AJNR

INTERVENTIONAL NEURORADIOLOGY

Charles M. Strother

AJNR Am J Neuroradiol 2000, 21 (1) 19-24
http://www.ajnr.org/content/21/1/19

INTERVENTIONAL NEURORADIOLOGY

During the last 20 years, techniques in interventional neuroradiology have evolved from procedures that were dangerous, often ineffective, and seldom used to those that are safe, effective, and used daily to treat hundreds of patients throughout the world. Improvements in imaging, catheters and other devices, pharmaceuticals, the understanding of cerebrovascular diseases, and establishment of formal training programs in interventional neuroradiology have all combined and converged to account for this progress. During the last 20 years, many of these advances have been described and illustrated in the pages of the *AJNR.*

Tools

Although the invention and development of CT and MR imaging revolutionized the diagnosis of central nervous system diseases, it was the invention and development of digital subtraction angiography (DSA) that provided the foundation on which the growth and development of interventional neuroradiology could be based. The first volume of the *AJNR* contained one article describing a prototype DSA device and, a second, regarding clinical experiences using intravenous digital video subtraction angiography for evaluation of the extracranial vasculature (1, 2). Six months later, in volume 2, a report described the use of this technique for imaging intracranial vasculature (3) and, within another year, Manelfe and colleagues (4) had accumulated experiences with intravenous video subtraction angiography in a series of 1000 patients. Only 3 years after its initial description, Sherry and colleagues (5) discussed the use of DSA as an aid for performance of therapeutic neuroradiologic procedures. The infancy and preteen years of the *AJNR* (1980–1989) included reports by Brant-Zawadzki comparing DSA obtained after the intra-arterial injection of contrast medium with film-screen angiography, by Hieshima documenting the utility of the technique as an intraoperative tool, and by Schumacher describing digital rotational radiography (6–8). It is no coincidence that, parallel with rapid dissemination and acceptance of DSA, there was a simultaneous increase in both the number and type of therapeutic interventional procedures reported in the *AJNR.*

The milieu created by the availability of DSA was a fertile one for the rapid evolution of interventional techniques. Prior to 1980, these procedures had almost entirely been limited to ones that were performed working through catheters placed in the extracranial vasculature—most procedures being variations on a theme where appropriate delivery of injected particulate material was governed solely by vascular geometry and blood flow. In a very real sense, the ‘‘toolbox’’ of the interventional neuroradiologist was almost empty. In this regard, the second issue of volume 1 of the *AJNR* is especially important because of the presence of back-to-back articles by Kerber (9) and Berenstein (10). Kerber describes catheterization of intracranial arteries achieved by using a novel, flow-directed balloon catheter, and Berenstein illustrates the use of a new liquid embolic agent. Although neither of these techniques proved to be of widespread utility, they clearly demonstrated the potential for improvement in the endovascular approach. (These two articles also mark the start of multiple future contributions by authors who, 20 years later, continue to be among the leaders in innovations that are advancing the capacity of interventional neuroradiology.) During the 5 years that followed, the interventionalist’s armamentarium expanded rapidly as Debrun (11) described use of a latex detachable balloon for the treatment of giant aneurysms, Mehringer (12), working with Heishema, reported use of a silicon detachable balloon for management of vascular trauma, and Tomsick (13) discussed use of both balloons and coils during performance of neurointerventional procedures. By 1987, Jungreis (14) showed that the sophistication of catheters and guidewires suitable for use in the intracranial vasculature had evolved to the extent that catheterization of intracranial arteries was no longer dependent upon the use of flow-directed catheters. By 1990, both over-the-wire and flow-directed catheters suitable for use in the intracranial circulation had become widely available. Investigators now began efforts to improve both the safety and the functionality of these new devices further (15–18). As these new access devices (catheters and guidewires) and therapeutic agents were described, soon there followed reports of their use in clinical practice.

Applications

In the early years of the *AJNR,* few therapeutic devices were designed specifically for use in the vasculature of the head and neck. Thus, many procedures required not only innovation but also modification of devices and techniques that were designed for other applications. Kerber’s report (19) of angioplasty of a proximal carotid stenosis during performance of an endarterectomy at the carotid bifurcation is a significant example of this aspect of early interventional procedures.

Between 1980 and 1985, Berenstein and a group from New York University (20) described treatment of carotid cavernous fistulas with detachable balloons and Fox and colleagues in London, Ontario (21), described improvement in neurologic

function after the embolization of Rolandic arteriovenous malformations (AVMs) with 2-isobutyl-cyanoacrylate (IBC). These early articles were among the first that demonstrated, in a substantial number of patients, that there was clear clinical benefit to be derived from the endovascular approach. Another report, again generated from New York University (22), is important, because it not only represents an early attempt to define and describe techniques for embolization but also correlates radiologic, pathologic, and clinical results. During these early years, provocative descriptions of percutaneous transluminal angioplasty (PTA) in the brachiocephalic (23, 24), the external carotid artery (25), and the cavernous segment of the internal carotid artery (26) set the stage for future development of this technique.

After 1985, both the number and the sophistication of articles related to interventional techniques increased significantly. Small clinical series rather than isolated case reports became more common (ie, regarding PTA [27]; parent artery occlusion for the treatment of giant intracavernous carotid aneurysms [28]; and preoperative embolization of brain AVMs [29]). Hieshima (30) clearly illustrated the potential for endovascular treatment of saccular aneurysms by describing, in 1986, treatment of a carotid ophthalmic artery aneurysm performed using a detachable balloon placed within the aneurysm, which allowed preservation of the parent artery. During this period, Hieshima and his colleagues at UCSF (31), greatly advanced the understanding and scope of endovascular therapeutic procedures (ie, Higashida [32], PTA of the basilar artery; Halbach [33], techniques and indications for treatment of a variety of arteriovenous fistula). Before 1990, Theron (34) reported on attempts to use the endovascular approach to treat ischemic stroke by using intra-arterial administration of thrombolytic agents.

As the ''Decade of the Brain'' began in 1990, the ''toolbox'' of the neurointerventionalist was much fuller than it had been only 10 years earlier. Nevertheless, serious limitations persisted, especially in regard to the availability of therapeutic materials—the ability to access intracranial vessels had improved greatly, but the ability to intervene once at the disease site was still very restricted. Soon, availability of new over-the-wire catheters, reliable detachable and nondetachable balloons, and pushable platinum coils improved this situation. Now, for the first time, it appeared that the goal of applying endovascular techniques for the treatment of patients with saccular aneurysms was a realistic one. Reports using detachable balloons for treatment of aneurysms while preserving patency of the parent artery (35) and, of angioplasty of a stenotic middle cerebral artery (36), stimulated both physicians and industry to increase efforts for development of devices that were designed specifically for use in the vasculature of the brain. Between 1990 and 1993, articles describing treatment of AVFs (37, 38) and an acutely ruptured saccular aneurysm (39), by using pushable platinum coils, appeared in the *AJNR*. Although the use of pushable coils for the endosaccular treatment of aneurysms would be short-lived, these experiences were of great value as they stimulated further development of more ideal tools for aneurysm treatment. Pushable coils would prove to be of great utility in the treatment of a variety of other vascular diseases. Adding further to the armamentarium of the interventionalist during these early years of the Decade of the Brain were reports of a retrieval device designed specifically for use in small vessels (40, 41), a technique for percutaneous vertebroplasty (42), Doppler guidewire use for monitoring blood flow during endovascular procedures (43), and mechanical clot disruption and PTA as techniques in the treatment of acute ischemic stroke (44, 45). In 1994, an article from UCLA discussing the importance of aneurysm neck size in determining the outcome of treatment of saccular aneurysms with electrically detachable coils and a commentary regarding a Phase III trial testing the efficacy of intra-arterial thrombolytic administration for the treatment of acute ischemic stroke marks a time when, like the *AJNR*, interventional neuroradiology reached maturity (46, 47). Between 1995 and the present, interventional techniques have assumed a major role in the management of patients with cerebrovascular disease. Safety, precision, and effectiveness have all been improved. Analysis of large clinical series undergoing carotid test occlusion (48, 49), attempts to modify physiologic parameters during such testing (50), and the use of transcranial Doppler monitoring during carotid test occlusion (51) were all important in advancing understanding, safety, and utility of this technique. During these 5 years, there was also a large increase in the number of reports describing the use of PTA and stenting for neurovascular applications. Reports of performing PTA to open an occluded internal carotid artery (ICA) (52), the use of stents for treatment of pseuroaneurysms or dissections of the extracranial segments of the ICA or vertebral artery (53, 54), and the use of PTA plus stenting for treatment of intracranial carotid stenosis (55) all were significant. Recent description of a clinical series describing the use of PTA for treatment of symptomatic middle cerebral artery stenosis from Korea (56) and a report of a small clinical series with angiographic follow-up after intracranial PTA from Japan (57) have expanded the understanding of both the techniques and the indications for this procedure. Further maturation of the endovascular treatment of aneurysms is also evident in reports that appeared during this period. Techniques were described that expanded the number of aneurysms that could be managed using the endovascular approach (58, 59). Reports of pathologic changes in humans after treatment of aneurysms with the Guglielmi detachable coil (GDC) appeared (60, 61) along with analysis of factors predicting successful outcome after GDC treatment (62, 63) and a study of the cost effectiveness of this treatment (64).

These and other studies solidified the concept that the future of aneurysm therapy likely would be one that uses an endovascular approach (65). The use of endovascular techniques for the treatment of ischemic stroke continued to evolve, as evidenced by reports showing that complete vascular recanalization reduced the extent of tissue that progressed to infarction (66). Additional studies demonstrated that there was a pressing need to define and improve techniques for selection of patients who were suitable for this therapy (67, 68). The ''toolbox'' was expanded as fibered GDC coils were described (69), and early experiences with a novel rheolytic catheter were reported (70, 71). Reports of the use of MR angiography for studying patients who had undergone aneurysm treatment with GDC coils (72, 73) or as a tool for assessing patients suffering an acute ischemic stroke (74) are significant, as they mark what will almost surely become the widespread use of this technique by the endovascular therapist.

Laboratory Studies and Training

The *AJNR* has, since its inception, been a leading source for the dissemination of information gleaned from preclinical laboratory investigations. These studies have been critical both to furthering the understanding of basic mechanisms involved in cerebrovascular diseases and to developing and testing of devices that could be used for their treatment. In 1986, a report from Spiegal and colleagues (75) described experiments that led to techniques useful in adjusting the polymerization time of IBC. Pile-Spellman and colleagues (76) used experimental arteriovenous fistulas to describe the angiopathy that occurs under conditions of long-term increased flow and pressure. An experimental stroke model suitable for testing the effect of selective infusion of thrombolytic agents was described in 1988 (77), and the first attempt to develop the swine rete model as a tool for testing embolic agents was reported by Lee and colleagues (78) in 1989. Early in the Decade of the Brain, a series of articles described animal models and techniques that were useful either for understanding fundamental issues related to aneurysm hemodynamics or for testing devices that were intended for use in aneurysm therapy (79–84). During this same period, other investigators described and developed animal models that were useful for testing and developing stents and embolic materials (85–87). Together, these experimental studies resulted in a significant improvement in the understanding of the pathophysiology of aneurysms and vascular malformations. They were also of real value in guiding the evolution of the therapeutic tools that ultimately would be useful in clinical practice. Between 1995 and the present, animal models continue to be used for development of new techniques or for modification of stents, coils, and embolic materials (88–94). The potential for adding additional goods to the toolbox is indicated by reports describing a new concept for the endovascular treatment of aneurysms and the use of intravascular sonography as a means to obtain clear definition of aneurysm ostia (95, 96).

Many of the experimental models described in the preceding paragraphs have also been of utility in the training of physicians. The swine rete model, the experimental canine aneurysm model, and the swine arteriovenous fistula model are especially noteworthy in this regard. Clear evidence exists that experience improves outcome (97).

The Future

These and numerous other experiences have created a basis that now provides today's interventionalist with the capacity to work in an environment where real-time biplane acquisition of vascular images having submillimeter resolution is possible. Postprocessing capacities and appropriate workstations allow for three-dimensional reconstructions as well as other interactive capacities (eg, endovascular viewing). Using widely available tools, it is possible to perform catheterization on most vascular structures of the brain safely and quickly. Once at the site of an abnormality, many options exist for its correction. What will further improve this situation? In my opinion, the major factors that limit further expansion of the capacity to treat cerebrovascular disease by endovascular approach are: 1) the inability to clearly see at the site where an intervention is being performed; 2) the inability to monitor and control energy sources that might be delivered to abnormal tissue; and 3) the inability to monitor, in a precise way, changes in physiology that may be occurring as the result of an intervention. All of these may be removed if techniques are developed so that the endovascular therapist can work in an MR environment rather than in one that is dependent upon X-ray fluoroscopy and angiography. Using MR imaging, easily refreshable three-dimensional data sets of both parenchyma and vasculature, combined with endovascular imaging, should allow much improved visualization of the site of pathology as well as of the effect produced by an intervention. Temperature-sensitive imaging, in conjunction with interactive real-time MR images, offers the promise for monitoring and control during delivery of energy from a variety of sources (eg, sonography, radiofrequency, and laser). Diffusion and perfusion imaging provide an ideal method for identification of those patients with acute ischemia, who may benefit from local thrombolysis; these imaging sequences should also serve as tools to monitor the progress of such therapy. Available microelectronics embedded in catheters and guidewires that are made from appropriate materials can transform these devices from simple access products to ones that can be used for the detection of and perhaps even regulation of local changes in physiology. The *AJNR* will continue to be the primary medium through which these advances are reported. How

great it would be to be just beginning a career in interventional neuroradiology!

CHARLES M. STROTHER, MD
Senior Editor

References

1. Christenson PC, Ovitt TW, Fisher HD, et al.**Intravenous angiography using digital video dubtraction: intravenous cervicocerebrovascular angiography.** *AJNR Am J Neuroradiol* 1980;1: 379–386
2. Ovitt TW, Christenson PC, Fisher HD, et. al.**Intravenous angiography using digital video subtraction: X-ray imaging system.** *AJNR Am J Neuroradiol* 1980;1:387–390
3. Strother CM, Sackett JF, Crummy AB, et al.**Intravenous video arteriography of the intracranial vasculature: early experience.** *AJNR Am J Neuroradiol* 1981;2:215–218
4. Manelfe C, Ducos de Lahitte M, Marc-Vergnes JP, et al.**Investigation of extracranial cerebral arteries by intravenous angiography: report of 1000 cases.** *AJNR Am J Neuroradiol* 1982;3:287–294
5. Sherry RG, Anderson RE, Kruger RE, Nelson JA. **Real-time digital subtraction angiography for therapeutic neuroradiologic procedures.** *AJNR Am J Neuroradiol* 1983;4:1171–1174
6. Brant-Zawadski M, Gould R, Norman D, et al.**Digital subtraction cerebral angiography in intraarterial injection: comparison with conventional angiography.** *AJNR Am J Neuroradiol* 1982; 3:593–600
7. Hieshima GB, Reicher MA, Higashida RT, et al.**Intraoperative digital subtraction neuroangiography: a diagnostic and therapeutic tool.** *AJNR Am J Neuroradiol* 1987;8:759–768
8. Schumacher M, Kutluk K, Ott D. **Digital rotational radiography in neuroradiology.** *AJNR Am J Neuroradiol* 1989;10:644–649
9. Kerber CW, Bank WO, Manelfe C. **Control and placement of intracranial microcatheters.** *AJNR Am J Neuroradiol* 1980;1: 157–160
10. Berenstein A. **Flow-controlled silicone fluid embolization.** *AJNR Am J Neuroradiol* 1980;1:161–166
11. Debrun G, Fox A, Drake C, et al.**Giant unclippable aneurysms: treatment with detachable balloons.** *AJNR Am J Neuroradiol* 1981;2:167–174
12. Mehringer CM, Hieshima GB, Grinnell VS, et al.**Therapeutic embolization for vascular trauma of the head and neck.** *AJNR Am J Neuroradiol* 1983;4:137–142
13. Tomsick TA, Ball JB. **Balloons and coils: aids in particulate/liquid head-neck embolization.** *AJNR Am J Neuroradiol* 1985; 6:598–601
14. Jungreis CA, Berenstein A, Choi IS. **Use of an open-ended guidewire: steereable microguidewire assembly system in surgical neuroangiographic procedures.** *AJNR Am J Neuroradiol* 1987; 8:237–242
15. Pinto RS, Robbins E, Seidenwurm D. **Thrombogenicity of teflon versus copolymer-coated guidewires: evaluation with scanning electron microscopy.** *AJNR Am J Neuroradiol* 1989;10:407–410
16. Theron J, Courtheoux P, Alachhkar F, Bouvard G, Maiza D. **New triple coaxial catheter system for carotid angioplasty with cerebral protection.** *AJNR Am J Neuroradiol* 1990;11:869–874
17. Mathis JM, Evans AJ, DeNardo, et. al.**Hydrophilic coatings diminish adhesion of glue to catheter: an in vitro simulation of NBCA embolization.** *AJNR Am J Neuroradiol* 1997;18:1087–1092
18. Kallmes DF, McGraw JK, Evans AJ, et al.**Thrombogenicity of hydrophilic and nonhydrophilic microcatheters and guiding catheters.** *AJNR Am J Neuroradiol* 1997;18:1243–1251
19. Kerber CW, Cromwell LD, Loehden OL. **Catheter dilatation of proximal carotid stenosis during distal bifurcation endarterectomy.** *AJNR Am J Neuroradiol* 1980;1:348–349
20. Berenstein A, Kricheff II, Ransohoff J. **Carotid-cavernous fistulas: intraarterial treatment.** *AJNR Am J Neuroradiol* 1980;1: 449–458
21. Fox AJ, Girvin JP, Vinuela F, Drak CG. **Rolandic arteriovenous malformations: improvement in limb function by IBC embolization.** *AJNR Am J Neuroradiol* 1985;6:575–582
22. Berenstein A, Kricheff II. **Microembolization techniques of vascular occlusion: radiologic, pathologic and clinical correlation.** *AJNR Am J Neuroradiol* 1981;2:261–268
23. Motarjeme A, Keifer JW, Zuska AJ. **Percutaneous transluminal angioplasty of the brachiocephalic arteries.** *AJNR Am J Neuroradiol* 1982;3:169–174
24. Damuth HD, Diamond AB, Rappoport AS, Renner JW. **Angioplasty of subclavian artery stenosis proximal to the vertebral orgin.** *AJNR Am J Neuroradiol* 1983;4:1239–1242
25. Vitek JJ, Morawetz RB. **Percutaneous transluminal angioplasty of the external carotid artery: preliminary report.** *AJNR Am J Neuroradiol* 1982;3:541–546
26. O'Leary DH, Clouse ME. **Percutaneous transluminal angioplasty of the cavernous carotid artery for recurrent ischemia.** *AJNR Am J Neuroradiol* 1984;5:644–645
27. Tsai FY, Matovich V, Hieshima G, et al.**Percutaneous transluminal angioplasty of the carotid artery.** *AJNR Am J Neuroradiol* 1986;7:349–358
28. Raymond J, Theron J. **Intracavernous aneurysms: treatment by proximal balloon occlusion of the internal carotid artery.** *AJNR Am J Neuroradiol* 1986;7:1087–1092
29. Pelz DM, Fox AJ, Vinuela F, et al.**Preoperative embolization of brain AVMs with Isobutyl-2 cyanoacrylate.** *AJNR Am J Neuroradiol* 1988;9:757–764
30. Hieshima GB, Higashida RT, Halbach V, et al.**Intravascular balloon embolization of a carotid-ophthalmic artery aneurysm with preservation of the parent vessel.** *AJNR Am J Neuroradiol* 1986;7:916–918
31. Higashida RT, Hieshima GB, Tsai FY, et al.**Transluminal angioplasty of the vertebral and basilar artery.** *AJNR Am J Neuroradiol* 1987;8:745–750
32. Halbach VV, Hieshima GB, Higashida RT, et al.**Carotid cavernous fistulae: indications for urgent treatment.** *AJNR Am J Neuroradiol* 1987;8:627–634
33. Halbach VV, Higashida RT, Hieshima GB, et al.**Treatment of dural arteriovenous malformations involving the superior sagittal sinus.** *AJNR Am J Neuroradiol* 1988;9:337–344
34. Theron J, Courtheoux P, Casasco A, et al.**Local intraarterial fibrinolysis in the carotid territory.** *AJNR Am J Neuroradiol* 1989;10:753–766
35. Higashida RT, Halbach VV, Barnwell SL, et al.**Treatment of intracranial aneurysms with preservation of the parent vessel: results of percutaneous balloon embolization in 84 patients.** *AJNR Am J Neuroradiol* 1990;11:633–640
36. Purdy PD, Devous MD, Unwin DH, et al.**Angioplasty of an atherosclerotic middle cerebral artery associated with improvement in regional cerebral blood flow.** *AJNR Am J Neuroradiol* 1990;11:878–880
37. Smith MD, Russell EJ, Levy R, Crowell RM. **Transcatheter obliteration of a cerebellar arteriovenous fistula with platinum coils.** *AJNR Am J Neuroradiol* 1990;11:1199–1201
38. Lane B, Marks MP. **Coil embolization of an acutely ruptured saccular aneurysm.** *AJNR Am J Neuroradiol* 1991;12:1067–1069
39. Halbach VV, Higashida RT, Barnwell SL, et al.**Transarterial platinum coil embolization of carotid cavernous fistulas.** *AJNR Am J Neuroradiol* 1991;12:429–434
40. Graves VB, Rappe AH, Smith TP, et al.**An endovascular retrieving device for use in small vessels.** *Am J Neuroradiol* 1993;14: 804–808
41. Smith TP, Graves VB. Halbach, et al.**Microcatheter retrieval device for intravascular foreign body removal.** *AJNR Am J Neuroradiol* 1993;14:809–811
42. Gangi A, Kastler BA, Dietemann JL. **Percutaneous vertebroplasty guided by a combination of CT and fluoroscopy.** *AJNR Am J Neuroradiol* 1994;15:83–86
43. Chaloupka JC, Viñuela F, Kimme-Smith C, et al.**Use of a Doppler guidewire for intravascular blood flow measurements: a validation study for potential neurologic endovascular applications.** *AJNR Am J Neuroradiol* 1994;15:509–517
44. Barnwell SL, Clark WM, Nguyen TT, et al.**Safety and efficacy of delayed intraarterial urokinase therapy with mechanical clot disruption for thromboembolic stroke.** *AJNR Am J Neuroradiol* 1994;15:1817–1822
45. Tsai FY, Berberian B, Matoich V, et al.**Percutaneous transluminal angioplasty adjunct to thrombolysis for acute middle cerebral artery rethrombosis.** *AJNR Am J Neuroradiol* 1994;15: 1823–1830
46. Zubillaga AF, Guglielmi G, Vinuela F, Duckwiler GR. **Endovascular occlusion of intracranial aneurysms with electrically detachable coils: correlation of aneurysm neck size and treatment results.** *AJNR Am J Neuroradiol* 1994;15:815–820

47. Del Zoppo GJ, Higashida RT, Furlan AJ. **Commentary: the case for a phase III trial of cerebral intraarterial fibrinolysis.** *AJNR Am J Neuroradiol* 1994;15:1217–1222
48. Mathis JM, Barr JD, Jungreis CA. **Temporary balloon test occlusion of the internal carotid artery: experience in 500 cases.** *AJNR Am J Neuroradiol* 1995;16:749–754
49. Meyers PM, Thakur GA, Tomsick TA. **Temporary endovascular balloon occlusion of the internal carotid artery with a nondetachable silicone balloon catheter: analysis of technique and cost.** *AJNR Am J Neuroradiol* 1999;20:559–564
50. Standard SC, Ahuja A, Guterman LR, et al.**Balloon test occlusion of the internal carotid artery with hypotensive challenge.** *AJNR Am J Neuroradiol* 1995;16:1453–1458
51. Eckert B, Thie A, Carvajal M, et al.**Predicting hemodynamic ischemia by transcranial Doppler monitoring during therapeutic balloon occlusion of the internal carotid artery.** *AJNR Am J Neuroradiol* 1998;19:577–586
52. Spearman MP, Jungreis CA, Wechsler LR. **Angioplasty of the occluded internal carotid artery.** *AJNR Am J Neuroradiol* 1995; 16:1791–1796
53. Horowitz MB, Miller G, Meyer Y, et al.**Use of intravascular stents in the treatment of internal carotid and extracranial vertebral artery pseudoaneurysms.** *AJNR Am J Neuroradiol* 1996;17:693–696
54. Dorros G, Cohn JM, Palmer LE. **Stent deployment resolves a petrous carotid artery angioplasty dissection.** *AJNR Am J Neuroradiol* 1998;19:392–394
55. Nadim Al-Murbarak, Camilo R, Comez J, et al.**Stenting of symptomatic stenosis of the intracranial internal carotid artery.** *AJNR Am J Neuroradiol* 1998;19:1949–1952
56. Suh DC, Sung K-B, Cho YS, et al.**Transluminal angioplasty for middle cerebral stenosis in patients with acute ischemic stroke.** *AJNR Am J Neuroradiol* 1999;20:553–558
57. Mori T, Fukuoka M, Kazita K, Mori K. **Follow-up study after intracranial percutaneous transluminal cerebral balloon angioplasty.** *AJNR Am J Neuroradiol* 1998;19:1525–1534
58. Baxter BW, Rosso D, Lownie SP. **Double-microcatheter technique for detachable coil treatment of large, wide-necked intracranial aneurysms.** *AJNR Am J Neuroradiol* 1998;19:1176–1178
59. Sanders WP, Burke TH, Mehta BA. **Embolization of intracranial aneurysms with Guglielmi detachable coils augmented by microballoons.** *AJNR Am J Neuroradiol* 1998;19:917–920
60. Shimizu S, Kurata A, Takano M, et al.**Tissue Response of a small saccular aneurysm after incomplete occlusion with a Guglielmi detachable coil.** *AJNR Am J Neuroradiol* 1999;20:546–548
61. Castro E, Fortea F, Villoria F, et al.**Long-term histopathologic findings in two cerebral aneurysms embolized with Guglielmi detachable coils.** *AJNR Am J Neuroradiol* 1999;20:549–552
62. Ayton Hope JK, Byrne JV, Molyneux AJ. **Factors influencing successful angiographic occlusion of aneurysms treated by coil embolization.** *AJNR Am J Neuroradiol* 1999;20:391–400
63. Turjman F, Massoud T, Sayre J, Viñuela F. **Predictors of aneurysm occlusion in the period immediately after endovascular treatment with detachable coils: a multivariate analysis.** *AJNR Am J Neuroradiol* 1998;19:1645–1652
64. Kallmes DF, Kallmes MH, Cloft HJ, Dion JE. **Guglielmi detachable coil embolization for unruptured aneurysms in nonsurgical candidates: a cost-effectiveness exploration.** *AJNR Am J Neuroradiol* 1998;19:167–176
65. Nichols DA. **Endovascular Therapy as the Preferred Method of Treatment for "Surgical" Aneurysms: What Must Happen for This to Become Reality?** *AJNR Am J Neuroradiol* 20:1391–1392
66. Sasaki O, Takeuchi S, Koizumi T, et al.**Complete recanalization via fibrinolytic therapy can reduce the number of ischemic territories that progress to infarction.** *AJNR Am J Neuroradiol* 1996;17:1661–1668
67. Jansen R, von Kummer M, Forsting M, et al.**Thrombolytic therapy in acute occlusion of the intracranial internal carotid artery bifurcation.** *AJNR Am J Neuroradiol* 1995;16:1977–1986
68. Yuh WTC, Maeda M, Wang A-M, et al.**Commentary: fibrinolytic treatment of acute stroke: are we treating reversible cerebral ischemia?** *AJNR Am J Neuroradiol* 1995;16:1994–2000
69. Halbach VB, Dowd CF, Higashida RT. **Preliminary experience with an electrolytically detachable fibered coil.** *AJNR Am J Neuroradiol* 1998;19:773–777
70. Dowd CF, Malek AM, Phatouros CC, Hemphill JC. **Application of a rheolytic thrombectomy device in the treatment of dural sinus thrombosis: a new technique.** *AJNR Am J Neuroradiol* 1999;20:568–570
71. Opatowsky MJ, Morris PP, Regan JD, et al.**Rapid thrombectomy of superior sagittal sinus and transverse sinus thrombosis with a rheolytic catheter device.** *AJNR Am J Neuroradiol* 1999;20: 414–418
72. Derdeyn CP, Graves VB, Turski PA. **MR angiography of saccular aneurysms after treatment with Guglielmi detachable coils: preliminary experience.** *AJNR Am J Neuroradiol* 1997;18: 279–286
73. Gonner F, Heid O, Remonda L, et al.**MR angiography with ultrashort echo time in cerebral aneurysms treated with Guglielmi detachable coils.** *AJNR Am J Neuroradiol* 1998;19:1324–1328
74. Gillard PJ, Oliverio PB, Oppenheimer SM, Bryan RN. **MR angiography in acute cerebral ischemia of the anterior circulation: a preliminary report. AJNR Am J Neuroradiol**1997;18: 343–350
75. Spiegel SM, Viñuela F, Goldwasser MJ, et al.**Adjusting the polymerization time of Isobutyl-2 cyanoacrylate.** *AJNR Am J Neuroradiol* 1986;7:109–112
76. Pile-Spellman JMD, Baker KF, Liszczak TM, et al.**High-flow angiopathy: cerebral blood vessel changes in experimental chronic arteriovenous fistula.** *AJNR Am J Neuroradiol* 1986;7: 811–815
77. Phillips DA, Davis MA, Fisher M. **Selective embolization and clot dissolution with tPA in the internal carotid artery circulation of the rabbit.** *AJNR Am J Neuroradiol* 1988;9:899–902
78. Lee DH, Wriedt CH, Kaufmann JCE, et al.**Evaluation of three embolic agents in pig rete.** *AJNR Am J Neuroradiol* 1989;10: 773–776
79. Geremia GK, Hoile RD, Haklin MF, Charletta DA. **Balloon embolization of experimentally created aneurysms: an animal training model.** *AJNR Am J Neuroradiol* 1990;11:659–662
80. Kerber CW, Liepsch D. **Special report: flow dynamics for radiologist, I: basic principles of fluid flow.** *AJNR Am J Neuroradiol* 1994;15:1065–1075
81. Graves VB, Partington CR, Rufenach DA, et al.**Treatment of carotid artery aneurysms with platinum coils: an experimental study in dogs.** *AJNR Am J Neuroradiol* 1990;1:249–252
82. Strother CM, Graves VB, Rappe A. **Aneurysm hemodynamics: an experimental study.** *AJNR Am J Neuroradiol* 1992;13:1089–1096
83. TerBrugge KG, Lasjaunias P, Hallacq P. **Review article: Experimental models in interventional neuroradiology.** *AJNR Am J Neuroradiol* 1991;12:1029–1034
84. Kwan ESK, Heilman CB, Roth PA. **Endovascular packing of carotid bifurcation aneurysm with polyester fiber-coated platinum coils in a rabbit model.** *AJNR Am J Neuroradiol* 1993;14: 323–333
85. Geremia G, Haklin M, Brennecke L. **Embolization of experimentally created aneurysms with intravascular stent devices.** *AJNR Am J Neuroradiol* 1994;15:1223–1232
86. Massoud TF, Ji C, Viñuela F, et al.**An experimental arteriovenous malformation model in swine: anatomic basis and construction technique.** *AJNR Am J Neuroradiol* 1994;15:1537–1546
87. Chaloupka JC, Vinuela F, Robert J, Duckwiler GR. **An in vivo arteriovenous malformation model in swine: preliminary feasibility and natural history study.** *AJNR Am J Neuroradiol* 1994; 15:945–952
88. Wakhloo AJ, Tio FO, Lieber BB, et al.**Self-expanding nitinol stents in canine vertebral arteries: hemodynamics and tissue response.** *AJNR Am J Neuroradiol* 1995;16:1043–1052
89. Massoud TF, Turjman F, Ji C, et al.**Endovascular treatment of fusiform aneurysms with stents and coils: technical feasibility in a swine model.** *AJNR Am J Neuroradiol* 1995;16:1953–1964
90. Dawson RC, Shengelaia GG, Krisht AF, Bonner GD. **Histologic effects of collagen-filled interlocking detachable coils in the ablation of experimental aneurysms in swine.** *AJNR Am J Neuroradiol* 1996;17:859–863
91. Yoshimura S, Hashimoto N, Goto Y, et al.**Intraarterial infusion of high-concentration papaverine damages cerebral arteries in rats.** *Am J Neuroradiol* 1996;17:1891–1894
92. Byrne JV, Hope JKA, Hubbard N, Morris JH. **The nature of thrombosis induced by platinum and tungsten coils in saccular aneurysms.** *AJNR Am J Neuroradiol* 1997;18:29–24
93. Reul J, Weis J, Spetzger U, et al.**Long-term angiographic and histopathologic findings in experimental aneurysms of the carotid bifurcation embolized with platinum and tungsten coils.** *AJNR Am J Neuroradiol* 1997;18:35–42

94. Derdeyn CP, Moran CJ, Cross DT, et al.**Polyvinyl alcohol particle size and suspension characteristics.** *AJNR Am J Neuroradiol* 1995;16:1335–1343
95. Turk AS, Strother CM, Crouthamel DI, Zagzebski JA. **Definition of the ostium (Neck) of an aneurysm revealed by intravascular sonogrphy: an experimental study in canines.** *AJNR Am J Neuroradiol* 1999;20:1301–1308
96. Jeffree MA, Byrne JV, Royston DD, et al.**The porous guidewire-directed detachable aneurysm liner: a new concept in the endovascular treatment of intracranial aneurysms.** *AJNR Am J Neuroradiol* 1999;20:774–779
97. Wikholm G, Lundqvist C, Svendsen P. **Transarterial embolization of cerebral arteriovenous malformations: improvement of results with experience.** *AJNR Am J Neuroradiol* 1995;16:1811–1817