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Special Article

Interventional Neuroradiology: A Neurosurgeon's Perspective

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I am grateful to Dr. Juan Taveras, founding editor of the *American Journal of Neuroradiology*, and to Dr. Michael Huckman, current editor of the Journal, for this opportunity to comment on the present status of interventional neuroradiology, a field in which I was once engaged and have subsequently followed for many years. As requested, I will emphasize the early development of the endovascular approach. Considerations at that time are in certain respects pertinent today. Because the present-day relationship between interventional neuroradiology and neurosurgical practice in the United States has not been fully examined, I polled the program directors in neurosurgery to gain some information as to the nature of this relationship at their centers. Such information may be helpful for formulating the most appropriate relationship for the future.

Historical Background

The endovascular approach was an outgrowth of the limited state of our knowledge and surgical techniques in the late 1950s and early 1960s. At that time the importance of vasospasm was hardly recognized, a diversity of aneurysm clips was not available, and the operating microscope was not in general use. The importance of clinical grading following aneurysmal subarachnoid hemorrhage was only beginning to be appreciated. Aneurysms of the vertebrobasilar system were generally regarded as unapproachable except in a few instances. The operative mortality for aneurysms exceeded 30% in most centers. Although there were reports of successful excision of medium-sized and, occasionally, large cerebral AVMs, these were scattered; most such lesions were regarded as unsuitable for total removal. Proximal ligation of the internal carotid artery for internal carotid artery aneurysms and for some AVMs was the management of choice in many centers. Compared with its use today, the exovascular approach was hardly satisfactory, so an alternative, endovascular approach was pursued.

For certain large cerebral AVMs an endovascular approach could be achieved by utilizing the differential blood flow and size among the enlarged feeding arteries, normal arteries, and the abnormal vascular channels at the origins of the fistulous sites [1]. Initially, the procedure was called "artificial embolization." Subsequently, and more appropriately, it became known as "surgical embolization." Many embolic materials were tested, including Gelfoam, muscle, various connective tissues, and plastic. Silastic spheres became the standard because they could be easily manufactured in molds to the appropriate sizes for each case. When size was accurate, an occlusion could be affected precisely at the site of the fistula. When large emboli passed through the fistulas, the emboli were tethered with silk sutures and held in place to permit completion of the process. The sites of arrest for each size became predictable, and transient complications from aberrant emboli, or those arresting too proximally, became rare. It was demonstrated in animals that the response of cortical arteries to embolic obstruction was immediate dilatation, and

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in patients this was confirmed when proximally arrested emboli passed into AVMs in a delayed fashion [2].

After initial successes with these flow-directed emboli the procedure was extended to the external carotid territory to include glomus jugulare tumors, meningiomas at the skull base, angiofibromas of the face and neck, and various extracranial and dural fistulas. A large internal carotid cavernous fistula was managed with a tethered embolus.

A few giant aneurysms of the middle cerebral artery were treated by flow-directed emboli but it was apparent from the outset that controlled catheterization with inflatable balloons would be necessary [3]. Although this type of procedure introduced new technique challenges, the primary concern was whether the cerebral arteries would, in fact, tolerate the necessary intravascular manipulation. This was first tested by allowing tethered emboli to pass to the distal sylvian arteries in AVM cases and then withdrawing them. After further testing in various models and animals, it was obvious that to traverse the siphon one had to rely on the force of flow alone. Various Silastic catheters were designed and, finally, with the aid of the Heyer-Schulte Corporation of California, inflatable balloon catheters were made for clinical trial [4]. These included inflatable hollow cylinders that could line the arterial walls and allow continuation of flow. Although the use of magnetic fields for directing the catheter tips was explored, it was certain that flow-directed catheters could reach the terminus of the middle cerebral artery in most cases.

This endovascular approach for aneurysm treatment reached limited clinical trial [5]. However, technical support at the time was sparse and a steady improvement in exovascular techniques was simultaneously in progress, accelerated by the use of the operating microscope and the perfection of more suitable aneurysm clips. It was our judgment that catheter techniques for an endovascular approach would not keep pace with this progress, and hence their use would be restricted mostly to proximal, single-site fistulas. However, for the AVMs we believed that the endovascular approach would continue to have a significant role when closely integrated with the conventional surgical techniques, also rapidly improving at the time [6–8].

I have always regarded Djindjian, in Paris, as the pioneer in initiating superselective catheter techniques through his efforts involving the external carotid artery territory [9]. De Brun, then in France, devised a detachable balloon catheter for internal carotid cavernous fistulas independent of, but later than, the work in the Soviet Union [10].

During the 1960s there was limited medical exchange between the United States and the Soviet Union. Although they were receiving some of our publications, we received almost none of theirs. Only in subsequent years was the parallel development in the Soviet Union appreciated. In the early 1960s their efforts were directed toward the treatment of internal carotid artery-cavernous sinus fistulas with balloon catheters, following a lead from Brooks's 1932 description of a case in which he had inserted muscle into the internal carotid artery. Upon our demonstration of the suitability of the cerebral arteries for intravascular manipulation, the Soviet investigators were encouraged to extend their balloon technology distally [11]. It is my perception that Serbinenko and co-workers in Moscow persisted through the frustrating technological barriers of the time, because experience with the rapidly evolving exovascular approaches lagged somewhat in the Soviet Union and may not have presented as favorable an alternative.

After the early 1970s, endovascular techniques, along with diagnostic angiography, became part of innovative catheter techniques in radiology. This brought various advantages for endovascular therapy, particularly for the cerebral AVMs. It became possible to selectively occlude more of the smaller arteries to AVMs, and thus a greater number of the smaller and slow-flow lesions became suitable for endovascular treatment. To compensate for the limited luminal size of the catheters, particulate emboli were replaced by inflatable balloons and injectable liquid substances to offer a greater potential for widespread thrombosis within the AVM. This technology, along with an acquired skill in catheter manipulation from a transfemoral entry, became the basis for the field of interventional neuroradiology. Because of frequent changes in catheters and injectable thrombosing agents, most formal reports were anecdotal. At present there seems to be a move toward standardization, but most of the techniques remain experimental.

This evolution of interventional neuroradiology carried with it an array of new and serious clinical complications, considered to be justified by the seriousness of the diseases being treated.

There is practically no accurate information about the interrelationship between the practice of neurosurgery and interventional neuroradiology. Directors of the neurosurgical programs in the United States were polled by questionnaire, and the responses from 75 are tabulated in Table 1.

The Relationship Between Interventional Neuroradiology and Neurosurgery in University Hospitals

Endovascular procedures are carried out from time to time at nearly all centers, but there is considerable variation in their application and varying degrees of skill among the interventionalists in terms of their ability to manipulate the catheters. Over half of the centers have a designated interventionalist; in the remainder the procedures are carried out occasionally by neuroradiologists with some catheter experience, by teams consisting of neurosurgeons and neuroradiologists, or, in one institution, by neurosurgeons alone. In 18% of the centers the interventionalists have joint appointments in radiology and neurosurgery; in 11% they have had supplemental clinical training in either neurosurgery or neurology. In more than half of the institutions, the interventional neuroradiologists consult on patients independent of the neurosurgeons, but it is not certain whether this is mostly for extracranial lesions, such as angiofibromas, and other vascular lesions of the head that are referred from other specialties.

The interventional neuroradiologists have privileges to admit patients in 14% of the responding institutions, but presumably these patients are primarily under the care of clinicians.

TABLE 1: Neurosurgery and Interventional Neuroradiology in 75 University Hospitals

Designated INR in teaching institutions or major affiliates (two institutions have three)		54%
In 36 institutions with no designated INR, procedures are done occasionally by:		
Neuroradiologist	9	
Neurosurgeons	1	
Neurosurgeons + neuroradiologist	9	
Neuroradiologist + referred	13	
All referred elsewhere	4	
Not done	0	
INR has an academic appointment in:		
Radiology		80%
Neurosurgery		2%
Both		18%
Neuroradiologist or INR has some formal training in:		
Neurosurgery		8%
Neurology		3%
Only in neuroradiology and fellowships		89%
INR consults on patients independent of neurosurgery		54%
INR carries out procedures without neurosurgical input		30%
INR has privileges to admit patients to hospital		14%
Anesthesia service monitors procedures in radiology suite or operating room		75%
Neurosurgeon monitors procedures:		
Almost always or always		72%
Occasionally		21%
Never		7%
Neurosurgeon participates in selection of interventional techniques:		
Almost always or always		69%
Occasionally		29%
Never		2%
Immediate results of procedures are known to neurosurgeon and collected for statistical purposes (collected but not for statistics = 2)		70%
Neurosurgeon follows patients, and complications are known:		
All patients		55%
Only neurosurgical patients		45%
INR is considered an important adjunct for management of:		
CCFs		100%
AVMs		93%
Aneurysms		60%
Certain tumors		89%
(also vasospasm = 2)		
At present neurosurgeons regard interventional neuroradiology as:		
An extension of neurosurgery		18%
An extension of neuroradiology		18%
An independent specialty		8%
An extension of both neurosurgery and neuroradiology		48%
A specialty and extension of neurosurgery		1%
Undecided		8%

Note.—INR = interventional neuroradiologist.

Anesthesia service monitors the procedures in the radiology suite or operating room 75% of the time, and neurosurgeons monitor the procedures and participate in the selection of techniques in almost all the neurosurgical patients. In 70% of the institutions the immediate results of procedures are known and collected for statistical purposes by neurosurgeons. A few respondents indicated that the results are known but not collected for statistical purposes. The poll did not specifically inquire whether these statistics became a part of neurosurgical statistics or remained solely within the department of radiology. Although the neurosurgery department appears to have full knowledge of the therapeutic outcome in all of its patients, the outcomes in the others may not be known to them. For example, a patient with a basilar aneurysm could be referred for treatment to an interventionalist by an internist or neurologist and thereafter referred back with a satisfactory or unsatisfactory result without any neurosurgical participation or knowledge.

All the responding program directors agreed that interventional neuroradiology is an important adjunct for the management of internal carotid cavernous fistulas. Ninety-three percent thought that it contributed to the management of cerebral AVMs, and 89% indicated that it helps in the surgery of certain tumors. Sixty percent agreed that it contributed to aneurysm management in general, but presumably this referred to certain giant aneurysms and to others on the posterior circulation. Two respondents added that it contributed to the management of vasospasm, although this question was not asked in the survey.

Eighteen percent of program directors perceived interventional neuroradiology as an extension of neurosurgery, and an equal percent saw it as an extension of radiology; however, a far greater percent believed it was more appropriately an extension of both.

Patient Management and Interventional Neuroradiology

There have been several proposals for the future direction of interventional neuroradiology [12]. These include the establishment of minimal standards for the acquisition of technical skills or expertise (e.g., fellowships at established centers) and additional clinical training exposure comparable to 1 or 2 years of clinical neurosurgery leading to subspecialty certification within radiology. A further extension would establish interventional neuroradiology as an independent specialty with its own clinical services and facilities [13]. Finally, an avenue should be open for those qualified in neurosurgery to enter the field after additional years of formal training in radiology.

For background comparison it may be useful to examine two other areas of interventional radiology—coronary artery angioplasty and peripheral vascular angioplasty—that also evolved from diagnostic angiography. These areas differ from interventional neuroradiology in that the volume of clinical need is considerably greater and the technical problems far less complex. Coronary artery angioplasty settled within the domain of cardiology alone, and the needed catheter skill was acquired by preceptorship as part of a cardiology fellowship. In contrast, peripheral vascular angioplasty has remained within radiology and at present is the definitive management for approximately 40–50% of patients with lower-extremity occlusive disease. Further, in many centers, this interventionalist is the primary point for referral and management decisions; that is, angioplasty versus endarterectomy/bypass.

Although endovascular techniques for neurosurgical problems predated angioplasty, the interspecialty status is not as well established. In addition, the equipment, including catheters and embolic materials, have not reached a satisfactory state of standardization and most procedures are, or should be, carried out under experimental protocol. The thrust of interventional neuroradiology remains one of expectation. It may be useful, therefore, to examine some of the important areas in which interventional neuroradiology is participating.

Internal carotid artery angioplasty, by present techniques, carries too great a risk for general use and is restricted to rare instances of intimal hyperplasia. For testing the tolerance of internal carotid artery occlusion, intraluminal balloon occlusion is quite certainly the preferred method. For single-site fistulas of the vertebral or proximal internal carotid arteries, endovascular techniques have been a therapeutic success and can now be regarded as the standard for management.

The adjunctive use of endovascular techniques within the entire anatomic spectrum of the cerebral AVMs may have some applicability in approximately half, or 1200, of the 2400 or so newly diagnosed cases yearly. The group of AVMs in which endovascular techniques have had the greatest success for total obliteration includes those AVMs in which surgical obliteration is comparatively straightforward with negligible risk. For the remainder, the most highly perfected microcatheter techniques may be able to effect total obliteration in approximately 10%. The anatomic diversity of the remaining lesions is beyond the limitations inherent in the methodology.

The most important question is whether therapeutic gain corresponds to the degree of apparent angiographic reduction. For certain large and inoperable AVMs this quite certainly is the case, since early neurological deterioration can be reversed and its subsequent progression forestalled. However, there is no reason to hope that anatomically altering any one lesion, to any degree, by endovascular techniques significantly alters its potential for bleeding. Also, there is a small but significant number of occurrences of bleeding during and immediately after embolization that may be the result of an increased perfusion pressure transmitted to residual portions of the lesion. Studies to find a correlation between varying degrees of endovascular obliteration and bleeding rate are an impractical undertaking at this time. The most important therapeutic objective for endovascular techniques for AVMs remains the temporary conversion of inoperable lesions to a state of operative feasibility.

A small group of lesions, mostly large or giant aneurysms on the vertebrobasilar and proximal internal carotid circulations, is suitable for selective ballooning, with or without simultaneous occlusion of the parent artery. It is possible that the effectiveness of this in terms of mortality and morbidity is equal to or better than direct surgery in the most experienced hands.

The impetus for extending endovascular techniques to include a considerably wider range of aneurysms, particularly those on the anterior circulation, comes from the experiences of Romadanov and Scheglov at the Neurological Institute in Kiev [14]. There, the endovascular approach has been the primary method of management for many years. Their technique requires the crafting of detachable balloons to conform to the individual characteristics of each aneurysm. At last report, ballooning had been attempted in 617 of 725 patients, with good or satisfactory occlusion achieved in 80% [15]. The mortality was 5.4%. In contrast, Serbinenko at the Burdenko Neurological Institute in Moscow now employs endovascular techniques in only 14% of all aneurysms encountered or those considered to be unclippable [16]. Further, many of these cases required preliminary bypass surgery because of the possibility of parent artery occlusion. Success was achieved in most with a mortality of 7.5%. Neither of these series offers important data concerning the long-term fate of ballooned aneurysms. Hence, the permanency of the occlusion remains uncertain. Also, the series mostly included quiescent aneurysms, management of which is no longer an important problem for neurosurgery. It is unlikely, therefore, that endovascular techniques will advance to an important place in overall aneurysm management as it is currently practiced in the United States.

Recommendations for the Future of Endovascular Therapy

At present there is less than optimal standardization and testing of the equipment and materials employed in endovascular procedures, a shortcoming that may account for most of the complications and failures. This problem should steadily resolve.

An interval of approved training at an established center in the form of a structured fellowship should be mandatory before an interventionist can assume procedure responsibility. Training beyond this (i.e., clinical) would not be useful in my opinion. One or two years on a neurosurgical service would not qualify a trainee for unsupervised patient care responsibilities and most of the knowledge acquired would not be pertinent.

There should be rigid criteria for determining the success, failure, and morbidity of each interventional procedure measured against preset objectives within the context of total patient care. For example, inability to occlude a particular arterial feeder when this is a preset goal should be recorded as a procedural failure. Only complete angiographic obliteration of an aneurysm is a success, and "good" occlusion or "near complete" occlusion are also procedural failures. The end point of an AVM embolization procedure should conform to neurosurgical need, which is not always the same as measured angiographic reduction.

The important point is that the mortality and morbidity of endovascular procedures are too high and must be reduced to nearly zero, because the overall methodology does not offer a sufficient chance of "cure" or long-term therapeutic gain to justify significant risk. It is inappropriate for a patient to face two management risks; that is, an endovascular risk followed by a surgical risk.

The future of endovascular therapy requires closer integration with neurosurgery with the interventionist becoming a member of the neurosurgical team. This will become even more important if endovascular techniques for vasospasm are explored. The greatest mistake for the future would be directing interventional neuroradiology toward a competitive form of definitive management independently offered to patients as a treatment alternative.

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The reader's attention is directed to the commentary on this article, which appears on the following pages.