
Author(s):
Huanwen Chen, MD¹; Jose Marino, MD²; Andrew B Stemer, MD³; Inder P Singh, MD, MPH⁴; Michael T Froehler, MD, PhD⁵

Corresponding Author:
Huanwen Chen, alvin.huanwen.chen@gmail.com

Affiliation Information for All Authors:
1. National Institute of Neurological Disorders and Stroke, National Institutes of Health; 2. Department of Neurology, University of Maryland Medical Center; 3. Department of Neurology, Georgetown University Hospital; 4. Department of Neurosurgery, Georgetown University School of Medicine; 5. Department of Neurology, Vanderbilt University Medical Center

Equal Author Contribution:

Contributions:
Huanwen Chen: Drafting/revision of the manuscript for content; including medical writing for content; Major role in the acquisition of data; Study concept or design; Analysis or interpretation of data; Additional contributions (in addition to one or more of the above criteria)
Jose Marino: Drafting/revision of the manuscript for content; including medical writing for content; Additional contributions (in addition to one or more of the above criteria)
Andrew B Stemer: Drafting/revision of the manuscript for content; including medical writing for content; Additional contributions (in addition to one or more of the above criteria)
Inder Paul Singh: Drafting/revision of the manuscript for content; including medical writing for content; Additional contributions (in addition to one or more of the above criteria)
Michael T Froehler: Drafting/revision of the manuscript for content; including medical writing for content; Study concept or design; Analysis or interpretation of data; Additional contributions (in addition to one or more of the above criteria)

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Abstract
Interventional neurology is a subspecialty at the cross-section of neurology, neurosurgery, and neuroradiology that uses image-guided endovascular catheter techniques to diagnose and treat neurovascular disorders. While interventional neurology techniques have existed for decades, recent landmark trials in stroke thrombectomy have catalyzed dramatic changes to the interventional neurology field, and there is rising neurology interest and representation. Unlike other neurology subspecialties, however, interventional neurology training and fellowship applications are not standardized. Thus, it can be difficult for neurology trainees to navigate this rapidly changing and multi-disciplinary field. This article seeks to provide neurology residents and residency program directors with a brief overview of the modern interventional neurology field, the current fellowship application process, as well as tips on how neurologists can best prepare for a career in interventional neurology. To this end, we conducted a nationwide survey of interventional neurology fellowship program directors regarding training neurologists. Here, we distill survey responses into concrete, actionable items for neurology trainees.

Introduction
Interventional neurology is a subspecialty at the cross-section of neurology, neurosurgery, and neuroradiology centered around the diagnosis and treatment of neurovascular diseases using image-guided procedures. The field was conceived with the advent of cerebral angiography in the 1920s by Portuguese neurologist Antonio Egas Moniz [1], and it has undergone steady and remarkable growth. The history of interventional neurology and the role of neurologists were highlighted by Chen and Nguyen in the initial Emerging Subspecialties article in 2008 [2].

Recently, the explosive growth of endovascular thrombectomy (EVT) for large vessel acute ischemic strokes has catalyzed substantial changes [3-5]. Now more than ever, interventional neurologists familiar with the natural history and overall management of cerebrovascular diseases (particularly that of ischemic stroke) are in high demand. As such, the number of neurology-trained specialists in the interventional neurology workforce has rapidly increased [6].

Despite growing neurology interest and representation in the interventional neurology field, many academic interventional neurology programs are not housed in departments of neurology, but rather reside in departments of neurosurgery or radiology. For neurology trainees, this can create systemic barriers to fully understanding the interventional neurology field and how to best prepare for this career path. A recent survey of neurology trainees found that 40% felt that neurology, vascular neurology, nor neurocritical care adequately prepared them for a career in interventional neurology [7]. In this article, we seek to provide an updated overview of the interventional field and career path for neurologists. We also conducted a nationwide survey of fellowship program directors to provide data on the current state of the interventional neurology fellowship application process and training.

What is interventional neurology?
Interventional neurology primarily focuses on diagnosing and treat cerebrovascular and spinal diseases in adult and pediatric populations. It is also known as neuro-interventional radiology, neuroendovascular surgery, and neurointerventional surgery. The diagnostic angiogram serves as the foundation of the field, upon which interventional procedures are performed to treat a variety of diseases. Some specialists also perform non-endovascular procedures. A list of interventional procedures is presented in Supplementary Table 1. In addition to performing
procedures, interventionalists also provide comprehensive pre- and post-procedural care in inpatient and outpatient settings.

How to become an interventional neurology specialist as a neurologist
In the United States, interventional neurologists need to complete a neurology residency as well as a vascular neurology fellowship and/or a neurocritical care fellowship. Afterward, neurologists would then typically need to complete two years of interventional neurology training, although program structures vary. Accreditation of interventional neurology fellowship training by one of three accrediting bodies (CAST, ACGME, and UCNS) is desired though not necessary. Most programs offer one to two fellowship positions per year. Some programs offer two-year fellowships for neurologists, but not all. Some programs also offer combined 3- to 4-year stroke/ICU and interventional neurology fellowships for neurologists. After completion of an interventional neurology fellowship, neurologists can apply for an American Board of Medical Specialties (ABMS) Recognition of Focused Practice (RFP) in CNS Endovascular Surgery, which is a new credentialing mechanism for interventional neurologists. There is currently no board certification in interventional neurology through the ABMS. In Canada, the Royal College of Physicians and Surgeons of Canada is developing an Area of Focused Competence (AFC) in Neuro-Intervention. Graduates in neurology, neurosurgery, and radiology will be eligible.

Jobs for interventional neurologists vary widely. There are two “traditional” models: 1) a full-time interventional neurology model in which interventionalists focus exclusively on procedures and peri-procedural management; and 2) a “hybrid” model in which interventional neurologists divide their time between a neurology service (general neurology, stroke, and/or critical care) and elective interventional neurology procedures while partaking in call coverage for emergent cases. While academic centers continue to hire interventional neurologists, many job openings may come from community hospitals seeking to start interventional neurology programs to meet the rising demand for acute stroke care; however, these positions could limit interventionalists to mainly stroke-related interventions, and the success of each start-up program is not guaranteed. Careful delineation of expectations may be needed to ensure access to procedures beyond thrombectomy.

Tips for fellowship application
To shed light on the nebulous interventional neurology fellowship application process, we surveyed 67 accredited interventional neurology program directors. 15 (22%) program directors responded (detailed methods in the Supplementary File). The results of the survey, as well as the authors’ opinions, are distilled into the following tips.

1. Start early, but choose wisely
73% of interventional neurology fellowships recruit on a rolling basis. The application process is competitive, and because training positions are also offered to neurosurgeons and neuroradiologists, only 29% of the fellowship graduates in the last 5 years have been neurologists. 60% of programs recruit 3 years or less in advance, so, neurology residents should apply for interventional neurology fellowship during early PGY3 year if planning to pursue a stroke fellowship, or early PGY4 year if planning to pursue a neurocritical care fellowship (Figure). It is important to note that 40% of programs fill their spots more than 3 years in advance. Thus, neurology residents could consider starting their application process as early as PGY2 year. During interventional fellowship, neurology trainees should aim for as many cases as possible as the first-assist for a wide spectrum of endovascular procedures (Supplementary Table 1); in our opinion, strong graduates acquire more than 800 cases over two years. Thus, when choosing programs, applicants should consider the total annual institutional case volume, the
diversity of cases, and the number of trainees sharing the call pool. We recommend prioritizing maximal case number and diversity to ensure optimal training.

2. **Hands-on experience is important but not necessary**
   Opinions on whether neurology applicants need hands-on procedural experience before fellowship varied. On one hand, 27% of programs stated no prior experience was needed; on the other hand, 27% preferred 6 months or more. A majority (67%) of interventional programs prefer at least one month of hands-on experience. Thus, neurology applicants should try and secure some procedural experience during residency. Doing so will help residents confirm their interest in the field and become familiar with the breadth of interventional neurology procedures (and their associated pathologies) beyond stroke thrombectomy. Furthermore, neurology residents with some procedural experience in residency can make better use of their short time in interventional neurology fellowship training appreciating the nuances of endovascular techniques. Some basic skills that can be mastered at a resident level include filling syringes, handling wires and catheters on the table, preparation of flush lines and connectors, and arterial access and closure. Given that most neurology residencies are “front-loaded,” finding time for hands-on experience during PGY1 and PGY2 years may be difficult. Neurology residency program directors should be aware of the diversity of opinions on procedural experience among interventional neurology fellowship program directors and make accommodations when possible.

3. **Master neurovascular anatomy and non-stroke pathology**
   Anatomy is of paramount importance for proceduralists and surgeons. While clinical neurology training focuses on interpreting signs and symptoms from history and exam to generate differential diagnoses based on neurological localization, surgical anatomy focuses on the spatial relationship of anatomical structures with each other, anatomical variants, and detailed interpretation of diagnostic imaging. As such, neurology residents may need to rely on self-directed learning to gain full mastery of neurovascular anatomy for the purposes of interventional neurology. Neurology residents should also pay special attention to the anatomy of external carotid arteries and spinal vasculature. Finally, in addition to mastering the management of ischemic stroke patients, neurology trainees should actively seek opportunities to gain exposure to the management of hemorrhagic strokes and interpretation of diagnostic neuroimaging, perhaps through dedicated rotations in neurosurgery or neuroradiology. Useful resources include *Practical Neuroangiography* by Pearse Morris and *Diagnostic Cerebral Angiography* by Anne Osborn.

4. **Get involved with research**
   Being involved and productive in cerebrovascular research may also be helpful for demonstrating interest, research abilities, and a deep understanding of disease processes and treatments. Presenting research work at national conferences is a great way to gain visibility, as many interventional neurology fellowship faculty routinely attend national conferences, and fellowship openings are sometimes advertised in person at these venues. Trainees should attend and present at the annual conferences of the Society of Neurointerventional Surgery (SNIS) and/or the Society of Vascular and Interventional Neurology (SVIN). Trainees should also consider joining these societies as junior members.

5. **Find mentors and advocates**
   Recommendation from other neuro-interventionalists is the most important factor for 87% of fellowship program directors when considering neurology applicants. Thus, neurology residents should identify mentors within the interventional field. Mentors can also inform trainees of changes in the constantly evolving interventional neurology practice landscape and provide tailored career advice. Neurology residents with access to interventional neurology at their...
home institutions should identify mentors early and build relationships. For those without direct access to interventional faculty at their home institutions, residency program directors and other faculty within the program may help facilitate introductions to mentors at other institutions. Other resources are also available, such as the Mentor Match program facilitated by the Society of Neurointerventional Surgery [8].
References

1. Moniz E (1927a) L’encéphalographie artérielle, son importance dans la localisation des tumeurs cérébrales. Rev Neurol (Paris) 2:72–90


A. Stroke pathway

- Preparations
- Main application window
- PGY-1
- PGY-2
- PGY-3
- PGY-4
- PGY-5
- PGY-6
- PGY-7

- Medicine
- Neurology
- Stroke
- Interventional

B. Neurocritical care pathway

- Preparations
- Main application window
- PGY-1
- PGY-2
- PGY-3
- PGY-4
- PGY-5
- PGY-6
- PGY-7
- PGY-8

- Medicine
- Neurology
- Neurocritical care
- Interventional