrast	11 (9 were single exposure)
Total	29 (36%)

TABLE 12. *Arteriography Results*

Vanderbilt University Medical Center 1950–57

Procedures	Number	Diagnostic
Thoracic aortogram	25	18 (72%)
Abdominal aortogram	127	89 (70%)
Peripheral arteriogram	81	52 (64%)
Total	233	159 (68%)

hematuria occurred in a young boy with severe malignant renal hypertension. Transient hypotension had no obvious explanation but may have been due to spinal anesthesia in at least one case.
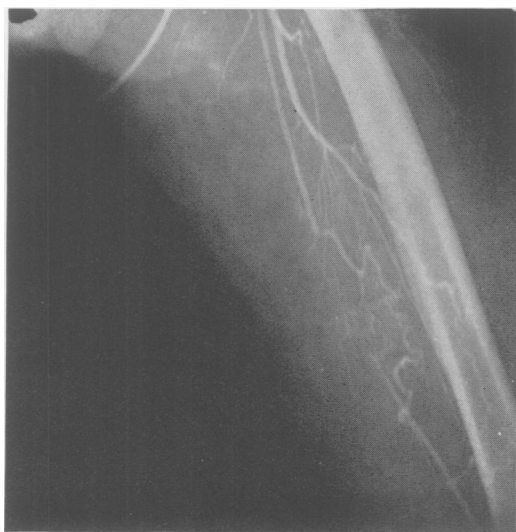

FIG. 11. Percutaneous femoral arteriogram demonstrating segmental arteriosclerotic block of superficial femoral artery with collateral filling of popliteal artery.

Major Complications: There were four major complications, two following percutaneous femoral arteriograms and two following translumbar abdominal aortograms.

Case Reports

Case 1: A 58-year-old man presented with signs and symptoms of arteriosclerotic occlusive disease in the left leg. An excellent left femoral pulse was palpable but the left popliteal and pedal pulses were absent. There was an indolent ulcer of the sole of the left foot. For 3 days prior to the arteriogram severe pain in the left leg required repeated para-vertebral sympathetic blocks. A percutaneous femoral arteriogram was performed under spinal anesthesia, using 2 injections of an unknown amount and concentration of Diodrast. Roentgenograms revealed a complete block of the superficial femoral artery and patent profunda femoral artery, but the popliteal artery was not demonstrated with either injection. The following day the left leg became mottled, cold and more painful. The popliteal artery was explored and found to contain fresh amorphous thrombus, and a lumbar sympathectomy was performed. The leg proceeded to gangrene, and 8 days later an above-the-knee amputation was performed. The popliteal artery was occluded with thrombus. Excellent femoral artery pulsations were maintained. Postoperative course was uneventful.

Case 2: A 61-year-old man entered with signs and symptoms of arteriosclerotic occlusive disease in the right leg and gangrene of the 3rd toe. Excellent right femoral artery pulsation was present but the right popliteal and pedal pulses were absent. Under spinal anesthesia, 12 cc. of 35% Diodrast were injected, percutaneously, into the right common femoral artery. Roentgenograms revealed a segmental block of the superficial femoral artery with patent profunda femoral artery and collateral filling of the popliteal artery. There was extravasation of dye around the common femoral artery. Post-arteriogram course was uneventful and 48 hours later a femoropopliteal artery exploration was carried out to perform a by-pass grafting procedure. Fresh thrombus was found occluding the common femoral, profunda femoral and popliteal arteries. The thrombus was removed, a femoropopliteal bypass crimped nylon graft interpolated and right lumbar sympathectomy performed. Postoperatively, the patient developed gangrene of the right leg and an above-the-knee amputation was performed. The popliteal artery was thrombosed. The graft was patent but there was no blood flow within the graft.

Case 3: A 43-year-old man entered with cardiac decompensation, evidence of impaired renal function and malignant hypertension. Blood pressure was 230/130. Specific gravity of urine was fixed at less than 1.010. PSP excretion was 10% in 1 hour. Serum NPN 76 mg.%, sodium 121 mg.% and chlorides 81 mg.%. Intravenous pyelogram was unsatisfactory. Electrocardiogram revealed left ventricular hypertrophy and strain pattern with 1° heart block. The patient was placed on a low salt diet, digitoxin, raudixin and ansolysen, and improved over the next 9 days. Blood pressure fell to the range of 170/100 and serum NPN decreased to 56 mg.%. Because of possible renal origin of the hypertension, under local anesthesia a two needle translumbar aortogram was performed using 30 cc. of 70% Urokon. Roentgenograms revealed a tortuous but otherwise normal aorta and renal arteries, without unusual concentration of dye within the kidneys. The following day the patient became febrile and dyspneic. The temperature rose daily over the next 5 days, ultimately reaching 104.8°, and dyspnea increased. The serum NPN rose to 96 mg.%, serum sodium fell to 107 mEq/L and serum chloride fell to 73 mEq/L. Urinary output was maintained in excess of a liter per day. Urine and blood cultures revealed a staphylococcus which was coagulase negative. The patient died 5 days after the aortogram. Post-mortem examination revealed arteriolar nephrosclerosis and ventricular hypertrophy. The brain was not examined. There was no evidence of acute renal necrosis nor evidence of retroperitoneal hematoma. An explanation for the fever was not found.

Case 4: A 50-year-old man * entered complaining of intermittent claudication in both calves, thighs and buttocks. The femoral arterial pulses were palpable but no other pulses were present in either leg. The past history revealed a 7 year history of severe hypertension previously treated by a bilateral thoraco-lumbar sympathectomy,

TABLE 13. *Complications of Aortography and Peripheral Arteriography*

(233 Procedures Performed)

Minor Complications	
Skin rash	2
Horner's syndrome	1
Transient ischemia of arm	1
Gross hematuria	1
Severe back pain	3
Nausea and vomiting	4
Transient hypotension	3
Major Complications	
Popliteal artery thrombosis	1
Femoral artery thrombosis	1
Renal damage	1
Permanent paraplegia	1
Total	19 (8%)

FIG. 12. Aortograms and peripheral arterigrams, Vanderbilt University Medical Center 1950–57.

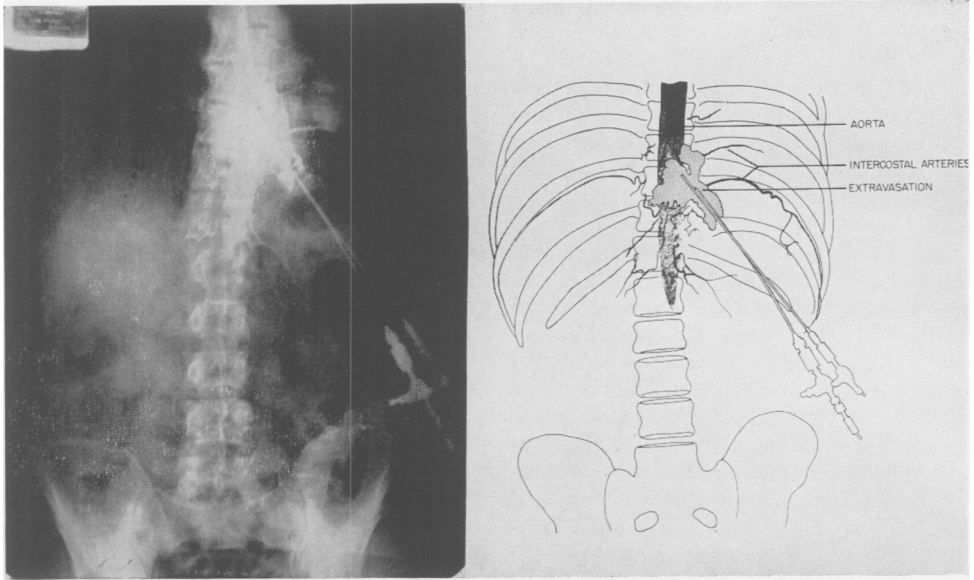* Case previously reported, see reference 19.

FIG. 13. (A-left), (B-right). First injection roentgenogram in Case #4 with artist's sketch to emphasize extravasation of dye and filling of intercostal arteries.

which produced little improvement. Two years prior to admission the patient underwent a left nephrectomy because of chronic infection and nonfunction of the left kidney. On this admission blood pressure ranged from 230/110 to 150/90. Serum NPN was 44 mg.%. Urinary PSP excretion was 30% after 2 hours. Under thiopental anesthesia two needles were inserted into the abdominal aorta, 12 cc. of 70% Urokon was injected rapidly and the needles were removed. There was para-aortic extravasation of the dye and the aortogram was unsatisfactory. The needles were reinserted into the aorta and 20 cc. of 70% Urokon injected. Serial thigh exposures as well as a single abdominal x-ray exposure were performed with each injection. The first injection was stopped at 12 cc. because the film changer jammed. The second injection of dye opacified the abdominal
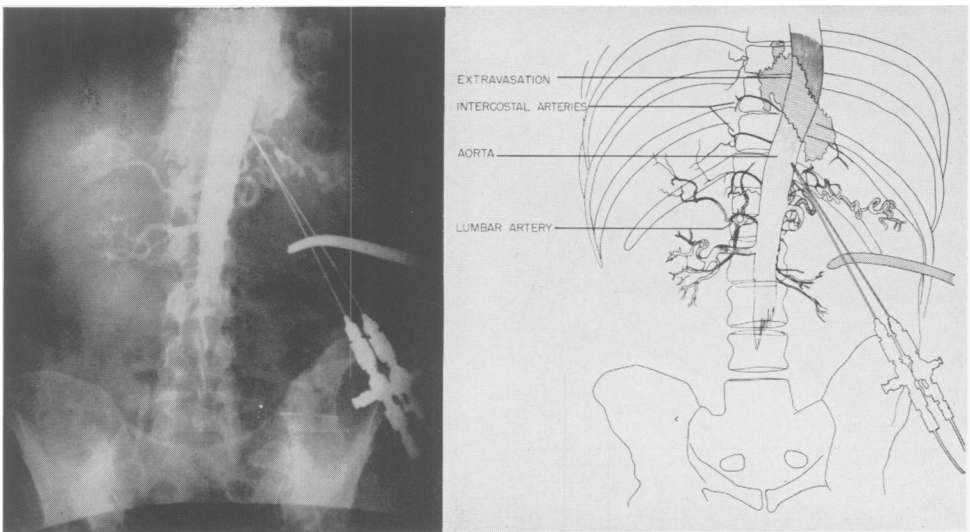

FIG. 14. (A-left), (B-right). Second injection roentgenogram in Case #4 with artist's sketch to emphasize retrograde filling of thoracic aorta, intercostal arteries and lumbar artery.
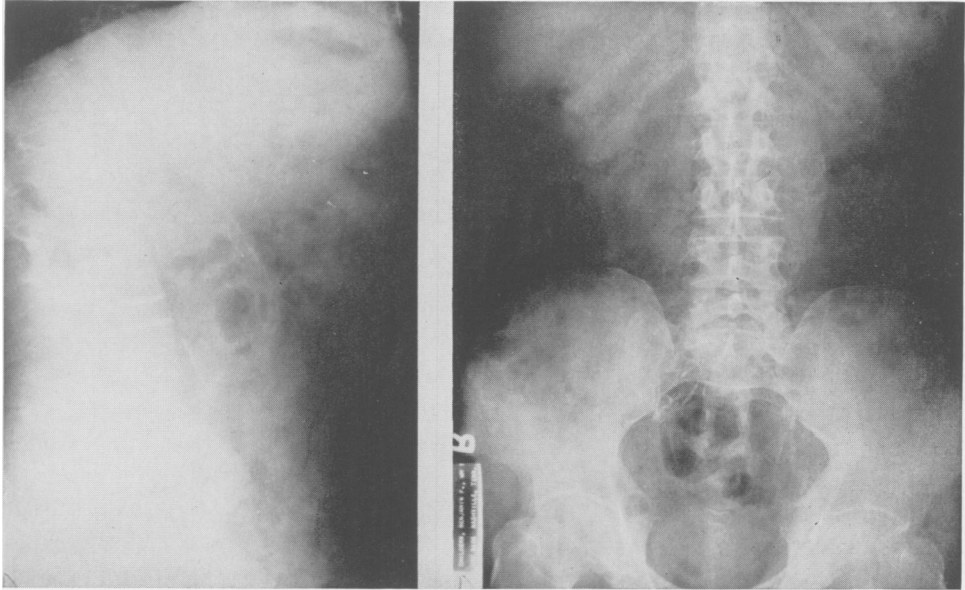
Fɪɢ. 15. (A-left), (B-right). Aneurysm of abdominal aorta. The diagnosis can often be established with a plain roentgenogram, such as these showing calcified wall of aneurysm.

and lower thoracic aorta. The bifurcation of the aorta was not demonstrated. At the first injection the needles were at the level of the 10th thoracic vertebra and the 2nd pair of needles were located at the 11th thoracic vertebral level. The second pair of needles were clearly within the aortic lumen. At least 4 or more intercostal arteries were opacified with each injection (Fig. 13, 14). Upon recovery from anesthesia the patient was found to have complete flaccid paraplegia with a sensory level at T-11. Neurologic examination a few days later revealed scattered areas of vague tactile sensation in both legs. The patient remains paraplegic after 18 months.

Comment

The case of paraplegia and the case of femoral artery thrombosis seem to have been direct results of the arteriographic procedures. The case of popliteal artery thrombosis is less convincing and may have been coincidental progression of the disease process. The death of the patient with severe renal disease may not have been due to the aortogram. The urinary output remained normal during the post-aortogram period. The necropsy findings did not reveal evidence of renal necrosis as has been reported in cases of renal damage due to aortic dye injection.

Discussion

Contrast angiography can provide information, not otherwise obtainable: however, these procedures involve a definite risk and should only be undertaken with good indication. Thoracic aortography is useful in the demonstration of aneurysm and dissecting aneurysm. Atypical cases of coarctation of the aorta or patent ductus arteriosus sometimes require aortography for demonstration. Recent interest in arteriosclerotic occulsive disease of the thoracic aortic branches (i.e., subclavian, carotid and coronary arteries) will undoubtedly result in more thoracic aortograms.[21]

The indications for abdominal aortography seem fairly limited at the present time. Renal hypertension, arteriosclerotic narrowing of the terminal aorta and suspected abdominal aortic aneurysm comprise the major indications. In recent years exploratory laparotomy, without preoperative abdominal aortography, has been fre-
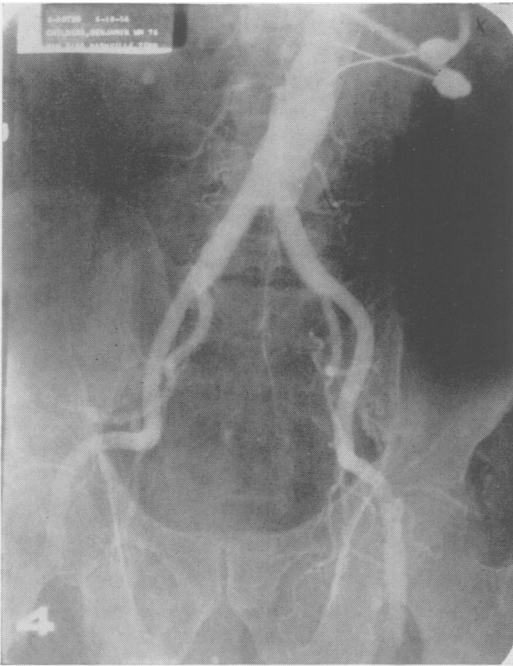
Fig. 15C. Because of the laminated clot within aneurysmal sac, an aortogram often will not reveal the true extent of the aneurysm.

quently employed in patients with abdominal aneurysm or with evidence of complete arteriosclerotic occlusion of the terminal aorta (Fig. 12). Experience has shown aortography to be of little value in these patients.[11] A plain roentgenogram is often sufficient to demonstrate the aneurysm (Fig. 15). The possibility of a renal origin of hypertension is the justification for assuming the increased risk of aortography in patients with pre-existing kidney disease.

Aneurysm, arteriovenous fistula and occlusive disease are the common indications for peripheral arteriography. Information regarding segmental occlusive disease and the adequacy of the distal arterial run-off is most accurately determined by, and often only by, arteriography.

Results of Arteriography: In discussing the results of a diagnostic procedure, such as contrast angiography, two separate and often conflicting aspects must be considered. They are the incidence of diag-

nostic results and the safety of the procedure.

I. Factors Concerned in Diagnostic Arteriography

There is little written in the literature of arteriography about how often contrast angiography yields valuable diagnostic information. In the 233 arteriograms of this series, 159 or 68 per cent yielded diagnostic results. Probably of more importance is the fact that in 74 patients, or 32 per cent of the series, the procedure failed (Table 12). While it is not possible to assign a single cause for failure in every instance, certain factors were apparent. These factors can best be discussed under the following four headings: anesthesia, x-ray technic, injection technic and contrast medium.

Anesthesia: The anesthetic requirements for successful arteriography seem simple and basic. The patient should be spared undue risk, undue pain and should be immobile during the procedure. Movement of the patient incident to the puncture of the vessel or injection of the dye can lead to complications and/or failure of the procedure. In this series, one femoral arteriogram, under local anesthesia, failed because of movement of the patient.

X-Ray Technic: Several facets of x-ray technic seem worthy of comment as regards successful arteriography.

The use of a scout film prior to the arteriogram serves to eliminate failures due to faulty technic and may help in planning the placement of the needle.

In this series the use of rapid serial exposure of six to 12 x-rays proved better than a single x-ray exposure. All the thoracic aortograms were made with serial exposure technic. In abdominal aortography serial x-ray exposure technic yielded diagnostic results in 76 per cent of the procedures whereas single x-ray exposure succeeded in 54 per cent of the cases (Table 6). If

the failures due to improper needle placement and mechanical failure of the equipment are eliminated, the corrected figures are then 87 per cent success with serial exposure as compared to 60 per cent success in the single roentgenogram group. In the peripheral arteriograms, serial exposure was associated with success in 76 per cent of the procedures, and single x-ray exposure was successful in 63 per cent of the cases (Table 10). If technical failures are eliminated, these figures change to 87 per cent for serial exposure group and 81 per cent for single exposure group. Single exposure technic probably fared better in peripheral arteriography because the operative peripheral arteriograms, with proximal occlusion of the artery, employed single exposure. Menendez and Linton have expressed satisfaction with the use of single exposure aortograms and arteriograms employing prolonged exposure and fractionated injection of large quantities of dye.[31] They routinely employ 50 to 60 cc. of 70 per cent Diodrast for abdominal aortography. By prolonging the exposure of a single roentgenogram over 2.5 to 5 seconds they obtain a composite radiogram of the opacification during the entire exposure period. The addition of fractionated injections, timed in relation to the degree of arterial obstruction, has further increased the success of single exposure arteriograms. Except for general statements, the incidence of diagnostic results with prolonged exposure arteriography has not been reported. In the arteriograms of this study the exposure time was short, 0.03 to 0.10 second, with both serial or single exposure technic. Perhaps the advantages of both serial and prolonged exposures could be obtained by exposing a series of films for a longer period of time.

Injection Technic: To obtain satisfactory arteriograms a sufficient quantity of dye must be delivered rapidly enough to produce arterial opacification at the mo-

ment of x-ray exposure. In this series several circumstances prevented the accomplishment of this objective in 30 per cent of the aortograms and arteriograms. Faulty injection technic in the form of faulty equipment and improper placement of the needle caused 40 per cent of the failures. Faulty connections and tubing leakage resulted in failure of six procedures in this series. Luer-lok connectors and strong plastic tubing securely fastened within the connectors are now available. The improper placement of needles led to 22 failures due to tissue extravasation or injection of the wrong vessel in the 195 percutaneous aortograms and arteriograms. A 5 cc. injection of the contrast material and preliminary roentgenogram has been advocated to ascertain proper needle position.[11] The simpler expedient of checking free pulsatile arterial flow with a syringe of saline should not be neglected.

In thoracic aortography a rapid injection of dye is crucial.[41] In transcarotid needle injection of the thoracic aorta this is readily accomplished by manual injection. There were seven thoracic aortogram failures in this study; three were due to improper needle position and the other four were due to inadequate contrast. These four cases occurred with catheter injection of the thoracic aorta via the brachial artery. The syringe, connectors, and tubing of such a system offer tremendous resistance to the manual injection of a viscous solution. Successful thoracic aortograms can be obtained with such an injection system, but to obtain uniform success an automatic pressure injection device is probably required. Measures to minimize the resistance in the injection system include: maximum internal diameter of tubing, minimum length of tubing, large bore connectors and similarly enlarged bore of the syringe outlet. In abdominal aortography measures to reduce the resistance of the injection system can also be of value. The two-needle technic accomplishes this while perhaps increasing

the risk of complications. The use of a special thin wall number 18 needle, ground out connectors and syringe outlet, minimum length of tubing, and metal handles on the syringe may allow almost as rapid delivery of the dye as the two-needle technic. Warming of the contrast medium to body temperature will reduce the viscosity and further aid rapid injection. The rapid dilution and dispersion of the dye can be minimized by various means such as the use of thigh tourniquets with abdominal aortograms and by proximal occlusion of the femoral artery at the time of operative femoral arteriogram.[13, 17, 31]

Contrast Medium: The ideal medium for contrast angiography would be a substance easily injected, providing good opacification of the vessels injected and exerting no ill effects. Such a medium is not presently known to exist.

The radiopacity of the currently employed contrast media is dependent on the iodine concentration and not the concentration of the organic compound in solution. The dyes of greatest contrast (exclusive of concentrated sodium iodide) are Urokon 70 per cent and Hypaque-M 90 per cent. The iodine contents of these dyes are 461 mg./cc. and 462 mg./cc. respectively. Diodrast 70 per cent and Neo-Iopax 75 per cent have iodine content of less than 400 mg./cc.

The angiographic contrast is not only dependent upon the radiopacity of the medium used, but also on the rate of injection of the dye. This becomes a factor of paramount importance when there is a rapid dilution of the dye as in thoracic aortography. The use of larger needles (or cannulae) and automatic pressure injection counteract the rapid dilution factor but are not safe for percutaneous aortography. Thus in percutaneous aortography the viscosity of the dye assumes greater importance. Hypaque-M 90 per cent has a greater viscosity than Urokon 70 per cent and requires

warming to body temperature to prevent crystal formation.[26] Measures designed to allow more rapid injection, as discussed under injection technic, are of greater importance in the use of a dye such as Hypaque-M 90 per cent.

A review of the literature reveals little agreement concerning the quantity of dye required for satisfactory aortography. From 12 to 60 cc. of 70 per cent dye have commonly been reported adequate for abdominal aortography.[31, 43] For aortography in infants a dosage of ¾ cc. of 35 to 50 per cent media per Kg. body weight has proven satisfactory (Fig. 1). In peripheral arteriography 20 to 30 cc. of 35 to 50 per cent media have proven adequate. Hypaque 50 per cent is an excellent contrast medium for both peripheral arteriography and infant aortography, and is being employed with increasing frequency in adult abdominal aortography. It may prove quite adequate, especially if measures designed to promote rapid injection and delay of dye dilution are employed in conjunction with serial or prolonged x-ray exposures.

II. Factors Concerned in the Complications of Arteriography

The majority of the literature of arteriography has been concerned with or prompted by major complications. In a recent study McAfee reported a collected series of 13,207 abdominal aortograms; there were 135 serious complications (1.02 per cent) with 37 deaths (0.28 per cent).[29] A study of 1,706 collected cases of thoracic aortography has been reported by Abrams; there were 59 serious complications (3.4 per cent) with 29 fatalities (1.7 per cent).[1]

The commonly reported complications of arteriography include neuropathy, nephropathy, hemorrhage, thrombosis, embolism, allergic and other systemic manifestations. Renal damage and neurologic damage account for more than 50 per cent of the

serious complications of thoracic and abdominal aortography.[1, 2, 11, 29]

The etiology of complications in arteriography may be considered under the following headings: injection technic, anesthesia, contrast media and patient predisposition.

Injection technic: The introduction of a needle (cannula or catheter) into the aorta or one of its branches has resulted in serious complications. These include bleeding from puncture hole(s), embolism due to dislodgment of arteriosclerotic plaque and thrombosis originating at the puncture site. Vasospasm incident to needle puncture, intramural or extramural dye extravasation may lead to thrombosis and/or distal ischemia. Tissue extravasation of the dye was associated with three of the complications in this series: Horner's syndrome, paraplegia and femoral artery thrombosis. Peripheral neuropathy has been attributed to para-aortic dye extravasation.[13] The pressure of the dye injection has a direct influence on inadvertent injection of certain vital arteries. The visceral arteries opacified in this series were listed earlier. However, there were no complications associated with the injection of these arteries. Opacification of the segmental arteries in the case of paraplegia does seem significant. At least two groups of workers have demonstrated in experimental animals that abdominal aortography in the supine position is associated with an increased incidence of spinal cord damage.[22, 25] Following catheter and cannula retrograde aortography suture closure of the arteriotomy is performed; the implication regarding distal ischemia is obvious.

Perhaps the use of intra-arterial procaine, other local anesthesia or a vasodilator may counteract vasospasm and the use of local heparinization might be useful in retarding thrombosis.[18, 25] In choosing the point at which to puncture the abdominal aorta there seems to be agreement in selecting a site well above or below the origin of the renal arteries, depending upon the indication for aortography in the individual patient.[11, 29]

Abrams believes that retrograde needle injection of the thoracic aorta via the carotid artery should be abandoned because fatalities were five to ten times as common as with catheter injection of the thoracic aorta.[1] There were 16 retrograde needle injections of the thoracic aorta via the carotid artery in our series without a serious complication. While this series is small, it should be pointed out that Abrams' figures related to deaths in needle injection of the carotid artery involved the use of 70 per cent Urokon and Diodrast in infants less than one year of age. The neurotoxic properties of these dyes are well documented,[29, 46] and the fact that 70 per cent dye is not necessary for successful thoracic aortography in infants has already been mentioned (Fig. 1). In Abrams' collected cases it is not known whether proximal occlusion of the carotid arteries was employed.

Anesthesia: The use of general anesthesia has been implicated in 8 per cent of the complications of abdominal aortography and ten per cent of the deaths following thoracic aortography.[1, 29] In this series there were no significant complications attributable to the anesthesia. In the collected cases of abdominal aortography reported by McAfee complications were two to three times as common with spinal or general anesthesia as with local anesthesia. In the reports of McAfee and Abrams all six deaths attributed to anesthesia involved general anesthesia. Laryngospasm, cardiac arrest and cerebral depression culminating in death have been attributed to general anesthesia. Abrams points out two ways in which general anesthesia may predispose to serious complications. Incipient reactions to the contrast medium may not be detectable under general anesthesia, and there may be a summation of the depressant effects of the contrast agent and the general anes-

thetic on the central respiratory center. To minimize these hazards, local anesthesia should be used whenever possible, especially in poor risk patients. If general anesthesia is to be employed for abdominal aortography endotracheal intubation should be performed.

Movement of the patient while the needle is in the aorta, either as a response to pain or as a planned part of the aortogram, has resulted in serious complications. Movement in response to pain is undoubtedly more common with local anesthesia. However, it also occurs under light general anesthesia. The number of complications incident to such movement of a patient is probably small in comparison with complications secondary to general anesthesia. Menendez and Linton believe that proper mental preparation of the patient will minimize the incidence of movement in aortography with local anesthesia.[31]

Contrast Medium: The contrast media used in arteriography have been implicated in more complications than all other etiological factors combined. In the 13,207 abdominal aortograms reported by McAfee 94 of 135 serious complications (70 per cent) were probably due to toxicity of the contrast medium.[29] Contrast medium was probably responsible for 49 of 59 serious complications (83 per cent) in the 1,706 thoracic aortograms reported by Abrams.[1] The complications of arteriography due to the contrast medium depend on the particular dye employed, the concentration, the dosage, site of injection, the pressure of the injection and the number of injections performed.

Several aqueous organic iodides are currently employed in arteriography. Urokon sodium 70 per cent (sodium acetrizoate), which has been widely used in the past ten years, has definite neurotoxic and nephrotoxic properties.[4, 5, 6, 28, 38, 45] These toxic properties also exist to a lesser degree in Diodrast (iodopyracet) and Miokon (sodium and methylglucamine diprotrizoate)

of comparable concentration. Renagrafin and Hypaque (both are mixtures of sodium and methylglucamine diatrizoate) also have neurotoxic and probably nephrotoxic characteristics; however, the toxicity of these media is far less than that of Urokon in comparable concentration.[46] Urokon 70 per cent and Hypaque-M 90 per cent are of similar iodine content, 461 mg./cc. and 462 mg./cc. respectively. A comparative study of their toxicity in canine aortography has shown that whereas a standard dose of Urokon 70 per cent regularly produces paraplegia and uremia, the same dosage of Hypaque M-90 per cent rarely if ever causes paraplegia or uremia.[26] The importance of dye concentration, as regards toxicity, is emphasized by the fact that complications have been rare with 35 to 50 per cent aqueous organic iodides. In the thoracic aortography series of Abrams there were 1,162 procedures with 70 per cent media and 498 aortograms with 30 to 50 per cent media. There were 24 fatal complications in the 70 per cent media group (2.07 per cent) and three fatalities with 30 to 50 per cent media (0.60 per cent). There have been a number of fatal and serious complications with injection of as little as eight to 10 cc. of 70 per cent media into the abdominal aorta of adults.[11, 29]

Also of importance, in relation to complications, is the amount of dye injected. There is one reported series of 1,000 abdominal aortograms in which 12 cc. of 70 per cent Urokon or Diodrast was used without a serious complication.[44] In 30 per cent of the serious neurologic complications and 43 per cent of the renal complications of abdominal aortography over 40 cc. of 70 per cent contrast medium was employed.[29] Crawford et al. on the basis of their study feel that for safe abdominal aortography, no more than 15 to 25 cc. of 70 per cent Urokon should be injected.[11] On the other hand Menendez and Linton believe 50 to 60 cc. of 70 per cent Diodrast are quite safe for abdominal aortography.[31]

When the tip of the needle or catheter within the aorta is directed into a vital branch artery, complications have been shown to occur if the concentration and/or dosage of the dye is excessive. Vital artery injections reported to have caused trouble include the carotid, coronary, lumbar, intercostal, renal, adrenal, mesenteric, pancreatic and spermatic arteries.[1, 10, 11, 13, 29, 36] In peripheral arteriography gangrene of the extremity has been reported, this has usually been attributed to thrombosis following vasospasm or direct mechanical injury of the arterial wall.[1] That the toxic effect of the contrast medium may play some part in this complication cannot be ruled out. Iodides have been shown to produce vasospasm and in high concentration are capable of producing endothelial damage and thrombosis.[13] When the needle tip is so placed as to allow intramural or extramural arterial extravasation, the risk of complication is increased as has been previously discussed under injection technic.

Multiple injections of contrast medium in the performance of arteriography have been repeatedly associated with serious complications:[1, 11, 29] Multiple injections of dye are procedures in which the first injection is followed by another, either because the first injection was unsatisfactory or because x-rays in another position are desired. Two-needle, simultaneous injection of dye into the aorta is not counted as a multiple injection.

There were three complications in the 12 instances of second injection in this study; these were transient ischemia of an extremity, parplegia and popliteal artery thrombosis. In 15 cases of paraplegia following abdominal aortography described in the literature, the number of injections of dye performed was stated in six instances. In five of the six (83 per cent) paraplegia followed two injections of dye.[11,19, 20] In the cases of renal damage collected by Crawford there were 24 in which the number of injections was recorded and in 12 of the 24

(50 per cent) two injections of the dye were performed.[11] In the deaths following thoracic aortography collected by Abrams in 11 of the 24 cases, two or more injections of dye were performed.[1] McAfee did not report the incidence of multiple injections and in Abrams' study it is stated that "in about half of the responding institutions one injection was considered the maximum for each procedure." Crawford indicates that second injections should be avoided.[11] On the other hand Menendez and Linton state that they believe second injections in abdominal aortography and peripheral arteriography are safe and advocate leaving the needle in place until the films are examined.[31] Although the exact information as to how often multiple injections are performed is unknown it seems fairly safe to assume the incidence to be small. The incidence of multiple injection in association with serious complications is very high. The reasons for this association is not clear; however the contrast medium seems implicated in the majority of these complications. The organic and inorganic iodides are capable of producing tissue damage in several ways. Intra-arterial aqueous sodium iodide, in high concentration, has long been known to produce endothelial damage, severe vasospasm and thrombosis.[13, 23, 40] When sodium iodide is injected directly into certain vital arteries it causes necrosis of the organ supplied, i.e., kidneys, central nervous system and intestine.[11, 30] The aqueous organic iodides have these same properties to a lesser but significant degree. In addition to causing tissue necrosis by impairing the blood supply these organic iodides have been demonstrated to enter and produce direct cellular necrosis, i.e., brain, spinal cord and kidney. These effects have been well documented in the case of Urokon 70 per cent and Diodrast 70 per cent.[7, 45, 46] The dye injuries the capillary walls and this may be the portal of entry by which the dye gains access to the tissues. This may well be the reason multiple injection aorto-

grams often lead to serious complications. In the case of the central nervous system Broman and Olsson have shown that the blood brain barrier is broken down by the injection of 70 per cent organic iodide.[7] Thus it seems logical that a second injection of dye might then enter the tissue unimpeded. Other susceptible tissues might be similarly affected. The experimental work of Hol and Skjerven revealed an increased incidence of spinal cord damage with repeated injections of dye at short intervals.[22] One other concept, pertinent to dye toxicity, based on experimental work deserves comment. Hyperhydration of animals prior to aortography has been shown to prevent or decrease the magnitude of renal injury by usually toxic injections of dye.[33] Perhaps a similar form of protection to the spinal cord of dogs was obtained when another group of workers preceded the dye injection by an injection of glucose into the aorta.[25] Hydration of patients prior to aortography rather than the usual dehydrating regimen cetrainly merits clinical application.

In addition to producing ischemia and direct tissue damage, the iodides elicit an allergic response in some individuals.[37] The incidence of urticaria in arteriographic procedures ranges from 2 to 6 per cent. Nausea and vomiting, which may be an allergic response, occur in 4 to 8 per cent of contrast angiography.[29] These allergic reactions are usually transient and severe allergic reactions have not been included in the complications of aortography of the large reported series.[1, 29] However, it is not possible to exclude an allergic component in some of the reported instances of cardiorespiratory collapse following aortography.

Patient Predisposition: There are numerous factors in an individual patient which have been observed to predispose complications following arteriography. A bleeding tendency, renal disease, severe cardiopulmonary disease, age, arteriosclerotic occlusion of terminal aorta, hypertension, allergy and aneurysm of the aorta might be included among these factors.[3, 11, 29] A blood dyscrasia in the form of a bleeding tendency and azotemia are relative contraindications to the performance of a percutaneous aortogram. The nephrotoxic properties of the organic iodides have been discussed above and have obvious implications in patients with pre-existing renal disease. The presence of severe cardiovascular disease, pulmonary disease or cerebral arteriosclerosis undoubtedly increases the risk of general anesthesia. These same patients may be more vulnerable to the neurotoxic effects of contrast media. The toxicity of the contrast media provides an even narrower margin of safety in infants where the quantity of dye to be used should not exceed 0.75 to 1.0 cubic centimeters per kilogram of body weight. There is probably an increased risk of bleeding if an aortogram needle pierces the thin wall of an aneurysm.[29] Bleeding from a needle hole following percutaneous aortography has frequently occurred in patients with hypertension. McAfee reported hypertension in seven of the thirteen patients with serious bleeding in his series of abdominal aortography;[29] however the incidence of hypertension in the entire group of patients who had abdominal aortograms is not known. A suspected pheochromocytoma may be a contraindication to abdominal aortography. Two deaths have been reported following aortography in patients with pheochromocytoma.[27, 39] Many authors have suggested aortic obstruction as a contributing factor in aortogram complications.[2, 10, 11, 19, 20, 29] Of 39 serious renal complications recorded by McAfee, ten were in patients with aortic block (degree not stated).[29] Thus 40 per cent of the serious renal injuries were associated with aortic occlusive disease. Without information as to the incidence of aortic obstruction in all patients submitted to aortography the significance of this factor

is questionable. Furthermore, a recent experimental and clinical study revealed that aortic obstruction did not increase the incidence of renal damage.[4] In the 127 abdominal aortograms of this study the indication was occlusive disease in 63 per cent of the patients. Renal injury occurred in one patient with badly diseased kidneys, malignant hypertension and an unobstructed aorta. Patients with a history of allergic episodes and a positive reaction to organic iodide skin test have been found more likely to display an allergic reaction following injection of organic iodide.[3]

The question of patient predisposition to post-aortogram complications warrants consideration prior to the performance of an aortogram. However, as indicated above, the true significance of these factors is exceedingly difficult to assess. Perhaps future studies will consider these factors in relation to their overall incidence.

Conclusions

After consideration of the many factors involved in obtaining successful and yet safe arteriograms the following suggestions were formulated.

Suggestions designed to obtain safe and successful arteriograms

A. Injection Technic

  1. Single injection of dye.*
  2. Meticulous needle insertion technic.*
  3. Prone position for abdominal aortography.
  4. Employ minimum caliber needle (#18 for abdominal aortogram).
  5. Select good equipment designed to reduce resistance to injection.
  6. Check equipment prior to procedure.
  7. Adopt measures to impede rapid run-off.

  8. Rapid manual injection (automatic injection with catheters).
  9. In abdominal aortograms inject above or below renal arteries.
  10. Remove needle immediately following injection.
  11. Meticulous closure of arteriotomies.
  12. Carotid compression in thoracic aortography.
  13. Hydrate patient prior to aortogram.

B. Anesthesia

  1. Local anesthesia whenever possible.*
  2. Endotracheal intubation if general anesthesia is employed.
  3. Minimum movement of patient once needle is inserted.

C. Contrast Medium

  1. Employ dye of least toxicity (currently Hypaque 50–90% solution).*
  2. Minimum quantity of dye.
  3. Sensitivity testing.
  4. Warm dye to body temperature.

D. X-Ray Technic

  1. Rapid serial exposures or prolonged exposure.*
  2. Scout films.

E. Patient Predisposition

  1. Greater selectivity of patients for arteriography.*
  2. Careful consideration of history of allergy.
  3. Avoid direct puncture of aneurysms.
  4. Recognize added risk in patients with azotemia, bleeding tendency, hypertension, cardiac, pulmonary and cerebral disease.

These suggestions were considered in detail in the discussion, an asterisk notes the suggestions thought to be of greatest importance. The use of the term *minimum*

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* See discussion of contrast media.

obviously implies the minimum compatible with successful arteriographic contrast as discussed under the technic of each procedure.

In the 233 arteriographic procedures reviewed in this study the incidence of all complications was 8.2 per cent, of serious complications 1.7 per cent, and of fatal complications 0.9 per cent. McAfee's analysis of 13,207 abdominal aortograms, which did not include a tabulation of minor complications, revealed serious complications in 1.02 per cent and fatal complications in 0.28 per cent. In 1,706 thoracic aortograms Abrams found serious complications in 3.4 per cent and fatal complications in 1.7 per cent.

The over-all incidence of diagnostic results in this series of 233 arteriographic procedures was 68 per cent. Thoracic aortography succeeded in 72 per cent of the cases, abdominal aortography in 70 per cent and peripheral arteriography in 64 per cent. Failure to obtain useful information in 32 per cent of the procedures seems too great. A comparison of these figures with the results of others is not possible as the figures are not available. Most large reported series of aortograms and arteriograms do not include the incidence of success or failure of these diagnostic procedures. It seems worthwhile to recommend that future reports on technique and complications of arteriography should include an analysis of results in terms of success or failure.

Summary

A comprehensive review of the aortograms and peripheral arteriograms performed at the Vanderbilt University Medical Center from 1950 through 1957 has been presented. Factors involved in obtaining safe and successful contrast angiography have been discussed. Suggestions designed to allow safe and successful arteriographic procedures have been made.

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