

The History of “Endovascular Surgical Neuroradiology” in the United States from a Neurological Perspective

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Abstract

Background— Endovascular surgical neuroradiology uses minimally invasive techniques to treat cerebrovascular diseases. Although radiologists and neurosurgeons made significant contribution to this field, the role of neurologists has been increased over the past few decades.

Purpose— This article aims to review the endovascular surgical neuroradiology from a neurological standpoint and to elaborate the significant involvement and contribution of the neurologists to this field along with discussing the initial challenges until endovascular surgical neuroradiology became recognized by Accreditation Council for Graduate Medical Education (ACGME) as a fellowship training opportunity for neurologists.

Results— Currently, there are different pathways for neurologists to apply for the fellowship programs, resulting in an increased number of neurologists in training and practice. Upon completion of neurology residency, neurologists are required to complete a fellowship in either vascular neurology or neurocritical care in order to become eligible to apply for endovascular surgical neuroradiology fellowship.

Summary— Endovascular surgical neuroradiology has been evolved over time. Neurologists have made a significant influence on this field.

Keywords— History, Current Status, Endovascular Neurosurgery, Neurologists, Pioneers, Challenges, ACGME Approval, fellowship programs, Training, AAN, SNIS, SVIN, CAST.

BACKGROUND

The world of medicine has grown through the strength and determination of pioneers who developed an understanding of many diseases affecting humans or inventing new diagnostic and/or therapeutic procedures.¹ Of these, endovascular surgical neuroradiology is a subspecialty that offers minimally invasive techniques instead of surgical approaches.² Over the years, the terms endovascular neurosurgery, interventional neurology, interventional neuroradiology, neuro-interventional radiology, neuro-endovascular surgery, endovascular

surgical neurology and endovascular surgical neuroradiology have been used interchangeably.³ In the past decades, endovascular surgical neuroradiology has transformed rapidly through advances in devices and techniques. There are numerous applications for endovascular surgical neuroradiology such as diagnostic angiography of brain and spine, aneurysm embolization, embolization treatment for arteriovenous malformations (AVMs) and tumors of head/neck and spine, thrombectomy and intra-arterial infusion of medications (verapamil for vasospasm, WADA for provocative testing).⁴⁻¹⁰

New potential applications are still being developed in this field of medicine.¹¹

The role of neurologists in these procedures, however, has traditionally been limited. First of all, these procedures required radiographic imaging which typically fell under the purview of the department of radiology. Furthermore, when neurosurgeons began to perform these procedures, they shared the same benefit as cardiologists did in the performance of interventional cardiology i.e., they were often on the front lines of the continuum, and if a neurosurgeon was trained to perform angiography along with surgery, he could support the entire patient management. With time, the role of neurologists became more prominent.

The main purpose of this article is to review the history and status of endovascular surgical neuroradiology from a neurological standpoint and to elaborate the increased contribution of neurologists in this field over the past few decades. The article also describes the many challenges faced by neurologists until the field of endovascular surgical neuroradiology officially recognized their participation. In the end, opportunities and inquiries for endovascular surgical neuroradiology fellowship programs are highlighted.

THE BEGINNING OF A NEW ERA

The field of endovascular surgical neuroradiology was born in 1927 when a Portuguese neurologist, Egas Moniz, performed the first successful cerebral angiogram. Moniz, who had graduated from the University of Coimbra Medical School in Portugal, traveled to France to pursue specialty training in neurology, counting Joseph F. Babinski among his mentors. After a role in politics during World War I as Portugal's ambassador to Spain and subsequently as Portugal's Minister for Foreign Affairs, Muniz returned to academics in 1918, focusing initially on the study of the vasculature of the head and neck. He visualized these structures by injecting lithium bromide into cadavers, a procedure he termed "encéphalographie artérielle" (arterial encephalography).¹² As he transitioned his experiments from cadavers and dogs to humans, he abandoned lithium bromide as a radiographic contrast agent (which patients did not tolerate) in favor of sodium iodide. Moniz was still unable to properly opacify the cerebral vasculature on radiographs. Unfortunately, the difficulties in imaging were confounded by significant complications including one patient's death due to acute cerebral thrombosis eight hours after the angiography.^{12,13} Finally, on June 28, 1927, after eight failed attempts, he performed the first successful cerebral angiogram on a 20-year-old man with a pituitary tumor. Moniz eventually returned to Portugal and became a professor at his alma mater, and ultimately retired as the chair of the neurology department at the University of Lisbon in 1945. Moniz's legacy of radiographic imaging the arteries of the head and neck and contrast agents has endured, and the field has benefited from advances in arterial access, device development and radiographic techniques.^{12,13} The 1990s was one of the most significant periods in the history of endovascular surgical neuroradiology.¹⁴ Up until then, the neurologists in the United States had not trained and thus could not perform neurovascular interventions. "Interventional Neurology" was

first coined and proposed as a neurology subspecialty field in a paper in Neurology in 1993 by Dr. Shashidhar Kori, a neurologist from the University of South Florida, who was primarily focused on pain intervention.¹⁵ With the advent of intravenous thrombolysis for acute ischemic stroke, a sense of urgency emerged, which propelled many neurologists to gravitate toward the care of patients with acute cerebrovascular disease.¹⁶⁻²³ Dr. Camilo R. Gomez and his colleagues introduced the phrase "Time is Brain!" in the early 1990s which was an argument for the urge to accelerate the treatment of patients with signs of stroke. He also announced one of the first experiences using a "Code Stroke" system for managing acute stroke patients.^{24,25}

MILESTONES IN TECHNOLOGICAL ADVANCEMENTS

Endovascular surgical neuroradiology has been evolved over time in terms of techniques. In the field of ischemic stroke,²⁶ endovascular thrombectomy, alone or in combination with intravenous thrombolysis was recommended as the standard management for selected types of stroke.²⁷⁻²⁹ The advancement of digital subtraction angiography for both diagnosis and treatment of neurovascular diseases,³⁰ along with interventional advancements, led to the introduction and the United States Food and Drug Administration (US FDA) approval of US FDA-approved first-generation clot retrieval devices such as Merci® Retrieval system (Stryker Neurovascular, Fremont, CA, USA).^{31,32} With time, modern stent retrievers such as Trevo® and Solitaire™ stents were established with higher clinical efficacy and lower rates of complications.³³⁻³⁵

PIONEERS AND CHALLENGES

Neurologists contributed significantly to the field of endovascular surgical neuroradiology through caring for patients, developing procedures, conducting clinical trials, and training future leaders in endovascular surgical neuroradiology. Here are stories of some outstanding pioneers, many of whom overcame many obstacles in the pursuit of their career.

Dr. Gomez was one of the early experts in this field in the United States. He completed his neurology residency at Saint Louis University in Missouri following by completing an informal training through the interventional cardiology program since there was no official endovascular surgical neuroradiology program available in the United States at that time.³⁶

Dr. Rüdiger von Kummer from Germany, the other pioneer, who was a neurologist trained in radiology and endovascular surgical neuroradiology, led some of the most important interventional and stroke trials in the 1990s and 2000s (ECASS-1, -2 and -3, DIAS). A peer of Dr. Kummer is Dr. Shakir Husain from India who was trained at the University of Zurich and returned to India to train over 60 fellows in this field. During the 1990s there were several other neurologists who trained in endovascular surgical neuroradiology by completing full radiology residencies and then endovascular surgical neuroradiology fellowships. For example, Dr. Arani Bose as a neurologist made a significant contribution to this field by

developing devices for use in intracranial stenosis and acute ischemic stroke. He was certified by both the American Board of Radiology and the American Board of Psychiatry and Neurology. He co-founded SMART Therapeutics and Penumbra device (Penumbra, Inc., Alameda, CA, USA), two leading interventional device manufacturers. Their products included “Wingspan Stent (2005)”³⁷ for treating intracranial stenosis and “Neuroform Stent (2007)”³⁸ for treating intracranial aneurysms. Dr. Bose became a neuro-interventionalist with an academic appointment at New York University.^{14,39} Another respected pioneer, Dr. Adnan I. Qureshi had completed his neurology residency at Emory University followed by the neurocritical care fellowship at Johns Hopkins University. Dr. Qureshi along with Dr. Edgard Pereira was one of the first neurologists who completed a formal fellowship program in endovascular surgical neuroradiology at the University at Buffalo (State University of New York at Buffalo) in 2000 and became one of the first endovascular surgical neuroradiology graduates in the United States. This fellowship program was directed by Dr. L. Nelson Hopkins, a neurosurgeon who is recognized as the initiator of the modern discipline of endovascular surgical neuroradiology. By joining the fellowship program, Dr. Qureshi could be trained together with other neurosurgical fellows including those who became leaders in this field. In 2002, Dr. Qureshi joined the University of Medicine and Dentistry of New Jersey and initiated an endovascular surgical neuroradiology program where Dr. Andrew Xavier and Dr. Jawad F. Kirmani were two of his first fellows who completed the program in 2005. Dr. Nazli Janjua, one of his fellows, was one of the first women to complete endovascular surgical neuroradiology fellowship program. Soon afterward, an endovascular surgical neuroradiology fellowship was initiated by Dr. Qureshi at the University of Minnesota.¹⁵

Being a pioneer of carotid stent placement, Dr. Sidharth S. Yadav graduated from the Duke University Internal Medicine residency program. While being at Duke University, he completed his neurology residency followed by a neuroimaging fellowship at Dent Neurological Institute in Buffalo, New York.³⁶ Dr. Yadav was interested in performing diagnostic and therapeutic procedures through the endovascular approach. He underwent a hybrid training with interventional cardiology. Thereby, he completed a fellowship in general cardiology and interventional cardiology at the University of Alabama. In 2004, Dr. Yadav conducted the SAPHIRE trial (Stenting and Angioplasty with Protection in Patients at High Risk for Endarterectomy).²⁴ The purpose of this trial was to compare the outcome of carotid artery stent placement with an embolic protection device versus carotid endarterectomy in patients with either symptomatic carotid artery stenosis of at least 50 percent of the luminal diameter or asymptomatic stenosis of at least 80 percent who were at high risk for endarterectomy as defined by various physiologic and anatomic criteria. Dr. Yadav designed and used the self-expanding filter as a distal embolic-protection device, which came to be known as the Angioguard® XP (Cordis, Warren, NJ).²⁵ He was one of the first interventional neurology section chairpersons of the American academic of neurology. A similar story belongs to Dr. Peter Kim Nelson who had to switch from neurology to radiology to facilitate his entry into neuro-interventional pro-

cedures. He was the first person to start the ACGME program of Neurology, Radiology and Neuroradiology at New York University. One of the prominent pioneers who is known for his introduction of the “First Pass Effect” concept in mechanical thrombectomy which led to the “Revascularization Grading” consensus group of the field of endovascular surgical neuroradiology, is Dr. Osama Zaidat. He is another neurology-trained interventionist who completed endovascular surgical neuroradiology fellowship at Duke University, Durham, NC and started one of the first ACGME accredited training programs in this field at the Medical College of Wisconsin (MCW). Dr. Brian-Fred M. Fitzsimmons was the first fellowship program director at MCW. MCW has trained more than 15 neuro-interventionists. Dr. Zaidat sits on the joint commission technical advisory board for the comprehensive stroke centers as well as the Co-Chair of the endovascular committee for the Stroke Net National Institute of Health Consortium. Dr. Zaidat again was the lead principal investigator of the paramount trials including the VISSIT intracranial stenosis randomized clinical trial published in Journal of American Medical Association.⁴⁰

THE PATH TO THE ACGME APPROVAL

The one main event which led to the increase in training of neurologists was the creation of official board certification for vascular (previously called stroke) neurology. The motivation of this came from Dr. Alex Abou-Chebl who became the first recipient of the Egaz Moniz fellowship in endovascular surgical neuroradiology, sponsored by the American Society of Neuroimaging (ASN). He was a neurologist at the Cleveland Clinic who wanted to start training in endovascular surgical neuroradiology in 1999 but, like his contemporary neurologists, was unable to proceed. He started training with another important neurologist in the development of the specialty, Dr. Jay S. Yadav who has trained in both neurology and interventional cardiology. Drs. Lawrence Wechsler and Camilo Gomez, along with Cleveland Clinic stroke program director Dr. Anthony Furlan lobbied for the creation of an ACGME approved endovascular surgical neuroradiology fellowship, which in turn necessitated the creation of ACGME approval for vascular neurology. These attempts were blocked by some very prominent radiological organizations. The initial approval from ACGME did not specifically mention the eligibility of neurologist. A major effort by Drs. Furlan, Wechsler, Gomez, and Qureshi resulted in incorporation of neurologists as being eligible for the ACGME accredited programs in 2003 and consequently, the field of endovascular surgical neuroradiology was officially created. Thereby Dr. Qureshi became the first-ever neurologist as a program director of an accredited endovascular surgical neuroradiology fellowship program.¹⁵

ORGANIZATIONAL GROWTH

There have been two organizations in the United States that have exceptionally been helpful. The first organization is the Society of Neuro-interventional Surgery (SNIS), which was founded in the early 1990s. The first SNIS president was Dr. Charles Milton Strother in 1992, who was a professor emeritus of radiology at the University of Wisconsin. Although there

TABLE 1: List of SVIN presidents.

Adnan I. Qureshi (Founder)	Residency at Emory University Fellowship in Neurocritical Care at Johns Hopkins University Fellowship in Endovascular Surgical Neuroradiology at State University of New York at Buffalo
Osama O. Zaidat	Residency at Case Western Reserve University Fellowship in Vascular Neurology at Case Western Reserve University Fellowship in Neurocritical Care at Case Western Reserve University Fellowship in Endovascular Surgical Neuroradiology at Duke University
Dileep Yavagal	Residency at Harvard Medical School Fellowship in Neurocritical Care at Columbia University Fellowship in Endovascular Surgical Neuroradiology at University of California, Los Angeles
Tudor Jovin	Residency at Pennsylvania Hospital, Philadelphia, PA Fellowship in Vascular Neurology at University of Pittsburgh Medical Center, Pittsburgh, PA Fellowship in Endovascular Surgical Neuroradiology at University of Pittsburgh Medical Center, Pittsburgh, PA
Raul Noguiera	Residency at Harvard Medical School Fellowship in Neurocritical Care at Harvard Medical School Fellowship in Vascular Neurology at Harvard Medical School Fellowship in Endovascular Surgical Neuroradiology at Harvard Medical School
David Liebeskind	Residency at University of California, Los Angeles Fellowship in Vascular Neurology at University of California, Los Angeles
Italo Linfante (Current president)	Residency at Baylor College of Medicine Fellowship in Vascular Neurology at Harvard Medical School Fellowship in Endovascular Surgical Neuroradiology at Harvard Medical School and University of Miami

TABLE 2: List of additional SVIN founders & major contributors.

Jawad F. Kirmani	Residency at Ohio State University Fellowship in Neurocritical Care at State University of New York at Buffalo Fellowship in Vascular Neurology at State University of New York at Buffalo Fellowship in Endovascular Surgical Neuroradiology at University of Medicine and Dentistry of New Jersey
Andrew Xavier	Residency at Mount Sinai School of Medicine Fellowship in Vascular Neurology at State University of New York at Buffalo Fellowship in Endovascular Surgical Neuroradiology at University of Medicine and Dentistry of New Jersey
Nazli Janjua	Residency at University of Chicago Fellowship in Vascular Neurology at Columbia University Fellowship in Endovascular Surgical Neuroradiology at University of Medicine and Dentistry of New Jersey
Alex Abou Chebl	Residency at Tufts University Fellowship in Vascular Neurology at Cleveland Clinic Foundation Fellowship in Neurocritical Care at Cleveland Clinic Foundation Fellowship in Endovascular Surgical Neuroradiology at Cleveland Clinic Foundation
Thanh Nguyen	Residency at McGill University Faculty of Medicine in Canada Fellowship in Vascular Neurology at Harvard Medical School Fellowship in Neurocritical Care at Harvard Medical School Fellowship in Endovascular Surgical Neuroradiology at Centre Hospitalier de l'Universite de Montreal
Vallabh Janardhan	Residency at Boston University Fellowship in Neuroimaging at Dent Neurologic Institute Fellowship in Vascular Neurology at Harvard Medical School Fellowship in Neurocritical Care at Harvard Medical School Fellowship: Endovascular Surgical Neuroradiology at Cornell & Columbia Universities

TABLE 3: Milestones in the history of endovascular surgical neuroradiology.

Year	Individuals	Event
1993	Shashidhar Kori	"Interventional Neurology" was first coined and proposed as a neurology subspecialty in a paper in "Neurology"
Early 1990s	Camilo Gomez	Introduced the phrase "Time is Brain!" and "Code Stroke" system for managing stroke patients
1998		Formal training program for neurologists
2000	Adnan I. Qureshi, Edgar L. Pereira	First neurologists who completed formal fellowship program in Endovascular Surgical Neuroradiology at University at Buffalo
2000		"Endovascular Surgical Neuroradiology" program accredited by ACGME
2003		ACGME-accreditation recognized a pathway for neurology residents
2003	Adnan I. Qureshi	First neurology program in endovascular surgical neuroradiology
2003		Formal Endovascular Surgical Neuroradiology program for the first time -please check
2004	S. Yadav	The SAPPHERE trial
2005	Arani Bose	Wingspan Stent for treatment of intracranial atherosclerosis
2006		A group of interventional neurologists met in New York and created SVIN with its founder, Dr. Adnan Qureshi and Vice President, Dr. Alex Abou-Chebl.
2007	Arani Bose	Neuroform Stent for treating intracranial aneurysms
2007		ACGME-accreditation recognizes neurologists as program director
2008	Adnan I. Qureshi	First neurology program was accredited by ACGME
2013	Xinfeng Liu and Michael G.M. Hennerici	SVIN has created an official peer-reviewed journal of "Interventional Neurology"

have not been female presidents of this society so far, Drs. Nazli Janjua, Thanh Nguyen, and Robin Novakovic chaired the scientific annual meetings as women neurologists.⁴¹ The peer-reviewed journal which is associated with SNIS is the Journal of Neuro Interventional Surgery, launched on July 01, 2009.⁴² The second organization which has also been very supportive and helpful in the growth of this field is the Society of Vascular and Interventional Neurology (SVIN). In 2006, a group of almost every interventional neurologist in the world met in New York and created SVIN with its founder, Dr. Qureshi and Vice President, Dr. Abou-Chebl. Dr. Qureshi's first few trained fellows (Andrew Xavier, Jawad F. Kirmani, and Nazli Janjua), and some of the other endovascular surgical neuroradiology trained neurologists of that time (see table 1 and 2) became a part of the founding officers.

Dr. Raul Nogueira, former president of SVIN and professor of Neurology at Emory University, stated in his blog that "despite a relatively young existence, our scientific contributions have been remarkable". One of the main activities of SVIN is publication of clinical and training guidelines, and advocacies.⁴¹ Some of the revolutionary studies in the field of vascular neurology such as Interventional Management of Stroke (IMS) III, Vitesse Intracranial Stent Study for Ischemic Stroke Therapy (VISSIT), Mechanical Retrieval and Recanalization

of Stroke Clots Using Embolectomy (MR RESCUE), The Endovascular Treatment for Small Core and Anterior Circulation Proximal Occlusion with Emphasis on Minimizing CT to Recanalization Times (ESCAPE), Solitaire™ FR With the Intention For Thrombectomy as Primary Endovascular Treatment for Acute Ischemic Stroke (SWIFT PRIME) and Diffusion Weighted Imaging (DWI) or Computerized Tomography Perfusion (CTP) Assessment With Clinical Mismatch in the Triage of Wake Up and Late Presenting Strokes Undergoing Neurointervention (DAWN) clinical trials have been performed by the executive members of SVIN.^{40,43-49} Looking at the clinical trials being performed by the endovascular neurologists in the past decades clearly indicates their significant contribution to this field. SVIN has also created an official peer-reviewed journal of Interventional Neurology since 2013 by Dr. Xinfeng Liu (Nanjing University, Nanjing, China) and Dr. Michael G. Hennerici (University Medical Centre Mannheim, Mannheim, Germany). Another important activity of the SVIN is promoting collaboration with other societies such as the American Academy of Neurology.^{41,50}

ENDOVASCULAR SURGICAL NEURORADIOLOGY FELLOWSHIP PROGRAMS

There are two pathways for neurologists to apply for the endovascular surgical neuroradiology fellowship. After completing the neurology program, the candidates either need to complete a vascular neurology fellowship which is traditionally one year (or two years where the second year is mainly research), or complete a neurocritical care fellowship which is a two-year program.⁴¹ Since some overlaps occur, some programs offer a combined fellowship which contains all three fellowships (vascular neurology, neurocritical care, and endovascular surgical neuroradiology). This pathway can be completed in four years. Traditionally, applicants have a higher possibility of acceptance if they apply for a combined program where they complete either vascular and/or neurocritical care at the same institution in which they are going to train in endovascular surgical neuroradiology fellowship. The training guidelines required for endovascular surgical neuroradiology have been created and implemented by four neurosciences organizations⁵¹:

American Academy of Neurology (AAN), American Association of Neurological Surgeons/Cerebrovascular Section (AANS/CNS), Society of Neuro Interventional Surgery (SNIS), and Society of Vascular & Interventional Neurology (SVIN).

The Committee on Advanced Subspecialty Training (CAST) functions under the council of The Society of Neurological Surgeons. This society helps neurologists to be able to graduate from an endovascular surgical neuroradiology fellowship program and is responsible for accreditation and updating the subspecialty training requirements.^{49,50} The CAST committee members consist of neurologists including Drs. Tudor Jovin, Osama Zaidat and Italo Linfante as well as neurosurgeons including Drs. Howard Riina, Adnan Siddiqui, and Brian Ho along with neuro radiologists including Drs. Colin Derdeyn, Philip Meyer, and Aquilla Turk. The following are some of the major requirements by the CAST.^{41,50,52}

1. Preliminary Training:

- Satisfactory completion of an ACGME-approved residency in neurology.
- Eligibility for certification by the American Board of Psychiatry and Neurology.
- Satisfactory completion of an ACGME-accredited vascular/stroke neurology fellowship including, or in addition to, at least 3 months in the neuro-intensive care unit, or completion of and certification by a United Council

for Neurological Specialties or CAST-approved neurocritical care fellowship.

- Satisfactory completion of Maintenance of Certification (MOC) requirements to maintain good standing in the American Board of Psychiatry and Neurology.

2. Pre-requisite Training:

- Performance of at least 200 catheter-based diagnostic and interventional cerebral angiographic procedures as a primary operator.
- Demonstrated competency in catheter techniques as validated by the endovascular surgical neuroradiology fellowship program director.
- American Board of Neurological Surgery (ABNS) Milestones 1 to 4 for cerebrovascular diseases and endovascular surgical neuroradiology completed and signed off by both the residency and endovascular surgical neuroradiology fellowship program directors.

3. Advanced Training:

- 12 continuous months of a dedicated endovascular surgical neuroradiology fellowship experience which includes a minimum of 250 interventional procedures consists of:
 - a. 40 aneurysm treatments, including 10 presenting with rupture
 - b. 20 intracranial embolization (arteriovenous malformation, arteriovenous fistula, tumor)
 - c. 25 intracranial or extracranial stent placements (at least 5 in each category and may include stents or flow diverters for aneurysms)
 - d. 30 acute ischemic stroke treatments
 - e. 10 intracranial infusions (e.g., vasospasm, chemotherapy, and stroke)
 - f. 10 extracranial embolization
 - g. 5 spinal angiograms and embolization
- Satisfactory completion of ACGME Milestone Level 5 training and competence for cerebrovascular diseases signed off by the endovascular surgical neuroradiology fellowship.

Landmarks events in the history of the field are summarized in Table 3.

DISCLOSURE

Authors report no relevant disclosures.

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