Chapter 1

History of interventional neurology

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Interventional neurology is a subspecialty of neurology that uses catheter technology, radiological imaging, and clinical expertise to diagnose and treat diseases of the central nervous system.[1] Interventional Neurology was a term that was used by Dr. Kori[2] in his article on issues of neurological practice section in Neurology entitled “Interventional neurology: a subspecialty whose time has come.” He recommended performance of computed tomographic and magnetic resonance imaging guided procedures including nerve blocks, biopsies, aspirations, and destructive procedures; intra-arterial procedures including carotid angioplasty, carotid thrombolysis, embolizations, chemotherapy, and blood–brain barrier modification; interventional neurosonology; eletromyographic guided procedure including Botulinum toxin injections, trigger point injections; and nerve finder guided procedures to be included in this subspecialty. Over the last two decades, the definition has evolved to a more focused definition, which only includes procedures that are recognized as part of the training requirements of the “Endovascular Surgical Neuroradiology” fellowship according to Accreditation Council for Graduate Medical Education (ACGME). The advent of interventional neurology as a subspecialty has created an opportunity for vascular neurologists to play an active role in the procedural aspects of diagnosis and management of cerebrovascular diseases. However, the abovementioned description appears to oversimplify the history of interventional neurology, which includes a complex chain of events since 1927. Dr. Qureshi at the Interventional Section of American Academy of Neurology (AAN) in 2006 remarked that “the history of interventional neurology has been a saga of unwavering determination and unparalleled comradeship. What continues to bind us together as a community is the sense of pride. Pride in our heritage of neurology, pride in the sacrifices we made, pride in standing side by side, and finally pride in our vision of the future.” This chapter summarizes the events in a chronological order and captures the political and academic aspects of change and evolution over the last 80 years.

The journey starts: Egas Moniz and cerebral angiography

In 1928, Egas Moniz became a Professor of Medicine and subsequently Chair of Neurology at University of Lisbon in Portugal.[3] Since 1927, Dr. Moniz had attempted percutaneous injection of internal carotid artery in four patients, but was limited by irritation of tissue by contrast, intravascular contrast dilution, and radiological equipment. Subsequently, direct injection was attempted after surgical exposure of the internal carotid artery. In his paper in *Revue Neurologique*[4] in 1927, Dr. Moniz states the objective of his initial work to identify an opaque, non-oily substance which can easily pass through the capillaries for visualization of arteries. Iodides (compared with bromides) performed better as contrast media because of higher radio-opacity when injected in carotid arteries of cadavers in 30%, 20%, 10%, and 7.5% solutions. All solutions were found to opacify intracranial arteries despite the presence of cranium. Dr. Moniz then injected strontium bromide, lithium bromide, and sodium iodide into the common carotid arteries of dogs to obtain radiographs and determine toxicity and effect of dilution from ongoing blood flow. Further cadaveric work was done in collaboration with Almeida Dias and Almeida Lima to understand the radioanatomical appearances of cerebral arteries as described in his paper in *Journal de Radiologie* in 1927. Subsequently, Dr. Moniz tried to puncture the internal carotid artery in humans using 0.5–0.6 mm needles at the point of entry into the carotid orifice without success. He starting using the landmarks formed by the sternomastoid, digastric, and omohyoid muscles to access the artery under direct exposure. The first six patients were injected with sodium bromide, but the last patient died 8 hours after the procedure due to a stroke. Dr. Moniz changed the injections to sodium iodide injection (22%–25%) in the next four patients, one of whom was not injected because of puncturing a bad artery. The final case of a 20-year-old boy produced a satisfactory result with adequate visualization of intracranial arteries. In 1931, Dr. Moniz

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presented his results at the First International Neurological Congress in Bern. He subsequently published his book *Diagnostic des tomeurs cerebrales et epreuve de l'encephalographie arterielle* in 1931 that described his experience with the first 180 cerebral angiograms. The role of neurologists in diagnostic imaging was further enhanced by Karl Theodore Dussik, who was a neurologist at Allgemeine Poliklinik (General Polyclinic) and University of Vienna Medical School. He was the first to propose the use of ultrasound as a diagnostic device in a paper he wrote in 1941. He also developed the quartz ultrasound generator with help from engineers F Seidl and C Reisinger at the Physics Institute of the University of Vienna.

Transition to transfemoral approach and exclusion of neurology

The next two decades witnessed more emphasis on accessing the arteries through percutaneous puncture using needle-assisted small diameter cannulas followed by advancement of catheters to sites distant to the point of entry. The changing patterns also resulted in a movement which would eventually exclude neurologists from performance of these procedures. In 1941, Dr. Farinas[5] passed a urethral catheter through a trocar inserted in the exposed femoral artery and advanced it into the aorta. In 1947, Dr. Radner[6] performed angiography of the vertebral artery after catheterizing exposed and ligated radial artery. In 1949, Jonsson[7] from Roentgen Diagnostic Department in Karolinska Sjukuset, Stockholm, Sweden performed a percutaneous puncture of the common carotid artery using a blunt cannula with an inner sharp needle. The cannula was directed downwards using a silver thread to inject and visualize thoracic aorta. In 1953, Dr. Sven Seldinger[8] from Roentgen Diagnostic Department in Karolinska Sjukuset, Stockholm, Sweden described a new technique for acquiring percutaneous vascular access by placing a catheter subsequent to the needle puncture and therefore establishing a platform for diagnostic and therapeutic procedures. In the original 40 arterial catheterizations, 37 were performed through a femoral artery puncture. Three were performed after puncture of the brachial artery via the antecubital fossa with subsequent angiography of the subclavian arteries. However, neurological and neurosurgical services continued to carry out angiography using percutaneous puncture of the common carotid artery, and serial films were made by identical roentgenological techniques up to the early 1970s.[9] Selective angiography of the carotid and vertebral arteries by the femoral route was introduced into practice in the early 1960s. These procedures were performed only by radiologists and competed with angiography using percutaneous puncture of the common carotid artery. Hans Newton,[10] a radiologist, at the Karolinska Hospital, Sweden, started occasionally using the femoral route with subsequent catheterization of the carotid arteries in 1963. Cerebral angiography through the femoral route with subsequent catheterization of all supra-aortic arteries was described by Norwegian neuroradiologist, Per Amundsen[11,12] at the Ullevål Hospital in Norway in 1964. Subsequently, Amundsen' arrived at University of California at San Francisco, CA in 1965, to start teaching trainees in neuroradiology his technique in the United States.[13] A National Institute of Neurological Diseases and Blindness (NINDB) traineeship in neuroradiology in July 1965 involving 11 departments nationally[14] officially consolidated the neuroradiology based practice of cerebral angiography. The training grants were continued by the National Institute of Neurological Disorders and Stroke (NINDS) until about 1976, at which time they were discontinued along with other fellowship programs emphasizing clinical training.[15]

In 1970, Drs. Takahashi and Kawanami[16] reported the results of 422 cerebral angiographic examinations using femoral artery based catheterization. In 1973, Dr. Vitek reported the results for 2000 consecutive examinations[17] and in 1976, Drs. Bradac and Simon reported upon 965 examinations. All three reports suggested that selective angiography of the carotid and vertebral arteries by the femoral route was superior to direct puncture of the vessels in the neck and to retrograde brachial angiography.[18] Several reports were subsequently published with selective angiography of the carotid and vertebral arteries by the femoral route confirming similar findings.[19] By the early 1970s, cerebral angiography through direct carotid puncture by neurologists was an obsolete practice.

Therapeutic procedures: aneurysm embolization and intra-arterial thrombolysis

In 1941, Werner, who was faculty in the Department of Medicine, along with Blakemore, and King[20] from Columbia University College of Physicians and Surgeons, the Presbyterian Hospital and the Neurological Institute of New York, inserted silver wires into an intracranial aneurysm by use of a transorbital approach to prevent rupture by protecting the susceptible wall of the aneurysm from the stress of pulsatile blood flow. They reported a 15-year-old girl who presented to Vanderbilt clinic with diplopia, nausea, and vomiting for 5 months on September 25, 1936. On April 17, 1937, the patient was admitted to the Neurological Institute, New York with severe headaches. An aneurysm of the right internal carotid artery was suspected, based on atrophy of the anterior and posterior clinoid processes and destruction of the lateral and inferior wall of the right optic foramen on skull X-rays. A pneumoencephalogram demonstrated displacement of chiasmatic cistern. The patient was treated using a metal clip placed in the cervical internal carotid artery, with progressive occlusion over the next 5 days. However, the treatment did not improve the patient's symptoms. The patient's symptoms continued to progress with new bruit that could be auscultated over the right eye, visual loss in the right eye, and pituitary dysfunction resulting in multiple admissions. Additional ligations of the right external and superior thyroid arteries and common carotid artery were unsuccessful. On January 21, 1939, 2 years and 9 months after the first symptom, the procedure was carried out as follows:[20] "Under procaine hydrochloride anesthesia an incision was made through the lateral canthus of the right eye. Anesthetic solution was introduced into the orbital tissues. The eye was displaced medially. This gave access to the aneurysm, which had eroded the posterior orbit. Thirty feet of No. 34 gauge coin silver enameled wire was introduced into the aneurysm through a special needle. The velocity of blood flow through the aneurysm was measured and found to be low. The wire was heated to an average temperature of 80 °C. for a total of forty seconds. The aneurysm no longer bled when the needle was cleared at the conclusion of the operation." However, there was progressive diminution of the vision of the left eye after the procedure.

In 1958, Sussmann and Fitch[21] from the Division of Neurosurgery at Muhlenberg Hospital in Plainfield, New Jersey reported the results of slow intravenous infusion of fibrinolysin in three patients with hemiplegia. The site of occlusion of the cerebral vessels was located in each patient by angiography. The first patient was admitted to the hospital on September 6, 1957, because of the abrupt appearance of hemiplegia of the right side and inability to speak. Cerebral angiography on the sixth day of admission demonstrated no filling of the internal carotid artery beyond the bifurcation of the common carotid artery. On the same day, 50 000 units of fibrinolysin were given intravenously over a 3-hour period. Simultaneously, 25 000 units in 100 ml^3 were given after 1 hour, over a 15-minute period, into the left carotid artery. This was repeated on 3 of the next 4 days. A second left carotid angiogram taken 10 days after admission showed an incomplete 2 cm column of dye in the proximal internal carotid artery. An Additional 75 000 units of fibrinolysin were given daily, intravenously, over a 2-hour period for the following 6 days. Another angiogram after 18 days of admission demonstrated some improvement in filling of the left internal carotid artery. In another case, the angiogram demonstrated no filling of the middle cerebral arteries before treatment, while on the eighth day after beginning treatment good filling of the middle cerebral arteries was obtained. This patient showed the most favorable results, which could be attributed to starting treatment within 6 hours after the onset of symptoms. No complications were observed related to the diagnostic angiography or to the administration of fibrinolysin in any of these patients.

Entering the intracranial circulation

In 1963, Drs. Luessenhop and Velasquez[22] from the Division of Neurosurgery at Georgetown University Hospital, Washington, DC reported the results of manipulation of catheters and emboli within the intracranial arteries. The initial experiments comprised testing various existing improvised plastic and rubber catheters within glass models of internal carotid artery. The catheters with optimal performance (particularly those with flexible tips) were successfully manipulated to the terminal segment of the internal carotid artery in cadavers. The investigators found that a flow-directed Silastic tube directed by a 2.5 mm embolus at its end could be introduced through a 22 gauge needle in the common carotid arteries of the dogs and subsequently used to catheterize the thoracic aorta. They subsequently demonstrated that a catheter led by an embolus could be maneuvered through the internal carotid and middle cerebral arteries in a 33-year-old woman with cerebral arteriovenous malformation. A subsequent patient was a 51-year-old woman with an arteriovenous malformation and a right internal carotid artery intracranial aneurysm. The investigators were able to introduce flexible Silastic tubing with an enlarged inflatable tip and maneuver the catheter to the neck of the aneurysm using Polaroid films. The balloon was deflated and the catheter was withdrawn with brief occlusion in the common carotid artery to induce flow reversal. The technique was tested in the third patient with a ruptured intracranial aneurysm.

In 1959, Fedor Andreevitch Serbinenko who was a neurosurgeon in N.N. Burdenko Neurosurgery Institute in Moscow, Russia, organized a small laboratory to design a balloon catheter using materials including polyvinyl chloride, polyethylene, nylon materials, silicone, and latex. He had been performing cerebral angiography through direct carotid punctures since 1954 at the institute. On February 8, 1964, the first selective external carotid angiogram in a patient was performed with the assistance of temporary internal carotid balloon occlusion.[23,24] Serbinenko extended his work to permanent therapeutic occlusion of cervical and intracranial arteries. The first such reported vessel occlusion was performed on April 24, 1970 by Serbinenko,[24] to sacrifice an internal carotid artery and treat a carotid cavernous fistula.

Simultaneous work by Dr. G. Debrun from Serv Neuroradiol, Hop-Henri-Mondor, Creteil, Paris, France documented the use of inflatable detachable balloons to obliterate experimental carotid jugular fistulas and aneurysms in dogs.[25] The technique was then applied in a patient with vertebral artery fistula. He subsequently reported the results of intravascular detachable balloons in 17 post-traumatic carotid-cavernous sinus fistulas and 14 intracranial aneurysms.[26] By 1987, Jungreis and colleagues showed that catheters can be advanced and maneuvered in the intracranial circulation using steereable microguidewire to the extent that catheterization of intracranial arteries was no longer dependent upon the use of flow-directed catheters.[27] In 1991, Dr. Guido Guglielmi from the Department of Neurological Sciences, University of Rome Medical School, Rome, Italy and his colleagues from the Department of Radiological Sciences, Endovascular Therapy, University of California Medical Center, Los Angeles, California reported the use of a soft detachable platinum coil delivered through a microcatheter to treat experimental saccular aneurysms created on the common carotid artery of swine. The detachable platinum coil was soldered to a stainless steel delivery guidewire and manufactured by Target Therapeutics, San Jose, California. Thrombosis occurred because of the attraction of negatively charged white blood cells, red blood cells, platelets, and fibrinogen to the positively charged platinum coil positioned within the aneurysm.[28] The investigators reported the results of using electrically detachable coils introduced via an endovascular approach in 15 patients with intracranial saccular aneurysms. Thrombosis of the aneurysm (70% to 100%) was achieved in all 15 patients, with preservation of the parent artery in 14 patients.[29]

Advancements in image acquisition

Concomitant advancement in image acquisition promoted the possibility of real time imaging of catheters and device manipulations. Initially, images were obtained on a manual-pull or a power-driven (Sanchez Perez) film changer when cerebral angiography was performed using common carotid artery injections. Three or four film hard copies were obtained, and separate injections were required for each plane. In the 1960s, a serial roll film changer was used at the Neurological Institute at Columbia Presbyterian in New York, which allowed multiple images to be acquired rapidly, usually two per second for 3 seconds and then one per second for 6 seconds.[30] In 1979, Charles Mistretta invented the "digital vascular imaging" (DVI) technique that is now generally known as digital subtraction angiography (DSA). The subtraction of an image recorded without the use of contrast medium, and one with contrast medium, created a subtracted image that only demonstrated the contrast medium opacification.[31,32]

Sherry and colleagues in 1983 designed a system incorporating continuous recursive digital video filtration, allowing the operator to view a subtracted fluoroscopic image of each control angiographic sequence in real time.[33,34]

Modern era of interventional neurology

The era of modern interventional neurology started with Dr. Gomez and his colleagues. In 1991, Dr. Camilo R. Gomez was an Associate Professor at St. Louis University, St. Louis, Missouri (Fig. 1.1). He along with Dr. Mark Malkoff had set up an interventional protocol for treatment of acute ischemic stroke. Dr. Gomez had just returned from a conference in Argentina where he had met with Dr. Vinuela and had a productive and motivating discussion about the role of neurologists in interventional neuroradiology. Subsequently, Dr. Gomez, with the support of Chairman of Neurology, John B. Selhorst, MD at the Department of Neurology and Souers Stroke Institute, St. Louis University School of Medicine, St. Louis, Missouri, started performing neurointerventional procedures in collaboration with the Head of interventional cardiology, Morton J. Kern MD. The first procedure was performed by Dr. Gomez in the cardiac catheterization laboratory in December 1993. Drs. Gomez and Malkoff successfully incorporated acute response team or "Code Stroke"[35] and neurocritical care as essential components of management of patients undergoing neurointerventional procedures. They successfully connected all pagers of stroke team members to a common access number and instructed the emergency department staff to activate that number immediately upon arrival of a stroke patient (Code Stroke). This step allowed the

Fig. 1.1. Drs. Gomez (right) and Qureshi (left) share the podium in 2007.

integration of stroke neurologists in all aspects of care including evaluation, endovascular treatment, and post-procedural care. Subsequently, several diagnostic and interventional procedures were performed by Dr. Gomez in the cardiac catheterization laboratory at St. Louis University until July 1994. Later, a change in leadership in the medical school led to circumstances that resulted in Dr. Gomez moving to University of Alabama.

The Department of Neurology under the leadership of Dr. John N. Whitaker, who was Chairman of Neurology and President of the Health Services Foundation, provided Dr. Gomez with the opportunity to start another neurointerventional program in collaboration with interventional cardiologists at University of Alabama. The program was initiated on March 1, 1995 and Dr. Gomez started performing procedures in the cardiac catheterization laboratory. He was also able to build strong relationships with Dr. Jay S. Yadav, who was an interventional cardiology fellow and Dr. Gary S Roubin, who was a leading interventional cardiologist. Dr. Yadav had already completed a residency in neurology and fellowship in neuroimaging. Dr. Gomez was visiting Argentina for a meeting when he met with Dr. Marco Zenteno from Mexico. Dr. Gomez started visiting the Comprehensive Stroke Center, Hospital Angeles del Pedregal, Department of Neurological Endovascular Therapy, Instituto Nacional de Neurología y Neurocirugía, Mexico City, Mexico (National Institute of Neurology and Neurosurgery and Hospital LA at Mexico City) several times a year and performed interventional procedures with Dr. Zenteno.[36] Dr. Morgan Cambell joined Dr. Gomez at the University of Alabama as his first fellow for a 3-year fellowship in 1996, which included a combination of vascular neurology, neurocritical care, and neurointerventional procedures.

Dr. Adnan I. Qureshi (Fig. 1.1) was a neurology resident at Emory University in Atlanta, GA in 1994. Dr. Qureshi in 1996 joined a 2-year fellowship in neurocritical care at Johns

Hopkins Medical Institutions with the incorporation of some aspects of neuroradiology training within the fellowship. Dr. Qureshi subsequently joined the endovascular neurosurgical fellowship at University at Buffalo, State University of New York in July 1998. He was one of the first neurologists along with Edgard Pereira MD to join a formal fellowship program in neurointerventional procedures. The program at University of Buffalo was led by the Chairman of Neurosurgery, Dr. L. Nelson Hopkins, who was one of the most imminent neurosurgeons and considered to be the founder of the modern discipline of endovascular neurosurgery. Drs. Lee R. Guterman (neurosurgeon) and Ajay Wakhloo (neuroradiologist) were both well-reputed neurointerventionalists and formed the other faculty in the program. Dr. Qureshi had an opportunity to train with other neurosurgical fellows such as Drs. Lanzino, Fessler, Ringer, and Lopez, who all subsequently gained prominence in the field. His training included a wide spectrum of endovascular procedures for acute ischemic stroke, extra- and intracranial stent placement, and embolization of arteriovenous malformations and aneurysms. Dr. Qureshi worked diligently to incorporate academic research within the program at the University of Buffalo.

When Dr. Qureshi completed his fellowship in June 2000, he was invited to stay as faculty in the Department of Neurosurgery and trained several neurosurgery fellows during his two and half years at the University of Buffalo. He also developed an angiographic classification scheme for assessing initial severity of arterial occlusion in patients with acute ischemic stroke.[37] The classification scheme has been validated at multiple institutions since its first description and is currently referred to as the "Qureshi grading scheme."[38,39] In December 2002, Dr. Qureshi joined the University of Medicine and Dentistry of New Jersey, Newark, as a Professor of Neurology and Director of the Cerebrovascular Program on the invitation of Patrick Pullicino MD, who was Chairman of Neurology and Neurosciences at that time. An interventional neurology training program was simultaneously initiated, with Drs. Kirmani and Xavier starting as the first fellows in the program. In 2004, Nazli Janjua MD joined the program, becoming one of the first women to enter interventional neurology. Dr. Qureshi also received an RO-1 grant as principal investigator from the National Institutes of Health in 2004, starting a track of extramural funded research by interventional neurologists. The Zeenat Qureshi Stroke Research Center was initiated in 2004. Since its inauguration, the center has led the way in cutting-edge research in epidemiology, clinical trials, and basic research pertaining to cerebrovascular diseases. Zeenat Qureshi Stroke Research Center was transferred to the University of Minnesota in 2006. In 2007, the research center was ranked in the top 20 academic facilities for conducting biomedical research selected from hundreds of institutions representing several disciplines of biological sciences in the United States by *The Scientist*. Teaching, mentoring, and policies were ranked as the strengths of the center.

Fig. 1.2. The Minnesota Stroke Initiative team in 2007.

In November 2006, Dr. Qureshi joined the University of Minnesota in Minneapolis, Minnesota as a Professor of Neurology, Neurosurgery, and Radiology and Executive Director of the Minnesota Stroke Initiative.[40] An endovascular surgical neuroradiology fellowship was initiated (Fig. 1.2). Drs. Georgiadis, Shah, and Suri formed the first group of fellows in the newly started program. The ACGME in June 2000 had officially approved the Guidelines for Training in endovascular surgical neuroradiology. Subsequently, the program requirements for neurology were approved by the ACGME in May 2003. On January 1, 2008[41], the criterion for program directorship was modified to include physicians with current certification in the specialty by the American Board of Psychiatry and Neurology. In anticipation of this change, an application was submitted to the Neurosurgery Residency Review Committee at ACGME to request formal accreditation of the endovascular surgical neuroradiology fellowship at the University of Minnesota. The application was subsequently forwarded to a special committee of the Neurology Residency Review Committee with members from the

Fig. 1.3. Dr. Shah performing an endovascular procedure with Dr. Gomez (visiting professor) in 2008.

Fig. 1.4. A group photograph of several of the interventional neurology trainees in 2007.

Neurosurgery and Radiology Residency Review Committees. In May 2008, University of Minnesota became the first program to be accredited by the Neurology Residency Review Committee and Dr. Qureshi became the first neurologist to be a program director of an accredited endovascular surgical neuroradiology fellowship program. A total of three fellowship positions per year were approved. Over the years, the fellowship program has graduated outstanding fellows, who have received national awards and federal grants. The program has hosted world renowned visiting professors such as Dr. Gomez (Fig. 1.3), who was the President of the American Society of Neuroimaging (seen in the picture teaching fellows new techniques during his visit to University of Minnesota). In April 2008, Dr. M. Fareed K. Suri (Fig. 1.2) became the first interventional neurologist to receive the extramural K grant from National Institutes of Health for career development.

Interventional neurology: the national and international front

Interventional neurology was simultaneously gaining acceptance into the organized societies of Neurology (Fig. 1.4). In 1996, an “interventional section” was started within the American Academy of Neurology. The section was chaired

Fig. 1.5. Drs. Jovin (left) and Qureshi (right), Associate Editors of the *Journal of Neuroimaging*, share the podium in 2007.

by prominent interventional neurologists over the years including Kori (1996–1998), Gomez (1998–2000), Yadav (2000–2002), Hauser (2002–2004), Qureshi (2004–2006), and Pereira (2006–2008) leading to unprecedented growth. The interventional neurology field gained prominence in the programs of the annual meeting of the American Academy of Neurology and American Society of Neuroimaging. Dr. Gomez initiated the "Endovascular Therapy and Critical Care Course" and Dr. Suarez initiated the "Interventional Treatment of Acute Ischemic Stroke" course at the 55th Annual Meeting of the American Academy of Neurology, Honolulu, Hawaii, in March 2003. In January 2004, Dr. Qureshi initiated a course on angiography and interventional neurology at the 27th Annual Meeting of the American Society of Neuroimaging, in Phoenix, AZ. In April 2006, Dr. Qureshi initiated the half-day course on "Update on Endovascular Treatment of Cerebrovascular Disease" at the 58th Annual Meeting of the American Academy of Neurology, San Diego, CA. The interventional section of the American Academy of Neurology (AAN) had 267 active members by 2006. A plenary session dedicated to interventional neurology was the highlight of the American Society of Neuroimaging Annual Meeting in Miami in January 2007. The *Journal of Neuroimaging*, the official journal of the Society of Neuroimaging started an interventional section in 2007 with Drs. Qureshi and Jovin (Fig. 1.5) as Associate Editors dedicated to the section. Drs. Qureshi and Georgiadis edited the *Atlas of Interventional Neurology* that was published by Demos Medical Publishing, New York, NY, 2008 becoming the first textbook of interventional neurology. In January 2008, the *Journal of Vascular and Interventional Neurology* was published starting the first periodical for interventional neurology. Interventional neurology was also gaining recognition in other countries and was one of the highlights of the 45th Turkish Neurology Congress, Ulusal Noroloji Kongresi, Antalya, Turkey, 10–15 Kasim, 2009. In November 2009, the International Society of Interventional Neurology was started, with Drs. Qureshi (President), Pereira (Vice-President), Taylor (Secretary), and Shah (Treasurer) as the first office holders. The society started coordinating the efforts of interventional neurology groups within and outside the United States.

Collaboration also started between professional organizations of various specialties. The Neurovascular Coalition was formed in November 2004, led by John J. Connors, III, MD as the first Immediate Past President of the American Society of Interventional and Therapeutic Neuroradiology to ensure excellence in medical education, training, and research related to vascular conditions affecting the brain and thus promote high-quality patient care. The coalition members included the American Academy of Neurology, American Association of Neurological Surgeons, American Society of Interventional and Therapeutic Neuroradiology, American Society of Neuroradiology, Congress of Neurological Surgeons. AANS/CNS Cerebrovascular Section, and Society of Interventional Radiology. The coalition prepared a multi-society landmark consensus document[42] entitled "Training, competency, and credentialing standards for diagnostic cervicocerebral angiography, carotid stent placement, and cerebrovascular intervention" that defines minimum standards for the training, knowledge, and experience necessary to perform carotid stent placement and other diagnostic and therapeutic cerebrovascular procedures. This was followed by another document "Qualification requirements for performing neuro-interventional procedures: A report of the Practice Guidelines Committee of the American Society of Neuroimaging and the Society of Vascular and Interventional Neurology" that was authored by Qureshi, Abou-Chebl, and Jovin.[43] The document summarized the existing data derived from regulatory bodies, professional organizations, and clinical trials with direct pertinence to indications and qualifications required for performing neurointerventional procedures and provided recommendations regarding qualifications required for performing individual neurointerventional procedures. Such efforts have led to an increased recognition of interventional neurology as a subspecialty of neurology over the last decade.

The future

With sights set on excellence, interventional neurology will continue to grow and prosper. The enduring legacy of any effort or journey is not what we have achieved, but what we have become as a consequence. In the address to the interventional section at the American Academy of Neurology 59th Annual Meeting, Boston, MA, on May 2007, Dr. Qureshi summarized the evolution of Interventional Neurologist as follows: "Any organization that commits to self-sacrifice for the greater good has already taken the first step to greatness. The ramifications of this commitment will shake any organization to the core but their desire to seek greatness will bond them together into an eternal legacy that will last longer than their mortal existence."

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Chapter 2

Diagnostic cerebral angiography

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Cerebral angiography is a procedure by which the intracranial and extracranial head and neck circulation is evaluated.[1] It entails the placement of a catheter selectively into extracranial cerebral vessels using fluoroscopic guidance, followed by contrast material injection and image acquisition to delineate anatomy and abnormalities.

Utilization of cerebral angiography

The use of non-invasive cerebrovascular imaging was increased while the use of cerebral angiography has declined since 1985.[2] A prominent decrease was seen in pre-procedure cerebral angiograms among patients undergoing carotid endarterectomy.[3,4] According to the most recent Medicare data show that, in 2002, at least 92 000 cervicocerebral arteriograms (Current Procedural Terminology codes 75680 and 75676, respectively, for bilateral or unilateral cervical carotid arteriography) were performed, compared with 109 000 performed 5 years previously. However, in a recent study we found evidence that the overall use of cerebral angiography increased between 1990 and 1991 and 2000 and 2001. We used data from the Nationwide Inpatient Sample, the largest all-payer inpatient care database in the United States.[5] International Classification of Disease, 9th Revision, Clinical Modification primary diagnosis codes were used to identify the patients admitted with stroke and stroke subtypes and secondary codes to identify those with stroke-associated complications and related procedures. In a 2-year period, 1990 to 1991, there were 1 736 352 admissions for cerebrovascular diseases, and in another 2-year period, 2000 to 2001, there were 1 958 018 admissions. Cerebral angiography during hospitalization was performed in 126 572 (7.3%) patients in 1990–1991 and in 161 256 (8.3%) patients in 2000–2001. The rate of cerebral angiography increased most prominently for patients with subarachnoid hemorrhage, from 32% in 1990–1991 to 54% in 2000–2001. The recent increase in utilization during hospitalization is attributed to the increase in neurointerventional procedures among patients with cerebrovascular diseases.[6] Interventional angiography is cerebral angiography that is performed either prior to or during neurointerventional procedures to guide patient selection, planning technical aspects of the procedure, and monitoring the results of these procedures. Another reason for increased rates of angiography may be found in recent data suggesting that, in practice, the reliability of non-invasive studies may be inferior to angiography for appropriate guidance in patient selection.[7,8]

Recommended indications from professional organizations

The practice guidelines from the Stroke Council of the American Heart Association recommend cerebral angiography for imaging in transient ischemic attacks and acute stroke under selected conditions. Patients with retinal ischemic events or transient ischemic attacks are deemed to be candidates for cerebral angiography when there is reasonable evidence of carotid atherosclerotic disease that warrants consideration of endarterectomy. Evidence of luminal reduction greater than or equal to 70% on ultrasound, magnetic resonance angiography, or computed tomographic arteriography, is usually a strong indication for cerebral angiography in symptomatic patients who are candidates for endarterectomy. Some stenotic lesions measured at 50% to 69% by non-invasive techniques may show luminal reduction greater than or equal to 70% on cerebral angiography, making them eligible for endarterectomy. Conversely, occlusion on non-invasive testing may correlate with a residual hairline lumen on cerebral angiography in as many as 9% of patients (Class II, see Table 2.1). Cerebral angiography also is required to evaluate intracranial stenosis or occlusion. Selective subclavian and/or vertebral cerebral angiography remains the reference procedure for imaging of vessels in vertebrobasilar occlusive disease. The outline of arteries that are diseased, whether from stenotic or occlusive atherosclerosis, dissection, or arterial dysplasias, can be characterized more accurately than by current magnetic resonance angiography techniques. Selective cerebral angiography is the recommended procedure for diagnosis of cerebral aneurysm in patients with subarachnoid hemorrhage (type A). Cerebral angiography is recommended to detect beading, stenosis, or aneurysm, particularly in medium sized and small cerebral

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