The incidence of stroke has surpassed 800,000 cases each year, and acute stroke has become the leading cause of disability in the United States. Given that a person’s chronological age is a primary risk factor, and the United States will be experiencing exponential growth in the elderly population over the next 20 years, the incidence of stroke will grow substantially and the demand for dedicated stroke care will increase accordingly. In this report, we consider contemporary evidence-based practices for stroke care, the supply of vascular neurologists (VNs) and neurointerventionalists (NIs), potential causes for the supply–demand imbalance, and solutions aimed at increasing the supply of VNs within the ongoing healthcare reform effort.

Best Practices for Stroke Care
Evidence-based practices for stroke include medical interventions applicable to every patient and invasive endovascular interventions applicable only to a smaller subset of eligible patients. One of the most common evidence-based medical approaches for treating acute stroke includes use of recombinant tissue plasminogen activator in eligible patients given within 4.5 hours of when they were last seen normal, a treatment that is delivered most effectively within dedicated acute care stroke units with established clinical pathways for secondary prevention and management. In 2003, the Primary Stroke Center Certification program of the Joint Commission initiated an effort to increase the number of units with expertise in delivering evidence-based medical stroke care. A key component of these units is a stroke team, offering 24/7 coverage by physicians with advanced knowledge of evaluating and treating acute vascular diseases and who are able to recommend best emergent and preventive management. It has since become best practice in stroke treatment and management to incorporate these stroke units within a regional hub and spoke network in which the unit (ie, the hub) supports satellite clinics with video-based telemedicine or telephonic consultation. Given the improvements in patient care (measured in terms of decreasing complications and increasing compliance with guidelines), these hub and spoke models have proliferated across the United States. There now are almost 1000 certified primary stroke centers operating in 49 states. Although the American Stroke Association does not explicitly mandate that a neurologist be the sole provider of care to patients with acute stroke, best practices indicate that VNs should play the leading role in stroke units. The American Board of Psychiatry and Neurology began certifying VNs in the United States in 2005 as a way to formally recognize those who completed special training and who demonstrate competence in all aspects of vascular neurology care. The background of those VNs is diverse. The majority of them are adult neurologists, but some have a pediatric neurology background. Some have additional training in neurocritical care and may alternate a neurointensivist practice with vascular neurology. Others have a primarily neurohospitalist role and alternate vascular neurology with inpatient general neurology care. Because of their endorsed competency, board-certified VNs are preferentially sought for delivering stroke care in private and academic practices. VNs are also especially well suited to assume leadership positions in both primary and comprehensive stroke centers because of their expertise in delivery systems for stroke care.

Endovascular acute revascularization procedures are performed for a minority (5%) of patients with acute ischemia or hemorrhagic stroke. Endovascular procedures can also assist in reducing the risk of another stroke in some patients by strategies that include angioplasty and stenting in the carotid and intracranial vessels. The practice of neurointerventional surgery requires not only a neurointerventional specialist, but a team of professionals and infrastructure that is typically only available at larger comprehensive stroke centers. As a result, these procedures are less widely available. In contrast to vascular neurology, neurointerventional surgery is a multidisciplinary specialty, and mainly consists of neurologists (typically VNs), radiologists, and neurosurgeons. Some of the endovascular therapies provided by NIs, particularly for treatment of acute ischemic stroke, must be available continuously around the clock. Therefore, there is a minimum of at least 2 to 3 NIs per center to provide the necessary coverage. Although it is advantageous for multiple NIs to join together at a single center to handle call responsibilities, this necessitates sharing of the neurointerventional procedure volume, which may...
not create enough work for each NI. In that case, supplemental activities must be undertaken, such as diagnostic radiology, open surgery, or medical neurology, including general stroke care. However, the differences in reimbursement between these activities can create inequities among the cerebrovascular physicians and disrupt the team. The training requirements vary depending on the specialty of origin; for neurologists to become trained NIs, they must first obtain training in vascular neurology or neurocritical care (Figure). Currently, there is no board certification process for NIs in the United States.

**Problem Statement: Supply–Demand in Acute Stroke Care**

Besides the increased demand being created by the aging American population, the demand for primary and comprehensive stroke centers (and the VNs who should lead them) will also increase as the delivery of health care in the United States increasingly moves toward preventative, coordinated, population-based clinical care models operating within regional healthcare administrations.18,19 Within this movement, an increasing number of hospitals have either sought primary stroke center certification (ie, become hubs),8 or have partnered with larger institutions to receive such specialized support,20 either through telephonic consultation or within a telemedicine network23 (ie, become spokes). Comprehensive stroke centers capable of delivering tertiary stroke care are currently being certified nationally. Because VNs are sought to take leadership positions in both primary and comprehensive stroke centers, such administrative commitment could limit their time availability for patient care activities in vascular neurology.

Still, the current supply of VNs lags behind the development of these hub and spoke stroke center clinics.22 Table 1 shows that a total of 1115 VNs (1009 adult neurologists, 7 child neurologists, and 9 double-boarded psychiatrists/neurologists) have received vascular neurology certification from the American Board of Psychiatry and Neurology since it was first offered in 2005. This results in a current ratio of 717 strokes per VN per year. This ratio is expected to grow as stroke incidence increases and number of VNs remain static. In fact, the initial rate of VN certification is deceivingly high because it was a front-loaded process. Between 2005 and 2009, a considerable number of neurologists with past stroke expertise applied for certification and were grandfathered. Now that the grandfathering period has expired, vascular neurology certification is only conferred to diplomates who complete an American Council for Graduate Medical Education (ACGME) accredited fellowship. For the academic year 2011 to 2012, the ACGME identified 72 accredited vascular neurology programs with 77 on-duty fellows,23 representing just 14.8% of the ≈520 neurologists who have completed residency training.23 In short, this suggests that training and supply of vascular neurology fellows are not keeping pace with the expansion of stroke care clinics, and the shortage is particularly noticeable in rural and underserved urban communities. Although telemedicine may mitigate such geographical disparity, it does not completely solve the overall national shortage problem because telemedicine commits a VN to provide such service from a remote location, and then he or she becomes transiently unavailable to attend to his or her local institution or to other remote telemedicine sites. The VN shortage likely

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**Figure.** Current supply and demand of specialists for acute stroke care in the United States. NCC indicates neurocritical care; NI, neurointerventional; and VN, vascular neurologists.
Table 1. Trends for Vascular Neurology Certification in the United States

<table>
<thead>
<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2008</th>
<th>2009</th>
<th>2011</th>
<th>2012 (as per April 2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2005</td>
<td>2006</td>
<td>2008</td>
<td>2009</td>
<td>2011</td>
<td>2012 (as per April 2012)</td>
</tr>
<tr>
<td>Total examinees</td>
<td>238</td>
<td>150</td>
<td>343</td>
<td>286</td>
<td>165</td>
<td>56</td>
</tr>
<tr>
<td>Grandfathering track</td>
<td>131</td>
<td>84</td>
<td>200</td>
<td>200</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Non-ACGME fellowship track</td>
<td>102</td>
<td>56</td>
<td>92</td>
<td>33</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>ACGME fellowship track</td>
<td>5</td>
<td>3</td>
<td>45</td>
<td>37</td>
<td>140</td>
<td>50</td>
</tr>
<tr>
<td>Repeat examinees</td>
<td>0</td>
<td>7</td>
<td>6</td>
<td>16</td>
<td>13</td>
<td>6</td>
</tr>
<tr>
<td>Total certified</td>
<td>240</td>
<td>139</td>
<td>325</td>
<td>264</td>
<td>147</td>
<td>N/A</td>
</tr>
</tbody>
</table>

ACGME indicates American Council for Graduate Medical Education. Source: Courtesy of the American Board of Psychiatry and Neurology (ABPN) 2012.

will result in increased disparities in care and a large number of stroke patients being managed by non-VN specialists or non-neurologists who have less expertise and experience.

In contrast, there appears to be an excess supply of NIs relative to the projected demand for the interventions they can perform. There are currently ≈800 practicing NIs and 83 active neurointerventional fellowship programs in the United States, producing up to 100 new NIs each year. It is difficult to accurately measure the demand for neurointerventional procedures, but the best estimate for total number of annual aneurysm embolizations is ≈20,000, and for endovascular ischemic stroke treatment, it is ≈11,000. After accounting for other interventional treatment cases, such as embolization of arteriovenous malformations and carotid artery stenting, the total annual volume of neurointerventional procedures may be around 40,000. This translates into 50 procedures per year per NI. Arguably, the demand for NIs may increase over time, but the most aggressive models cap the maximum number of procedures at 90,000 per year. Even if the number of NIs were to remain stable at 800, this would result in only 112 procedures per year per NI. However, many of those optimistic predictions were based on assumptions of advances in interventional techniques, such as angioplasty and stenting in extracranial and intracranial vessels, or treatment of aneurysms or vascular malformations. The results of some recent clinical trials would suggest otherwise. For example, the Stenting and Aggressive Medical Management for Preventing Recurrent stroke in Intracranial Stenosis (SAMMPRIS) trial did not demonstrate any clear advantage of intracranial stenting over medical management,23 the Carotid Revascularization Endarterectomy versus Stenting Trial showed equipoise between carotid angioplasty and carotid endarterectomy, and the interventional management of stroke trial had to be stopped prematurely because of futility. Thus, the anticipated increase in neurointerventional procedures may not happen, which has led some to propose the discontinuation of all neurointerventional training.26

Regardless, a perpetual oversupply of NIs has the potential to lead to other problems. Specifically, more patients will be treated by neurologists and other providers with lower patient volumes and less experience. Also, low volumes will create increasing pressure for NIs to lower their threshold for intervening, altering their standards for medically necessary interventions at the risk of providing inappropriate and costly treatment at best, or increasing chance of medical errors at worst. This phenomenon has been observed in several other specialties, including interventional cardiology,31 where changes in medical necessity criteria resulted in an increase in the number of procedures, increased costs but no apparent improvement in patient outcomes. Of course, NIs may not view the exchange from this perspective, preferring to see that the marginal benefits delivered to patients who otherwise may forego care. Arguably, the regulators and administrators of the health reform era may be less inclined to support expanded definitions of medical necessity, and will place greater emphasis on offering more cost-effective, noninvasive forms of care.31

Potential Causes

So what lies underneath the inadequate supply of VNIs? Perhaps general neurologists might not be motivated to pursue VN training for financial reasons or lifestyle considerations. They may choose highly remunerated neurohospitalist positions or other more financially gratifying non-VN neurology subspecialties, such as clinical neurophysiology. To complicate matters, those general neurologists who enter vascular neurology training often continue on to complete NI training. That shunting of VNIs has consequences for the clinical stroke workforce because, although those NIs who are also trained as VNIs and could be seen as more versatile stroke specialists capable of covering the clinical stroke services as well, may in practice tend to favor endovascular interventions over medical vascular neurology work, perhaps because of personal interest and salary considerations. The concerns about salary differences between VNIs and NIs are not unfounded. Individuals with procedure-based specialty practices have experienced increasing incomes relative to all other medical practices, including VNIs, so the financial incentives are clear. Given the opportunity to earn a higher income and a more predictable (shift) work schedule, neurology residents are more likely to choose a neurohospitalist, neurointerventional, or other nonvascular neurology subspecialty over a plain vascular neurology position.

The Cardiology Experience

Vascular neurology could look to the field of cardiology for some insights about how to address this issue. Like vascular neurology, there is an expectation of increased future clinical demand that corresponds with the increasing incidence in cardiovascular disease brought about by the aging population. There also is an increasing demand for noninvasive evidence-based procedures provided within clinical care units that emphasize prevention and are organized within hub and spoke systems. There also appears to be a shortage of noninterventional cardiologists in critical rural and underserved regions, where elderly population are concentrated. To reconcile the supply of interventionists in the early 1990s, the excess supply of interventional cardiologists was compared with the number of clinical and preventative cardiologists. The conclusion at that time was that an excessive number of interventional cardiologists were being trained, and there was...
a need for more physicians trained in clinical and preventive cardiology. The recommendation was to reduce the number of cardiology training positions, especially interventional positions, but this resulted in an unexpected chill on the number of physicians who entered cardiology to begin with, and an overall reduction in the number of trained cardiologists. Now there is a national shortage of cardiologists, both clinical and interventional, and there is difficulty in addressing the unmet clinical demand. The lesson for neurologists is clear: do not address the excess of interventionalists by creating policy that decreases the root supply of clinicians in that specialty.

Potential Solutions/Alternatives

Potential solutions to the shortage for VNs are summarized in Table 2 and include (1) expansion of the critical mass of physicians contributing to stroke care, (2) expanding the number of VNs, and (3) decreasing the shunting of VNs into NIs. The first potential solution and a reasonable approach to rapidly expand the critical mass of physicians performing acute stroke work is to cross-train general neurologists with the goal of making them proficient and comfortable with updated acute stroke practices. Potential barriers are financial and cultural. Changing a departmental/group culture of not taking stroke call could be difficult, but it is crucial to break the vicious circle of general neurologists being uncomfortable with managing acute stroke patients because of lack of enough exposure. Adequate financial compensation for acute stroke call might help overcome that barrier. But this financial compensation would need to be substantial to be successful, because current levels of compensation are not stopping general neurologists from declining to take stroke call in many practices around the country. Moreover, given the existing shortage of general neurologists, particularly in rural areas, this approach would require an increase in the number of neurology residency positions. Those neurocritical care and neurohospitalists specialists who are not trained as VNs can still help with stroke call and emergent services. Unfortunately, their training is focused on limited aspects of stroke care, so their contribution to the VN shortage might be restricted to emergent services in detriment of other aspects of vascular neurology, such as outpatient stroke clinics, patients with stroke who do not require intensive care unit, etc.

The second potential solution is to increase the number of VN positions certified by the ACGME. In addition, efforts will be directed toward increasing the Medicare GME dollars allotted for VNs, possibly increasing fellowship reimbursements by 5% to 10% over the next 5 years. Still, current VN positions remain unfilled, suggesting that other unobserved factors are impacting the supply of VN specialists. Perhaps decreasing the tuition debt burden for those pursuing this path might help, but other efforts should be considered by promoting more appealing shift schedules. It is also worth considering how to release VNs of some night and weekend call burden and other clinic responsibilities to minimize burnout and increase the appeal of the specialty for future neurology trainees. In addition to increasing VNs, these efforts may create a positive externality in that general neurologists may become more comfortable and capable of working in vascular care, and, thus, make them more likely to accept stroke call responsibilities. Involving those trainees in non-ACGME fellowships who are allowed to moonlight, particularly the most predisposed neurocritical care and neurohospitalist trainees, might help to initiate a night call culture change in those departments. Finally, to incentivize students to choose VN residency, a compacted vascular track residency program could be developed to shorten total training time and reduce tuition debt burden. Returning to the cardiology example, reducing the path of training is a potential solution to manpower shortage. It is important to coordinate all these efforts to promote career in vascular neurology with the opening of additional training slots, particularly after all the current vascular neurology positions are filled. Another option is to decrease the immigration barriers for those foreign medical graduates wishing to remain in the United States to pursue a vascular neurology career.

The third potential solution is to decrease the shunting of VNs pursuing neurointervention, which results in an oversupply of NIs at the expense of vascular neurology supply. Rather than discouraging individuals from pursuing NI fellowships, perhaps it might be more effective to make NI fellowships more competitive, and in effect, limit the number of individuals who progress beyond VN fellowship training. However, because the supply of NI fellowships does not fall under any public policy making authority and these programs are typically not recognized by the ACGME and subjected to a board certification process, the demand for VN and NI fellows must be shaped by other, less direct forces. Increased ACGME oversight and certification of neurointerventional training programs could serve a dual purpose, to regulate the number of NIs and to assure the quality of NIs going into clinical practice. This appears a more reasonable alternative to those calls to stop the training of NIs altogether. Again, caution should be taken to not disincentivize neurologists who pursue vascular neurology, to avoid situations of shortage like those created in the cardiology world. Incentives should be provided for NIs who work part-time or full-time clinical stroke work.

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Table 2. Potential Solutions to the Manpower Shortage for Acute Stroke Clinical Work

<table>
<thead>
<tr>
<th>Potential Solutions to the Manpower Shortage for Acute Stroke Clinical Work</th>
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<tbody>
<tr>
<td>Expand the critical mass of physicians taking stroke call</td>
</tr>
<tr>
<td>Cross-train general neurologists in performing advanced stroke work</td>
</tr>
<tr>
<td>Increase payment rates for stroke clinic work</td>
</tr>
<tr>
<td>Increase the number of neurology residency programs</td>
</tr>
<tr>
<td>Expand the number of vascular neurologists</td>
</tr>
<tr>
<td>Increase the number of vascular neurology fellowship programs</td>
</tr>
<tr>
<td>Decrease the tuition debt burden</td>
</tr>
<tr>
<td>Improve lifestyle by providing night call, holiday, and weekend backup</td>
</tr>
<tr>
<td>Shorten the path of training for vascular neurologists with a fast-track</td>
</tr>
<tr>
<td>Decrease immigration barriers for foreign medical graduates wishing to</td>
</tr>
<tr>
<td>initiate a vascular neurology career in the United States</td>
</tr>
<tr>
<td>Decrease shunting of vascular neurology into neurointervention</td>
</tr>
<tr>
<td>Decreasing number/accessibility of neurointerventional fellowships</td>
</tr>
<tr>
<td>Equalize reimbursement rates for cognitive stroke work with interventional rates through Accountable Care Organizations (ACOs)</td>
</tr>
<tr>
<td>Compensate for effective care</td>
</tr>
<tr>
<td>Decrease the tuition debt burden</td>
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</tbody>
</table>
Another alternative would be to increase reimbursement rates for clinical cognitive stroke work, equal to the reimbursement of endovascular interventions. In this regard, we can think of a public/private partnership in which health systems use the shared saving they achieve from participating in Accountable Care Organizations (ACOs) to emphasize standard of clinical stroke care as opposed to more costly and less well-established interventions. Other aspects of the Affordable Care Act that may encourage health systems to move toward recruiting VNs involve bundled payments, quality indicators, and patient outcomes. Comparative effectiveness trials of medical stroke care versus neurointerventional treatments may also help to advance efforts to increase supply of VNs. While these approaches continue to evolve, professional societies should work with health system organizations to craft the regulations to support payment for such practice changes. Perhaps these systems could also further incentivize training positions in vascular neurology by offering fellowship opportunities that offer tuition debt reduction. This approach effectively addressed the supply of cardiologists. 36

We recognize there is no single magic bullet solution for this problem, and that some of the solutions proposed are ambitious and may be hard to implement. But the issue is worth the effort of planning. A failure to provide adequate VN support for the growing clinical demand in the United States could have untoward effects on the outcomes of a large number of patients. Progress in the management of acute stroke has the risk of becoming meaningless if there is no workforce able to implement those standards.

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Enrique C. Leira, Brian Kaskie, Michael T. Froehler and Harold P. Adams, Jr

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