Stroke Center Designations, Neurointerventionalist Demand, and the Finances of Stroke Thrombectomy in the United States

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Abstract

Purpose of the Review
This article aims to provide an update on the designation of stroke centers, neurointerventionalist demand, and cost-effectiveness of stroke thrombectomy in the United States.

Recent Findings
There are now more than 1,660 stroke centers certified by national accrediting bodies in the United States, 306 of which are designated as thrombectomy-capable or comprehensive stroke centers. Considering the amount of nationally certified centers and the number of patients with acute stroke eligible for thrombectomy, each center would be responsible for 64 to 104 thrombectomies per year. As a result, there is a growing demand placed on neurointerventionalists, who have the ability to alter the trajectory of large vessel occlusive strokes. Numbers needed to achieve functional independence after stroke thrombectomy at 90 days range from 3.2 to 7.4 patients in the early time window and 2.8 to 3.6 patients in the extended time window in appropriately selected candidates. With the low number needed to treat, in a variety of valued-based calculations and cost-effectiveness analyses, stroke thrombectomy has proved to be both clinically effective and cost-effective.

Summary
Advancements in the early recognition and treatment of stroke have been paralleled by a remodeling of health care systems to ensure best practices in a timely manner. Stroke center–accrediting bodies provide oversight to safeguard these standards. As successful trial data from high volume centers transform into real-world experience, we must continue to reevaluate cost-effectiveness, strike a balance between sufficient case volumes to maintain clinical excellence vs the burden and burnout associated with call responsibilities, and improve access to care for all.
In this review, we focus on how the widespread adoption and implementation of stroke thrombectomy have affected the landscape for patients with acute stroke and health care systems. In the September 2012 supplement to *Neurology®,* the public health impact of stroke thrombectomy was explored.1-3 Over the past 5 years, there has been expansion in patients with acute stroke eligible for thrombectomy and growth in the hospitals and providers performing stroke thrombectomy.4-6 This article reviews the evolution of stroke center designation, neurointerventionist demand, and the changing finances of stroke thrombectomy in the United States.

**Stroke Center Designations in the United States**

The quality of patient care is directly related to clinical outcomes in patients with acute stroke.7,8 Thus, guidelines endorse stroke center certification to enhance best practices by critically reviewing emergency protocols and hospital stroke team processes so that patients may receive appropriate treatment in the fastest achievable times.5 Traditionally, 3 levels of hospital certification have been designated under analogous titles: acute stroke–ready hospital, primary stroke center, and comprehensive stroke center, with comprehensive stroke centers representing the highest level of care8 (Table 1). However, to meet the growing demand of acute stroke intervention, a new designation of thrombectomy-capable center has been created.

To first establish guidance for the development, standards, and operations of stroke centers, the Brain Attack Coalition, a multidisciplinary organization of health care providers dedicated to stroke care, formed a working group to study the logistical aspects of stroke patient care, clinical outcome data, and the economic impact of stroke on the health care system.9 In 2000, the Brain Attack Coalition first recommended the establishment of primary stroke centers, highlighting the need for efficient transport of patients from emergency medical services to the emergency department, where triaging of patients would take place by an acute stroke team guided by rapid imaging evaluation and followed by inpatient care in stroke units.9 In 2005, the Brain Attack Coalition established recommendations for comprehensive stroke centers detailing the need for high-quality open and endovascular neurosurgical procedures and intensive care units.10 In the following years, the development of accrediting bodies helped to standardize acute stroke patient care.

The Joint Commission (TJC), DetNorske Veritas Healthcare, Inc (DNV), Healthcare Facilities Accreditation Program

**Table 1 Stroke Center Capabilities**

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<tr>
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<th>Acute stroke-ready hospital</th>
<th>Primary stroke center</th>
<th>Thrombectomy-capable stroke center</th>
<th>Comprehensive stroke center</th>
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Abbreviations: NCCT = noncontrast head CT; tPA = tissue plasminogen activator. Advanced imaging includes CT angiography, CT perfusion, MRI, magnetic resonance angiography, and magnetic resonance perfusion.

*Adapted from Adeoye et al.5 with permission. Copyright © 2019 American Heart Association.
(HFAP), and various state health departments are responsible for stroke center certification across the United States. The largest accrediting body, TJC, first developed a primary stroke care certification program with the American Heart Association/American Stroke Association in 2003, a comprehensive stroke center certification program in 2012, and later, a certification program for acute stroke ready hospitals in 2015.11 In 2008, DNV received notification from the US Centers for Medicare & Medicaid Services that it may judge hospitals in compliance with the Medicare & Medicaid Services Conditions of Participation for hospitals setting a course for their stroke center certification process.12 The HFAP was first accredited in 1965 and established a primary stroke certification program in 2006 guided by the Brain Attack Coalition recommendations.9 In 2012, HFAP finalized its comprehensive stroke certification program and has since added stroke-ready and thrombectomy certification programs.13 As of December 2019, there were 1403 TJC-accredited stroke centers, 221 DNV-accredited stroke centers, and 65 HFAP-accredited stroke centers12,13 (Figure).

Despite a near-uniform definition of certification levels by the various certifying bodies, there is evidence of differences in quality of care and outcomes among the certifying organizations. In a 3-year analysis from 2010 through 2012, primary stroke centers certified by TJC or DNV had higher tissue plasminogen activator use rates in eligible patients and shorter door-to-needle times compared to centers certified by state-based agencies when grouped as a whole. In-hospital mortality was also higher in centers certified by state-based agencies.14

**Acute Stroke-Ready Hospitals**
Acute stroke–ready hospitals have both CT access and stroke team readiness 24 h/d, 7 d/wk, 365 d/y and are thus capable of delivering recombinant tissue plasminogen activator to appropriate candidates with acute stroke at all times. Acute stroke–ready hospitals often serve smaller, more remote regions, where there may be gaps in primary stroke centers or comprehensive stroke centers. Acute stroke–ready hospitals are thus tasked with developing protocols for rapid evaluation and determination of the level of care that a patient with stroke requires and, as needed, emergency transfer to higher-level care centers for additional management.4 Given the often isolated location of acute stroke–ready hospitals, acute stroke evaluation may be conducted with the use of audiovisual telemedicine technology to incorporate neurologic expertise at the level of a primary or comprehensive stroke center.15 Such telestroke protocols help to incorporate acute stroke–ready hospitals into larger networks of acute stroke care by supporting the emergency use of IV thrombolysis and aiding the emergency transfer of patients with acute stroke to centers capable of performing stroke thrombectomy.

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**Figure** Continental US Stroke Centers Accredited by TJC, DNV, and HFAP

Shown by designation: acute stroke–ready hospital (blue, top left), primary stroke center (red, top right), thrombectomy-capable stroke center (green, bottom left), and comprehensive stroke center (purple, bottom right). Not included are Alaskan (n = 3), Hawaiian (n = 7), and Puerto Rican (n = 1) accredited stroke centers, as well as state-certified hospitals. Figure made in partnership with Zahra Parnianpour and Lynn Movish, Tableau Mapbox OpenStreetMap contributors. Data available under Open Database License at openstreetmap.org and opendatacommons.org. DNV = DetNorske Veritas Healthcare, Inc; HFAP = Healthcare Facilities Accreditation Program; TJC = The Joint Commission.
Primary Stroke Centers
Primary stroke centers differ from acute stroke ready hospitals primarily in that they can provide ongoing care of patients with acute stroke in dedicated stroke units, are often capable of performing stroke thrombectomy, and may admit patients with hemorrhagic stroke to a neurocritical care unit or intensive care unit. Primary stroke center status is the most common designation, with 1,262 TJC-, DNV-, and HFAP-certified primary stroke centers across the United States.

Comprehensive Stroke Centers
Comprehensive stroke centers are capable of the highest level of neurologic and neurosurgical care for all patients with ischemic and hemorrhagic stroke. Thus, comprehensive stroke centers provide wide-ranging etiologic evaluation for rare ischemic conditions and have the ability to treat intracranial hemorrhage with open and endovascular neurosurgical techniques, including the management of aneurysmal subarachnoid hemorrhages and hemorrhagic vascular malformations, among other conditions. As a result, comprehensive stroke centers commonly receive interfacility patient transfers for higher level of care. These centers are usually urban or centrally located tertiary or quaternary medical facilities where the volume of cases is large and clinical outcomes reflect refined experience. There are currently 262 TJC-, DNV-, and HFAP-certified comprehensive stroke centers across the United States.

Thrombectomy-Capable Stroke Centers
With the advent of endovascular thrombectomy for acute large vessel occlusive strokes, a new designation has emerged, albeit with some controversy: thrombectomy-capable stroke centers, centers capable of delivering acute endovascular stroke care. The new designation of thrombectomy-capable stroke center by the American Heart Association in collaboration with TJC has led to debate as to the optimal means of ensuring best practices. The debate hinges on 2 main issues: regionalization of care and procedural volume. A recent study of stroke center certification adoption between 2009 and 2017 found a greater distribution of certified stroke centers in urban, high-income, and high-profit-margin locations. While thrombectomy-capable stroke centers may operate by filling a void in regions without comprehensive stroke centers, the role of these centers emerging in regions with already operating comprehensive stroke centers is less clear. The concern exists that thrombectomy-capable stroke centers operating within a region of an already existing comprehensive stroke center may, by performing only a handful of thrombectomies a year, dilute the volume at nearby comprehensive stroke centers and adversely affect the quality of patient care for patients in a region without providing additional coverage. Therefore, thrombectomy-capable stroke centers may best operate in truly underserved or rural geographic regions without timely access to a comprehensive stroke center.

Perhaps the most critical issue of thrombectomy-capable stroke centers is the neurointerventionalist’s stroke thrombectomy experience. There is a direct relationship between a neurointerventionalist’s procedural volume and, more broadly, the procedural volume of a stroke center and the procedural success and clinical outcome of the thrombectomy. In a nationwide study including 118 institutions, high-volume institutions averaged >35 thrombectomies per year (>132 thrombectomies over the 45-month study) and had lower mortality rates compared to low- and medium-volume centers. Currently, as part of the eligibility criteria for both thrombectomy-ready and comprehensive stroke centers, TJC requires a mandatory procedural volume for each neurointerventionalists of 15 thrombectomies in the previous 12 months or 30 thrombectomies over the previous 24 months. While the eligibility criteria specify a given neurointerventionalist’s procedural volume, the total procedural volume of an institution is not addressed. Proficiency from the emergency department, acute stroke team, imaging technicians, nursing care, surgical team, neurointensive care team, and rehabilitative team is critical to procedural success and functional outcome after large vessel occlusive stroke. The robust treatment effect of thrombectomy demonstrated in randomized clinical trials occurred at high-volume centers, and limited data suggest that similar results can be achieved in lower-volume centers. The guidelines from an international consortium including the Society of NeuroInterventional Surgery, Society of Vascular and Interventional Neurology, World Stroke Organization, and World Federation of Interventional Neuroradiology, among others, recommend a minimum of 50 thrombectomies per center per year to maintain a thrombectomy-capable certification (level 1 or 2 center) with the expectation that each neurointerventionalist performs a minimum of 15 thrombectomies per year. However, further data are required to ascertain the total number of medical centers capable of matching procedural volume recommendations in an effort to achieve optimal procedural and clinical outcomes.

Neurointerventionalist Demand
The revolution of acute stroke care has ushered in an era in which thousands more patients with acute stroke annually may benefit from stroke thrombectomy, but there needs to be a commensurate increase in the provision of the treatment. The benefit of mechanical thrombectomy for patients with acute anterior circulation proximal large vessel occlusive strokes has now been extended up to 24 hours after symptom onset in select patients. In the early window (up to 6 hours after symptom onset), ~10% of patients with stroke are thrombectomy candidates, whereas early estimates demonstrate the ~9% of patients with stroke are eligible for thrombectomy presenting strictly in the extended time window (6–24 hours after symptom onset; 5.7%–12.9%, depending on inclusion criteria). This equates to 1.7% to 2.2% additional patients with acute stroke and a total of 11.7% to 12.2% of all patients with stroke being eligible for thrombectomy. However, this may reflect strict
inclusion criteria; a single-center study demonstrated that up to 20% of patients with anterior circulation large vessel occlusions were eligible for endovascular therapy using less restrictive criteria.31 Limited retrospective studies, with varying definitions of large vessel occlusion, revealed that 24% to 38% of acute ischemic strokes are due to a combination of anterior and posterior circulation large vessel occlusion.32,33 Using available data, we estimate that there may be ≈19,500 to 32,000 patients with acute stroke eligible for thrombectomy annually across the United States (Table 2).

If we consider the current demand of eligible candidates (19,502–31,896) and the current estimates of comprehensive stroke centers (262 certified by TJC, DNC, or HFAP) and thrombectomy-capable stroke centers (44 certified by TJC), each center would be responsible for 64 to 104 thrombectomies per year, or roughly 1 thrombectomy every 4 days. However, these projections do not consider the primary stroke centers capable of performing thrombectomies or the stroke centers that are not nationally certified. In addition, these projections do not consider variable population densities, geographic dispersion of stroke centers, and transfer patterns that influence the number of patients with acute stroke eligible for thrombectomy who are seen by thrombectomy centers.

With expectations that inclusion criteria for thrombectomy will continue to expand, it is only reasonable to believe that a growing number of neurointerventionalists will be needed. Despite a still-to-be-defined balance between supply and demand, there is consensus that multiple trained neurointerventionalists are needed to compose a team to provide adequate coverage and care. International consensus recommendations call for a minimum of 3 neurointerventionalists per team.24 In a 5-year South Korean study, the coverage provided by hospitals with 3 neurointerventionalists was associated with a 2-fold increase in a favorable outcome at 3 months compared to hospitals employing a single neurointerventionalist.34 Eligibility among accrediting bodies does not define the exact number of neurointerventionalists required for coverage, only that coverage is available 24 h/d, 7 d/wk, 365 d/y. The demand for a team of several neurointerventionalists is in direct contrast to the need for sufficient case volume to maintain clinical excellence vs the exhaustive burden of call requires further consideration.

Significant concern remains regarding burnout among neurointerventionalists. Increasing eligibility for stroke thrombectomy adds to greater call responsibility for neurointerventionalists, especially during nonworkhours and early mornings.35,36 In a recent survey, 56% of neurointerventionalists reported burnout, with nearly half of respondents reporting being on call every day or every other day. Added compensation was reported as a protective factor, whereas covering multiple hospitals and feeling underappreciated by departmental or hospital leadership were associated with greater odds of burnout.37 According to a nationally representative sample of Medicare beneficiaries from 2009 through 2015, most endovascular thrombectomy was completed by radiology-trained neurointerventionalists, followed by neurologists and neurosurgeons.38 According to fellowship trainees and society membership counts, there continues to be substantial representation from each of these training backgrounds.

### Finances of Stroke Thrombectomy

There are ≈795,000 new or recurrent strokes per year in the United States, of which 87% are ischemic stroke.39 By 2030, a 20.5% increase in the prevalence of US adults with stroke compared to 2012 is expected; thus stroke will continue to be a leading contributor to long-term disability among US citizens.39 Poststroke complications are vast and include deep vein thromboses, pulmonary emboli, urinary tract infections, aspiration pneumonias, seizures, constipation, decubitus ulcers, depression, anxiety, aphasia, pseudobulbar affect, cognitive impairment, gait instability, falls, and fractures, all of which contribute to long-term costs associated with stroke. The 2014–2015 estimate of the total (direct plus indirect) cost of stroke was $45.5 billion in the United States.39 The total direct costs are projected to more than double between 2015 and 2035 to $94.3 billion, with much of the cost attributed to the care of individuals ≥80 years of age.39

When considering the total cost of stroke, multiple studies have confirmed the relationship between the 3-month poststroke modified Rankin Scale (mRS) score and long-term outcomes, with less functional 3-month mRS scores correlated with higher costs despite shorter life expectancy.40-44 Large vessel occlusive strokes often contribute to less functional 3-month

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**Table 2** Estimates of Eligible Stroke Thrombectomy Candidates

| Total strokes in United States annually, n | 795,00039 |
| Percent ischemic stroke | 87%39 |
| Low-range estimate, n | 691,650 |
| High-range estimate, n | 31,896 |
| Percent ischemic stroke presenting with acute LVO | 24.1%32–37.8%32 |
| 166,688 |
| 261,444 |
| Percent acute LVO eligible for thrombectomy | 11.7%–12.2%20,23,30 |
| 19,502 |
| 31,896 |

Abbreviation: LVO = large vessel occlusion.
mRS scores and contribute to nearly 60% of poststroke dependency and 90% of poststroke mortality.\textsuperscript{32,44} Stroke thrombectomy has revolutionized the care for patients presenting with large intracranial vessel occlusions, achieving better outcomes among a broad range of baseline categories.\textsuperscript{40-49}

Stroke thrombectomy is by far the most effective intervention for anterior circulation proximal large vessel occlusive strokes, with numbers needed to treat to achieve treatment in- dependence at 90 days (mRS score 0–2) in the early time window ranging from 3.2 to 7.4 patients\textsuperscript{60,51} and 2.8 to 3.6 patients in the extended time window.\textsuperscript{27,28} In addition, in a patient-level data meta-analysis of 5 randomized controlled trials of endovascular thrombectomy for anterior circulation proximal large vessel occlusive strokes in the early window, the number needed to treat to reduce disability by 1 mRS grade was 2.6 patients.\textsuperscript{47} This type of ordinal analysis is beneficial in reflecting the nonlinear differences between mRS grades; e.g., shifts from mRS score of 2 to 3 to 4 demonstrated substantial leaps in costs,\textsuperscript{41,44} and a shift from mRS score of 3 to 4 demonstrated a considerable decline in quality of life relative to other shifts.\textsuperscript{52,53} In a recent study, acute medical care costs associated with stroke ranged from $6,302 (mRS score 0) to $14,918 (mRS score 2) to $26,071 (mRS score 5).\textsuperscript{44} Total costs 1 year after stroke were estimated at $9,114 (mRS score 0) to $26,061 (mRS score 2) to $83,326 (mRS score 5). This distribution of direct costs according to poststroke disability continued in the chronic phase after ischemic stroke.

The unequivocal functional outcome benefit led to numerous studies evaluating the cost-effectiveness and societal economic impact of endovascular thrombectomy.\textsuperscript{54-59} A recent analysis from the Highly Effective Reperfusion Evaluated in Multiple Endovascular Stroke Trials (HERMES) collaborators demonstrated the association among higher anterior circulation stroke thrombectomy reperfusion grades, functional outcomes (as measured by the mRS), and long-term cost savings with increased lifetime quality-adjusted life-years.\textsuperscript{77} The functional outcome and cost-effectiveness (at the health care and societal levels) were greatest with complete reperfusion.\textsuperscript{57}

However, there is an increased upfront cost of thrombectomy, driven primarily by the initial procedural costs.\textsuperscript{58} In the Solitaire With the Intention for Thrombectomy as Primary Endovascular Treatment for Acute Ischemic Stroke (SWIFT-PRIME) trial, the index hospitalization costs were $17,183 higher in those receiving anterior circulation stroke thrombectomy and standard medical therapy compared to those receiving standard medical therapy alone ($45,761 vs $28,578), and the 90 day poststroke costs were $12,279 higher in those receiving stroke thrombectomy and standard medical therapy compared to those receiving standard medical therapy alone ($57,031 vs $44,752). However, these initial treatment costs of stroke thrombectomy were offset by lifetime gains in quality-adjusted life-years and a health care cost savings of $23,203 per patient compared to standard medical therapy alone.\textsuperscript{58}

In an analysis of pooled patient-level data in the early window (<6 hours after stroke symptom onset), anterior circulation stroke thrombectomy in addition to standard medical therapy led to an increase of 1.59 quality-adjusted life-years (range 0.47–2.12 years) with economical incremental cost-effectiveness ratios (mean $3,110 per quality-adjusted life-year) across a variety of clinical subgroups compared to standard medical therapy alone.\textsuperscript{56} In a comparable analysis using a 20-year time horizon, the incremental cost per quality-adjusted life-year gained after anterior circulation stroke thrombectomy in the early time window over a 20-year period was $11,651.\textsuperscript{54} Similar results were found when thrombectomy was performed in the extended time window (between 6 and 24 hours after stroke symptom onset). Incremental cost per quality-adjusted life-year was $5,253 when performed up to 16 hours from symptom onset and $3,712 when performed up to 24 hours from symptom onset.\textsuperscript{59}

As the role of thrombectomy evolves to include larger ischemic cores and more distal occlusions, the cost-effectiveness of such procedures will need to be re-examined. In a recent study, the patient subgroups with large ischemic cores and with distal occlusions (classified as middle cerebral artery M2 segment occlusions) yielded the least favorable mean incremental cost-effectiveness ratios ($14,273 and $28,812 per quality-adjusted life-year, respectively) and the lowest acceptability rates (75.4 and 59.44%, respectively) at a willingness-to-pay of $50,000 per quality-adjusted life-year.\textsuperscript{56}

In summary, thrombectomy for anterior circulation large vessel occlusive strokes is clinically and cost-effective. However, it is not without high procedural costs and requires an investment in specialized training and customized stroke systems of care. Initial treatment, index hospitalization, and rehabilitation costs fall on policyholders and taxpayers, while specialized training and customized care network costs fall on health care systems. The benefit to society is seen in the reduction in long-term health care costs evidenced by additional lifetime quality-adjusted life-years.

**Conclusion**

Stroke thrombectomy improves clinical outcomes and is cost-effective. Advancements in imaging and expansion of the candidacy of patients with acute stroke for thrombectomy have been paralleled by a remodeling of health care systems to ensure best practices in a timely manner. Stroke center– accrediting bodies provide oversight to safeguard these standards. As the delivery of stroke thrombectomy expands outside of high-volume centers, the cost-effectiveness needs to continually be re-evaluated, balancing the potential for burnout, the need for sufficient volumes, and access to care.
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Appendix Authors

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<td>Rush University Medical Center, Chicago, IL</td>
<td>Drafting/revision of the manuscript for content, major role in the acquisition of data, analysis and interpretation of data</td>
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<tr>
<td>Michael Chen, MD</td>
<td>Rush University Medical Center, Chicago, IL</td>
<td>Drafting and reviewing manuscript, study concept and design, analysis and interpretation of data</td>
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References


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