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Neurologic Complications of Cerebral Angiography

Joseph E. Heiserman, Bruce L. Dean, John A. Hodak, Richard A. Flom, C. Roger Bird, Burton P. Drayer, and Evan K. Fram

PURPOSE: To examine the incidence of neurologic complications associated with modern cerebral angiography and to assess patient characteristics associated with an increased risk of complications. **METHODS:** One thousand consecutive cerebral angiographic procedures were evaluated prospectively. Examinations were performed using transfemoral catheterization and film-screen methods. For purposes of this trial, a neurologic complication was defined as any new focal neurologic deficit or change in mental status occurring during the angiogram or within the following 24 hours. Patients were evaluated during and at the completion of angiography. Follow-up evaluations were performed on the day of and the day after angiography. **RESULTS:** There were a total of 10 neurologic complications within 24 hours of angiography, 5 of which were persistent. Onset of 5 of the deficits occurred during angiography, the other 5 (3 persistent) were delayed. All complications occurred in patients being evaluated for stroke/transient ischemic attack or (in one case) asymptomatic bruit. A higher average age, longer average procedure time, and greater volume of radiographic contrast was noted in these patients than in the study population. **CONCLUSION:** Cerebral angiography was associated with a 1% overall incidence of neurologic deficit and a 0.5% incidence of persistent deficit. All complications occurred in patients presenting with a history of stroke/transient ischemic accident or carotid bruit, which may reflect the difficulty of performing angiography in this population at risk for atherosclerotic changes.

Index terms: Cerebral angiography, complications; Iatrogenic disease or disorder

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As the standard of reference for the evaluation of the cervical and intracranial vessels, conventional contrast angiography frequently is used to evaluate stenosis and occlusion, intracranial aneurysms, and arteriovenous malformations, and to demonstrate patterns of collateral flow (1). Although noninvasive methods such as Doppler ultrasound and magnetic resonance (MR) angiography have recently gained acceptance as screening modalities for some of these indications, conventional angiography

surpasses these techniques in achieving resolution and is required for definitive preoperative evaluation.

Over the years since the introduction of catheter cerebral angiography, a number of studies have documented a small but definite risk of associated neurologic complication (2-34). The present study was undertaken to examine the rate of neurologic complications in the modern era of angiographic catheters, contrast, and methods and to assess patient risk factors associated with an increased incidence of complications.

Materials and Methods

One thousand consecutive transfemoral cerebral angiograms performed on 688 patients were prospectively evaluated. In most cases, patients were referred for angiography by neurologists and neurosurgeons. Neurointerventional procedures, Wada tests, and intraarterial chemotherapy infusions were excluded. The examinations were performed at a single center (Barrow Neurological Institute, Phoenix, Ariz), primarily by neuroradiology fel-

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From the Barrow Neurological Institute of St. Joseph's Hospital and Medical Center, Phoenix, Ariz.

Address reprint requests to Joseph E. Heiserman, MD, PhD, Department of Radiology, Barrow Neurological Institute, 350 W Thomas Rd, Phoenix, AZ 85013.

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TABLE 1: Age distribution for 1000 cerebral angiograms, and distribution of neurologic complications by age

Age, y	No. of exams	Complications	
		Transient	Persistent
0-9	14	...	...
10-19	35	...	...
20-29	59	...	...
30-39	113	...	...
40-49	142	...	...
50-59	209	1	...
60-69	214	1	1
70-79	185	3	2
80-89	27	...	2
90-99	2	...	...
Total	1000	5	5

lows under the supervision of staff neuroradiologists, between January 27, 1992 and April 29, 1993. A total of seven fellows and six staff neuroradiologists were involved in this trial. When radiology residents were involved in a procedure, they were directly supervised by either a fellow or a staff neuroradiologist. No attempt was made to assign more difficult cases to more experienced angiographers; however, a staff angiographer was more likely to assist directly in a difficult case. Angiograms were distributed among different levels of training as follows: first-year fellows, 640 (64%); second-year fellows, 271 (27%); radiology residents, 61 (6%); and attending neuroradiologists, 28 (3%). Of the 1000 examinations, 552 (55%) patients were female and 448 (45%) were male. The average age was 53 years (range, 1 month to 96 years). Details regarding the age distribution are given in Table 1. Clinical indications for the examinations are listed in Table 2.

One examination, in which femoral catheterization was unsuccessful, was completed uneventfully by direct

carotid puncture. All other examinations were performed by transfemoral catheterization using standard catheter and guide wire techniques. In 781 (78%) examinations, a 5 French H1 catheter (Headhunter, Cook, Bloomington Ind) was used exclusively. In the remainder of the studies, a mix of other catheter types was used as needed.

Biplane magnification cut-film angiography was the primary imaging modality for all of the examinations, supplemented by digital subtraction angiography. Iohexol nonionic contrast media (Omnipaque 300, Sanofi-Winthrop Pharmaceutical, New York, NY) was used for angiographic injections, supplemented in 350 (35%) of the examinations by iohalamate meglumine ionic contrast media (Conray 60%, Mallinckrodt Medical, St. Louis, Mo) for test injections. Seven of the studies were carried out with aortic arch injections only; the remainder used selective injections. In 502 cases, bilateral carotid and left vertebral artery injections were performed. In 363 cases, one or both carotid arteries were injected. Sixty-five cases involved injection of one vertebral artery only. In 53 cases both carotid arteries and the left subclavian artery were injected. In 9 cases only the left subclavian artery was injected. Standard injection rates (expressed as rate in milliliters per s/total volume in milliliters) were as follows: common carotid artery, 10/12; internal carotid artery, 8/10; vertebral artery, 8/10; subclavian artery, 4/12. These values were varied as necessary based on observed blood flow rates. Meticulous technique was used to avoid air and thrombus embolization. As part of this routine, catheters were double-flushed at approximately 90-second intervals with heparinized saline solution (2000 U heparin/500 mL normal saline). Patients were not routinely anticoagulated with bolus heparin injections before angiography.

Patients were evaluated before angiography and monitored continuously during the examination by a radiologic nurse specialist, who performed a neurologic evaluation after each angiographic injection. The patient was evaluated in detail for neurologic deficits at the completion of the examination. In most cases, a staff neuroradiologist performed a follow-up evaluation of the patient on the day of and the day after the procedure. This evaluation consisted of a patient interview and chart review. Some outpatients were discharged the night of the procedure: in this case the second evaluation was conducted by telephone. The first-day evaluation was successfully completed in 785 (78%) cases, and the second-day check was completed in 860 (86%) cases. All patients were evaluated on at least one occasion. Average time after angiography for the first-day evaluation was 10 hours; the average time was 38 hours for the second day. In 58 of the cases in which only a single evaluation was performed, this evaluation was carried out at less than 24 hours. In these cases, a retrospective chart review was performed to confirm the lack of neurologic sequelae in this group during the 24 hours after angiography.

For each patient a data form was completed at the conclusion of the procedure by the registered nurse and

TABLE 2: Clinical indications for 1000 angiograms

Indication	Number
TIA/Stroke	227
Status postaneurysm clipping	201
Subarachnoid hemorrhage	137
Trauma	81
AVM	67
Intraparenchymal hemorrhage	66
Aneurysm	62
Postoperative AVM	44
Tumor	40
Postendarterectomy	21
Venous occlusion	11
Headache	10
Other	33

Note.—TIA indicates transient ischemic attack; AVM, arteriovenous malformation.

TABLE 3: Summary of neurologic events in the 10 patients with complications

Patient no.	Age, y/Sex	History	Findings	Event
17	79/M	TIA	Diffuse atherosclerosis	Transient hemiparesis
50	63/M	TIA	Mild carotid stenosis	Transient visual field cut
322	54/M	TIA	Severe carotid stenosis	Transient hemiparesis
345	69/F	Bruit	Mild carotid stenosis	Persistent facial paresis
485	86/M	CVA	Carotid occlusion	Persistent hemiplegia
499	72/F	Decreased LOC	Diffuse atherosclerosis	Persistent hemiplegia
522	74/F	TIA	Severe carotid stenosis	Transient arm weakness
627	82/M	CVA	Diffuse atherosclerosis	Persistent hemiplegia
829	75/M	IVH	Mild diffuse atherosclerosis	Transient aphasia
966	79/M	TIA	Moderate carotid stenosis	Persistent arm drift, aphasia

Note.—TIA indicates transient ischemic attack; CVA, cerebrovascular accident; LOC, level of consciousness; and IVH, intraventricular hemorrhage.

the angiographer. Apart from demographic information, the form included puncture and "catheter out" times, radiographic contrast type and amounts, summary of clinical status during the procedure, level of training for angiographer, brief summary of clinical indications for and results of the procedure, types of catheters and guide wires used, whether a vascular sheath was used, vessels selectively injected, a summary of immediate complications including status of groin and leg pulses, presence of a hematoma at the puncture site, and presence of neurologic deficits. Data from the follow-up examinations were also entered on this form.

For purposes of this trial, a neurologic complication was defined as any new focal neurologic deficit or change in mental status occurring during the angiogram or during the following 24 hours. Patients who underwent neurosurgical procedures in the 24 hours after angiography (140, 14%) were followed up until the time of surgery. Information on the data form was subsequently tabulated in a database for analysis after completion of the trial.

Confidence intervals for the case complication rate were calculated based on the full sample of 1000 examinations as well as the subsample of examinations performed for cerebral ischemic symptoms or asymptomatic bruit. This subgroup was defined by the following four indications for angiography: (a) stroke/transient ischemic attack, (b) asymptomatic neck bruit, (c) postendarterectomy, and (d) intraparenchymal hemorrhage. Statistical comparison was made for continuous variables such as age, contrast dose, and time of examination between the subgroup of examinations in which a neurologic complication occurred and the full sample, using the two-sample Student's *t* test. A similar analysis using the χ^2 statistic was used for discrete variables.

Results

Neurologic complications occurred in a total of 10 procedures. In 5 (50%) cases, neurologic deficits were present 24 hours after onset. In all

of these cases deficits were still present 1 week after onset and were classified as persistent. The remainder had completely resolved by 24 hours and were classified as transient. Age distribution for the transient and persistent complications is summarized in Table 1.

Of the five persistent deficits, four appeared after completion of the procedure (average time 1.5 hours). The remaining persistent deficit appeared immediately after injection of the right common carotid artery; however, the patient's deficits (aphasia and right hemiparesis) were referable to the *left* middle cerebral artery distribution.

Of the five transient deficits, two occurred after completion of the procedure (average time, 1 hour 15 minutes). The remaining three events occurred during angiography, although none occurred immediately after an injection. Two of these occurrences followed left vertebral artery injections, in both cases by 5 minutes. The third event followed a left subclavian artery injection by 1 minute.

Additional data for these 10 patients are summarized in Table 3. The average age of 73 years in this group was significantly greater than the average of 53 years for the complete sample ($P < .0005$). Significant differences were also observed in elapsed time of angiogram (1 hour 19 minutes versus 1 hour, $P = .023$), and total volume of contrast material (120 versus 93 mL, $P = .045$). The presence of severe stenosis (greater than 70% diameter narrowing according to the North American Symptomatic Carotid Endarterectomy Trial criteria [33]) or occlusion also was significantly correlated with the occurrence of neurologic complications.

TABLE 4: Percent complication rates and confidence intervals for full sample (N = 1000), and subgroup presenting with stroke/TIA history (N = 322)

	Complication rate (percent)	
	N = 1000	N = 322
Persistent	0.50	1.6
95% CI	0.18–1.2	0.57–3.8
Total*	1.0	3.1
95% CI	0.51–1.9	1.6–5.8

Note.—CI indicates confidence interval; *total indicates persistent and transient.

There was no significant association with level of training or number of catheters and guide wires used. In the four cases in which there was a temporal association with a selective injection, three cases involved injection of either the left vertebral or the subclavian artery. There was a marginally significant association of complication with injection of the left subclavian; however, the number of cases is small.

The case rate for neurologic events was calculated for the entire sample of 1000 examinations and also for the stroke/transient ischemic attack subgroup. All patients who suffered complications were members of this subgroup. Case rates and 95% confidence intervals are listed for these groups in Table 4. The average age for the stroke/transient ischemic attack subgroup was 65 years. For this group, average contrast volume was 116 mL, and average elapsed time was 1 minute, 5 seconds. When the group of patients who suffered complications are compared to the stroke/transient ischemic attack subgroup rather than the complete sample, only the difference in average age was statistically significant ($P = .02$).

Nonfocal complaints temporally related to angiography included three headaches all of which resolved spontaneously within 6 hours. Nonneurologic complications observed in the course of this trial included 81 (8.1%) minor groin hematomas, three vasovagal reactions requiring therapy, two femoral artery dissections with no loss of pulse, and one case of transient loss of femoral pulse during puncture.

Discussion

Four recent studies prospectively evaluated neurologic complications after angiography. Earnest et al (23) reported their observations

in 1517 procedures performed during 1980 to 1982. All but 107 of the procedures were transfemoral. Studies most likely used film-screen techniques given the years covered. Transient neurologic deficits (less than 24 hours) were observed in 2.2% of procedures, reversible deficits (less than 7 days) in 0.1%, and permanent (more than 7 days) in 0.33%. Reversible and permanent together comprised 0.43% of procedures. Older age, increased serum creatinine, and use of more than one catheter were all associated with a statistically increased risk of complication.

Dion et al (27) evaluated clinical events occurring during the 72 hours after cerebral angiography in 1002 procedures performed during 1983 and 1984. Transfemoral catheterization and film-screen techniques were used in virtually all cases. The neurologic event rate during the procedure and the following 24 hours was 1.3%, of which 0.1% persisted beyond 1 week. Procedure times longer than 60 minutes and systolic hypertension were associated with a greater risk of neurologic event.

Grzyska, Freitag, and Zeumer (31) examined complications occurring in 1095 procedures performed using transfemoral catheterization and intraarterial digital subtraction angiographic techniques. The complication rate during the first 24 hours was 0.55%, one (0.09%) persistent. For purposes of this trial, a complication was defined as an unanticipated event, and thus some events may have been excluded.

Waugh and Sacharias (34) studied complication rates in a group of patients undergoing digital subtraction angiographic procedures during 1988 to 1990, 939 of which were cerebral. Of these, 207 were limited to only nonselective aortic arch injections, which were deemed sufficient by the authors for evaluation of 69% of patients with carotid bifurcation disease. The neurologic complication rate was 0.9%, the rate of permanent deficits (more than 10 days) was 0.3%.

The rate of persistent deficits reported in these trials is compared to the present study in Figure 1. Although differences in method preclude detailed comparison, the complication rates among these recently performed studies all lie within 2 standard deviations of the value observed in the current study.

The advent of digital subtraction angiography has added a powerful new imaging tool to the

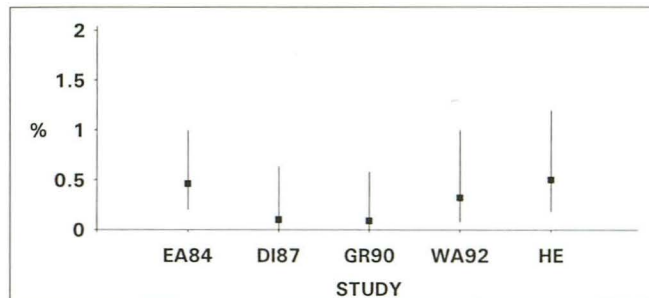


Fig 1. Complication rates for persistent neurologic deficits associated with angiography for recent prospective studies. Lines define 95% confidence intervals. EA84 indicates Earnest et al (23); D187, Dion et al (27); GR90, Grzyska et al (31); WA92, Waugh et al (33); and HE, present study. GR90 and WA92 used digital subtraction angiographic methods. The other trials used primarily film-screen techniques.

methods that can be used for cerebral angiography. Advantages of digital subtraction angiography include superior contrast resolution, reduced volumes of contrast material, and, in principle, decreased procedure time. However, modern digital subtraction angiographic systems achieve considerably less spatial resolution than magnification film-screen methods, and the lack of widespread availability of biplane digital subtraction angiographic systems negates some of the improvement in contrast load and procedure time. Recent studies (31, 34) have claimed a decrease in the neurologic complication rate associated with digital subtraction angiography, presumably related to a decrease in procedure time and contrast volume. However, based on the data from the prospective trials compared in Figure 1, there is no significant difference in the rate of neurologic complications between studies performed using film-screen and those using digital subtraction angiographic techniques. As pointed out by Pelz (35), to evaluate this question definitively a comparative trial would be necessary and has not yet been performed.

Increasing patient age has been suggested as a risk factor for angiographic complications in prior studies (23), and indeed this proved to be a significant risk factor in the current series. All neurologic complications occurred in patients older than 50 years of age. All patients suffering a persistent neurologic complication also presented with a history of stroke or transient ischemic attacks or (in one case) a carotid bruit. In Table 4 complication rates are tabulated for the subsamples with age greater than 50 years

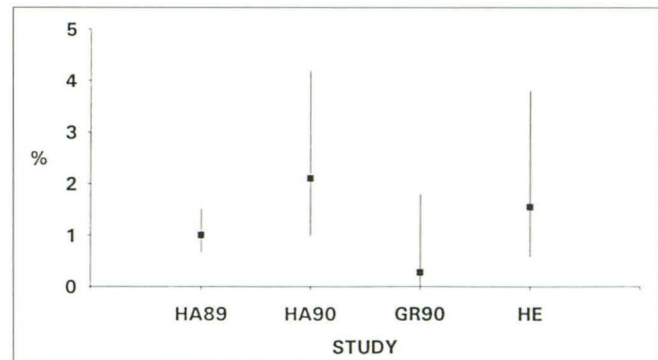


Fig 2. Complication rates for persistent neurologic deficits associated with cerebral angiography in patients presenting with a history of stroke/transient ischemic attack. Lines define 95% confidence interval. HA89 indicates Hankey et al (36). These data represent a review of eight prospective studies. HA90 indicates Hankey et al (32); GR90, Grzyska et al (31); and HE, present study.

and for patients presenting with a history of stroke/transient ischemic attack. The increased incidence of neurologic complications in patients presenting for evaluation of cerebral ischemia also has been previously described (32). In Figure 2, complication rates in the stroke/transient ischemic attack sub-group are compared with other recent studies from which these data could be derived, as well as with a recent review of several older studies (36). It is possible that the association with increased procedure time and contrast usage as well as previously reported associations such as systemic hypertension (27) are related to the increased difficulty and risk associated with selectively catheterizing vessels resulting from the high incidence of atherosclerotic change in this patient group. Stress related to angiography and hypovolemia associated with contrast induced diuresis also could contribute to neurologic symptoms. Transient ischemic attacks or stroke also can be temporally but not causally associated with cerebral angiography. This is particularly likely in a patient having frequent transient ischemic attacks. In this regard, it is worth noting that between 24 and 72 hours after performance of angiography, Dion et al observed rates of 1.8% for transient ischemic episodes and 0.3% development of persistent deficits, rates that are not significantly different from the rates observed in the 24 hours after angiography. It is likely that at least some of these delayed events represented part of the natural history or evolution of the underlying ischemic disease. The same reasoning can be applied to the time dur-

ing and after the angiographic procedure itself. Thus the neurologic complication rate would not be zero even if "perfectly safe" angiography could be performed (37).

Although not observed in this trial, complications can occur in younger patients related to nonatherosclerotic factors such as vasospasm. Patients with a history of migraine may be at increased risk for this form of complication (38). Other mechanical factors, such as catheter- or guide wire-induced dissection or thrombus or air embolism can also contribute to the observed complication rate (39). For these reasons, meticulous technique is imperative during performance of cerebral angiography to minimize the complication rate.

In conclusion, the present study was performed to further investigate the factors contributing to observed neurologic complications associated with cerebral angiography. As with all other studies of complication rates, factors such as referral bias limit the extent to which these results can be generalized. However, observed rates of 1.0% for transient neurologic deficits and 0.5% for persistent deficits during and for 24 hours after angiography confirms the low rates of both transient and persistent neurologic complications found by other investigators. In our series, all complications occurred in the subgroup of patients presenting with a history of stroke, transient ischemic attack, or asymptomatic bruit. These factors may reflect the difficulty of angiography in this population at risk for atherosclerotic changes.

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References

- Caplan LR, Wolpert SM. Angiography in patients with occlusive cerebrovascular disease: views of a stroke neurologist and neuro-radiologist. *AJNR Am J Neuroradiol* 1991;12:593-601
- Lang EK. A survey of percutaneous retrograde arteriography: Seldinger technic. *Radiology* 1963;81:257-263
- Amundsen P, Dietrichson P, Enge I, Williamson R. Cerebral angiography by catheterization: complications and side effects. *Acta Radiol Diagn (Stockh)* 1963;1:164-172
- Cronqvist S, Efsing HO, Palacios E. Embolic complications in cerebral angiography with the catheter technique. *Acta Radiol Diagn (Stockh)* 1970;10:97-107
- Wishart DL. Complications in vertebral angiography as compared to nonvertebral cerebral angiography in 447 studies. *AJR Am J Roentgenol* 1971;113:527-537
- Takahashi M, Kawanani H. Complications of catheter cerebral angiography: an analysis of 500 examinations. *Acta Radiol Diagn (Stockh)* 1972;13:248-258
- Vitek JJ. Femoro-cerebral angiography: analysis of 2000 consecutive examinations, special emphasis on carotid arteries catheterization in older patients. *AJR Am J Roentgenol* 1973;118:633-647
- Olivecrona H. Complications of cerebral angiography. *Neuroradiology* 1977;14:175-181
- Kerber CW, Cromwell LD, Drayer BP, Bank WO. Cerebral ischemia. I. Current angiographic techniques, complications and safety. *AJR Am J Roentgenol* 1978;130:1097-1103
- Mani RL, Eisenberg RL, McDonald EJ, Pollock JA, Mani JR. Complications of catheter cerebral angiography: analysis of 5000 procedures. I. Criteria and incidence. *AJR Am J Roentgenol* 1978;131:861-865
- Mani RL, Eisenberg RL. Complications of catheter cerebral angiography: analysis of 5000 procedures, II: relation of complication rates to clinical and arteriographic diagnoses. *AJR Am J Roentgenol* 1978;131:867-869
- Mani RL, Eisenberg RL. Complication of catheter cerebral angiography: analysis of 5000 procedures, III: assessment of arteries injected, contrast medium used, duration of procedure and age of patient. *AJR Am J Roentgenol* 1978;131:871-874
- Faught E, Trader SD, Hanna GR. Cerebral complications of angiography for transient ischemia and stroke: prediction of risk. *Neurology* 1979;29:4-15
- Huckman MS, Shenk GI, Neems RL, Tinor T. Transfemoral cerebral arteriography versus direct percutaneous carotid and brachial arteriography: a comparison of complication rates. *Radiology* 1979;132:93-97
- Miller JDR, Grace MG, Russell DB, Zacks DJ. Complications of cerebral angiography and pneumography. *Radiology* 1979;132:93-97
- Eisenberg RL, Bank WO, Hedgcock MW. Neurologic complications of angiography in patients with critical stenosis of the carotid artery. *Neurology (NY)* 1980;30:892-895
- Eisenberg RL, Bank WO, Hedgcock MW. Neurologic complications of angiography for cerebrovascular disease. *Neurology (NY)* 1980;30:895-897
- Reisner H, Samec P, Zeiler K. On the complication rate of cerebral angiography. *Neurosurg Rev* 1980;3:23-29
- Studdard W, Davis D, Young S. Cortical blindness after cerebral angiography. *J Neurosurg* 1981;54:240-244
- Wales LR, Nov AA. Transient global amnesia: complication of cerebral angiography. *AJNR Am J Neuroradiol* 1981;2:275-277
- Pexman JHW, Coates RK. Amnesia after femorocerebral angiography. *AJNR Am J Neuroradiol* 1983;4:979-983
- Skalpe IO, Anke IM. Complications in cerebral angiography: a comparison between the nonionic contrast medium iohexol and meglumine metrizoate (isopaque cerebral). *Neuroradiology* 1983;25:157-160
- Earnest F, Forbes G, Sandok BA, Piepgras DG, Faust RJ, Illstrup DM, Arndt LJ. Complications of cerebral angiography: prospective assessment of risk. *AJR Am J Roentgenol* 1984;142:247-253
- Fisher M, Sandler R, Weiner JM. Delayed cerebral ischemia following arteriography. *Stroke* 1985;16:431-434

25. Gasparini M, Arioso M, Galbiati N, Cappa S, Rota E, Bevilacqua L, Sterzi R. Neurological complications of cerebral angiography. *Ital J Neurol Sci* 1986;7:353-357
26. Thompson KR, Thompson SMA. Complications of cerebral angiography in a teaching hospital. *Australas Radiol* 1986;30:206-208
27. Dion JE, Gates PC, Fox AJ, Barnett HJM, Blom RJ. Clinical events following neuroangiography: a prospective study. *Stroke* 1987;18:997-1004
28. McIvor J, Steiner TJ, Perkin GD, Greenhalgh RM, Clifford RF. Neurological morbidity of arch and carotid arteriography in cerebrovascular disease. *Br J Radiol* 1987;60:117-122
29. Theodotou BC, Whaley R, Mahaley MS. Complications following transfemoral cerebral angiography for cerebral ischemia: report of 159 angiograms and correlation with surgical risk. *Surg Neurol* 1987;28:90-92
30. Leow K, Murie JA. Cerebral angiography for cerebrovascular disease: the risks. *Br J Surg* 1988;75:428-430
31. Grzyska U, Freitag J, Zeumer H. Selective cerebral intraarterial DSA: complication rate and control of risk factors. *Neuroradiology* 1990;32:296-299
32. Hankey JG, Warlow CP, Molyneux AJ. Complications of cerebral angiography for patients with mild carotid territory ischaemia being considered for carotid endarterectomy. *J Neurol Neurosurg Psychiatry* 1990;53:542-548
33. North American Symptomatic Carotid Endarterectomy Trial Collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients with high grade stenosis. *N Engl J Med* 1991;325:445-453
34. Waugh JR, Sacharias N. Arteriographic complications in the DSA era. *Radiology* 1992;182:243-246
35. Pelz DM. Complication rates of DSA and conventional film screen cerebral angiography. (letter) *Radiology* 1992;185:908
36. Hankey GJ, Warlow CP, Sellar RJ. Cerebral angiographic risk in mild cerebrovascular disease. *Stroke* 1990;21:209-222
37. Baum S, Stern GN, Kuroda KK. Complications of "no arteriography." *Radiology* 1966;86:835-838
38. Takeshima T, Nishikawa S, Takahashi K. Sublingual administration of flunarizine for acute migraine: will flunarizine take the place of ergotamine? *Headache* 1988;28:602-606.
39. Markus H, Loh A, Israel D, Buckenham T, Clifton A, Brown M. Microscopic air embolism during cerebral angiography and strategies for its avoidance. *Lancet* 1993;341:784-787

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