Original research

Updated estimates of large and medium vessel strokes, mechanical thrombectomy trends, and future projections indicate a relative flattening of the growth curve but highlight opportunities for expanding endovascular stroke care

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ABSTRACT

Background A study was undertaken to determine the incidence of acute ischemic stroke (AIS) and strokes related to large (LVO) and medium (MVO) vessel occlusions, and to estimate annual mechanical thrombectomy (MT) volume, past trends and future growth.

Methods A population-based analysis was performed to estimate the rate of AIS, LVOs (internal carotid artery terminus, M1 branch of the middle cerebral artery, basilar artery) and MVOs (M2 and M3 branches of the middle cerebral artery, anterior and posterior cerebral arteries). MT estimates were determined from multiple governmental data sources. Annual US numbers were adjusted for population growth.

Results The incidence of AIS is estimated at 216 (95% CI 199 to 238)/100 000 persons/year or 718 191 (95% CI 661 483 to 791 121) AIS/year in the USA. A vascular occlusion was observed in 21% of patients with AIS (95% CI 15 to 29). The rate of LVO was 24/100 000 persons/year (95% CI 19 to 31) or 80 075 (95% CI 62 457 to 104 375) LVOs/year, and the rate of MVO was 20/100 000 persons/year or 65 798 (95% CI 45 555 to 95 110) MVOs/year. MT estimates for 2021 are 39 164 procedures with a flattening of the growth curve from 2019 (9%, 2020–2021; 4%, 2019–2020) as opposed to initial steep growth from 2015 to 2018. Current MT procedures represent 5% of all AIS, 27% of all vascular occlusions (LVO+MVO) and 38% of all LVO and M2 occlusions. The current trajectory indicates a future growth of 5–10%/year for the next several years.

Conclusion A decline in MT growth is observed. The incidence of LVO+MVO is estimated at 44/100 000 persons/year or almost 144 000 large and medium vessel strokes annually. Of these, currently an estimated 27% undergo an MT procedure, indicating an opportunity for growth. Further expansion may require focusing on the elderly, medium vessel strokes and workflow efficiencies from diagnosis to treatment.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The incidence of large vessel occlusions has been reported in prior population studies. The mechanical thrombectomy volume has, however, not been studied.

WHAT THIS STUDY ADDS

⇒ The current study provides population-based estimates of all acute ischemic stroke and strokes related to intracranial vascular occlusions. The study also charts the annual volumes and growth of mechanical thrombectomy procedures from 2015 to 2021 and provides estimates for future trends.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The information provided from the study can be useful for research on distal and medium vessel occlusions and for planning workflow and systems of endovascular stroke care.

INTRODUCTION

The 'Heart disease and stroke statistics—2022 update' published by the American Heart Association (AHA) continues to list about 795 000 people having a stroke annually, of which 87% are estimated as ischemic.[1] The AHA publishes this comprehensive report every year, but the 795 000 estimate has not changed since 2010 despite the change in the US population. In particular, the 65 years and older population per the US Census Bureau grew by about 34% over the past decade (https://www.census.gov/newsroom/press-releases/2020/65-older-population-grows.html) and accounts for the majority of patients suffering from a stroke.[1] As endovascular therapy becomes more available with more hospitals and physicians offering this treatment, a review of the current landscape regarding disease burden and thrombectomy estimates can help define future directions.

Accurate measurement of disease incidence in a target population is built on three important parameters: (1) a well-defined population; (2) access to most if not all of the population; and (3) a reliable marker for diagnosing the disease. When determining large or medium vessel strokes as a percentage of all acute ischemic strokes (AIS), defining the denominator is also critical as heterogenous definitions can lead to variable results.[2 3] For example, the percentage of large vessel occlusions (LVOs) in patients with a National Institutes of Health Stroke Scale (NIHSS) score of >6 would be much higher than the rate of LVOs in all patients with suspected AIS.

The objective of this paper is to provide an updated population-based estimate of large and medium vessel strokes meeting the three key parameters of a well-defined target population, access to almost all of the population and vascular neuroimaging to localize the intracranial occlusion. The denominator is defined as all AIS using the same ICD codes on which the AHA estimates are based.[4] This was done to maintain consistency and to allow repeatability of the study in different geographic settings. The paper also presents an estimate of the current endovascular stroke procedures, the rate of growth of these procedures over the past 5 years, and a projected volume based on different growth rates for the next 5 years.

METHODS

Estimating the incidence and rate of large and medium vessel strokes

The methodology uses county level data for AIS coupled with vascular neuroimaging at admission to generate the disease incidence for the target population, similar to previous studies.[5 6] Patients with AIS were identified using ICD codes (433.xx, 434.xx and 435.xx) from a well-defined four-county target population, defined as the primary service area, served by a single comprehensive stroke center which received 85% of all patients with AIS from that catchment population. The 85% estimate is based on a comparison of a patient's domicile and the location of the treatment facility for the given ICD codes. The data were obtained for a 3-year period to smooth out variations.

A total of 2798 patients with AIS were identified over the 3-year period. Of these, 2739 (98%) had a vascular neuroimaging study at admission. The neuroimaging study was a CT angiogram in 2490 (91%) patients and an MR angiogram in 249 (9%) patients. An intracranial large vessel occlusion (LVO) was defined as involvement of the internal carotid artery terminus (ICA-T), middle cerebral artery (MCA) mainstem with or without involvement of a bifurcation branch (M1) or the basilar artery (BA). A medium vessel occlusion (MVO) was defined as an isolated proximal occlusion of a MCA bifurcation branch (M2), isolated occlusion of an M3 branch (M3), isolated occlusion of the posterior cerebral artery (PCA), and isolated occlusion of the anterior cerebral artery (ACA) A1 or A2 segments.

The incidence of LVO and MVO was calculated for the target population primary service area per 100 000 people per year. The results were extrapolated to the US population as of January 1, 2022 and stratified by age.

Estimating thrombectomy numbers

Data sources

We used the Medicare Severity–Diagnosis Related Group (MS-DRG) codes 23 and 24 to extract the thrombectomy numbers from three data sources. These sources were the Standard Analytic File (SAF), the Healthcare Utilization Project (HCUP) National Inpatient Sample (NIS), and the Medicare Provider Analysis and Review (MEDPAR) files.

Standard Analytic File (SAF)

The Medicare inpatient data were drawn from 2015 to 2021 Medicare 100% inpatient SAFs. These contain all hospital inpatient claims paid with dates of service during that time period for traditional Medicare fee-for-service beneficiaries. Beneficiaries enrolled in a Medicare Advantage managed care plan are not included, which accounted for 34% of all Medicare beneficiaries in 2017, 36% in 2018, 37% in 2019, 40% in 2020, and 43% in 2021. The 2017–2019 values come from 2018, 2019, 2020, 2021, and 2022 publications of the Annual Report of The Boards of Trustees of The Federal Hospital Insurance and Federal Supplementary Medical Insurance Trust Funds.

Inpatient SAFs were used to find the total Medicare fee-for-service (FFS) discharge volume based on the code groups listed on each code group worksheet. Discharges from facilities in US territories were excluded (Puerto Rico, Guam, Virgin Islands, American Samoa, Northern Marianas Islands, etc). Only short-term and critical access hospitals are included.

Healthcare Utilization Project (HCUP) National Inpatient Sample (NIS)

The national payer estimates were drawn from the calendar years 2017, 2018 and 2019 HCUP NIS data files. The HCUP NIS is a 20% sample of discharges from all community hospitals participating in HCUP, excluding rehabilitation and long-term acute care hospitals. The NIS covers all patients including individuals covered by Medicare, Medicaid or private insurance, as well as those who are uninsured.

Medicare Provider Analysis and Review (MEDPAR) files

The MEDPAR file contains records for 100% of Medicare beneficiaries who use hospital inpatient services (https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/MedicareFeeforSvcPartsAB/MEDPAR). The following MEDPAR sources were used:

- MedPAR FY 2015 final rule file (FY 2013 data) and 2012 HCUP
- MedPAR FY 2016 final rule file (FY 2014 data) and 2013 HCUP
- MedPAR FY 2017 final rule file (FY 2015 data) and 2014 HCUP
- MedPAR FY 2018 final rule file (FY 2016 data) and 2015 HCUP
- MedPAR FY2019 final rule file (FY2017 data) and 2016 HCUP
- MedPAR FY2020 final rule file (FY2018 data) and 2017 HCUP
- MedPAR FY2021 final rule file (FY2019 data) and 2017 HCUP
- MedPAR FY2022 final rule file (FY2020 data) and 2018 HCUP
- MedPAR FY2023 final rule file (FY2021 data) and 2019 HCUP

All-payer total volume calculations

The total market volume is equal to the estimate of total US discharges that include the specified procedure codes (online supplemental table 1) and/or diagnosis codes (online supplemental table 2) related to mechanical thrombectomy (MT) and AIS, respectively. In the first step the Medicare fee-for-service (FFS) beneficiary discharges are increased by the percent of Medicare Advantage (HMO) patients to get an estimate of the total Medicare FFS and Medicare HMO discharges. In the second step, the total market all-payer volume is calculated by inflating the total Medicare count (Medicare FFS+Medicare HMO) by the NIS proportion of Medicare to all discharges for that procedure type or condition. The final calculation is thus (Medicare FFS and HMO estimate)/NIS Medicare percent.

Table 1 Rate of intracranial vascular occlusion in patients with acute ischemic stroke (AIS) for the target population (n=1361)

Occlusion site	All AIS (n=1361)	Percentage	Lower CI	Upper CI
None	1079	79.3%	76.8%	81.5%
Any intracranial vascular occlusion	282	21%	15.3%	29%
Breakdown of vascular occlusion by site				
M1	120	9%	7.3%	10.6%
M2	41	3%	2.2%	4.2%
M3	35	2.6%	1.8%	3.7%
PCA	33	2.4%	1.7%	3.5%
BA	24	1.7%	1.1%	2.7%
ACA	15	1.1%	0.7%	1.9%
ICA-T	8	0.6%	0.3%	1.2%
Other*	6	0.4%	0.2%	1.0%

*Other: superior cerebellar artery, posterior inferior cerebellar artery, anterior inferior cerebellar artery.
ACA, anterior cerebral artery; BA, basilar artery; ICA-T, internal carotid artery terminus; M1, M2, M3, branches of middle cerebral artery; PCA, posterior cerebral artery.

RESULTS

There were 1361 patients with a diagnosis of AIS over the 3-year period in the target population. Of these, 53% were women. The mean±SD age of the cohort was 69±15.6 years and the median was 71 years (IQR 57–82). The majority of patients (n=1079, 79%) did not have an identifiable intracranial vascular occlusion. Any vascular occlusion was seen in 282 (21%) of the patients with AIS. There were 152 patients (11%, 95% CI 8.7% to 14.5%) with a LVO (M1, ICA-T, BA) and 125 patients (9%, 95% CI 6% to 13%) with a MVO. A breakdown of all the occlusion sites is shown in table 1.

The incidence of AIS was estimated at 216 (95% CI 199 to 238) per 100 000 persons per year. This extrapolates to 718 191 (95% CI 661 483 to 791 121) AIS per year in the USA, based on the US population as of January 1, 2022 (n=332 403 650) obtained from the US Census Bureau (https://www.census.gov/popclock/). Figure 1 shows an estimated incidence of 44/100 000 persons/year (95% CI 33 to 60) for all intracranial vascular occlusions or 145 873 (95% CI 108 102 to 199 485) LVOs and MVOs in the USA per year. The incidence of LVOs is estimated at 24/100 000 persons/year (95% CI 19 to 31) or 80 075 annual LVOs in the USA (95% CI 62 547 to 104 375). The incidence of MVO is estimated at 20/100 000 persons/year (95% CI 14 to 29) or 65 798 MVOs per year in the USA (95% CI 45 555 to 95 110). The incidence of LVO+M2 would be 31/100 000 persons/year or 101 801 LVOs per year that include M1, M2, ICA-T, and BA (95% CI 78 225 to 134 381). Different permutations of these can be obtained from the occlusion site breakdown in figure 1.

The majority of patients (63%) were in the ≥65 year age group. A vascular occlusion (LVO or MVO) was seen in 23% of patients in the ≥65 age group compared with 17% in the <65 age group (p=0.04; OR 0.73, 95% CI 0.54 to 0.99). The median NIHSS score was 16 (IQR 9–23) for patients with an LVO, 6 (IQR 3–12) for patients with an MVO, and 4 (IQR 2–9) for patients without an identifiable vascular occlusion (p<0.0001).

The estimated MT volume from 2015 to 2021 and year-over-year growth is shown in figure 2. The compound annual growth rate from 2015 to 2021 was 24%. A relative flattening of the growth curve is seen from 2018 to 2021. The regional distribution of 2021 MT volume in the USA in figure 3 shows that the North and the Southeast regions account for almost half of all

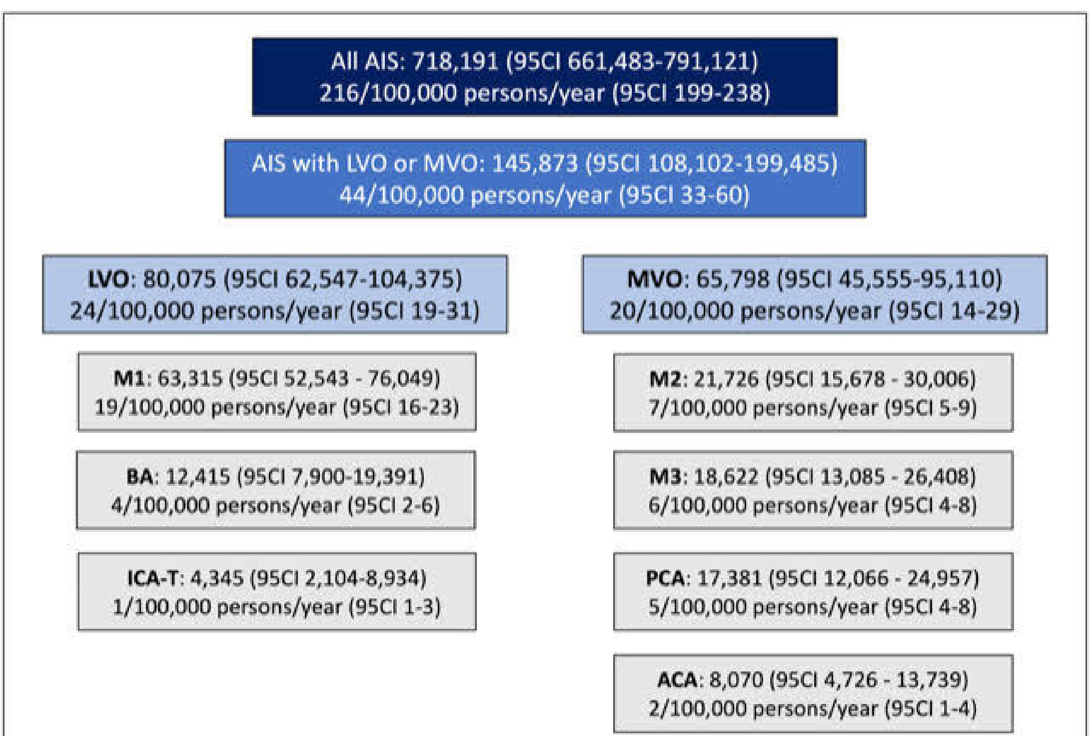

Figure 1 Population incidence of acute ischemic stroke and large and medium vessel strokes. The incidence is listed as rate per 100 000 persons per year and also as estimated total strokes per year. ACA, anterior cerebral artery; BA, basilar artery; ICA-T, internal carotid artery terminus; LVO, large vessel occlusion; MVO, medium vessel occlusion; PCA, posterior cerebral artery.

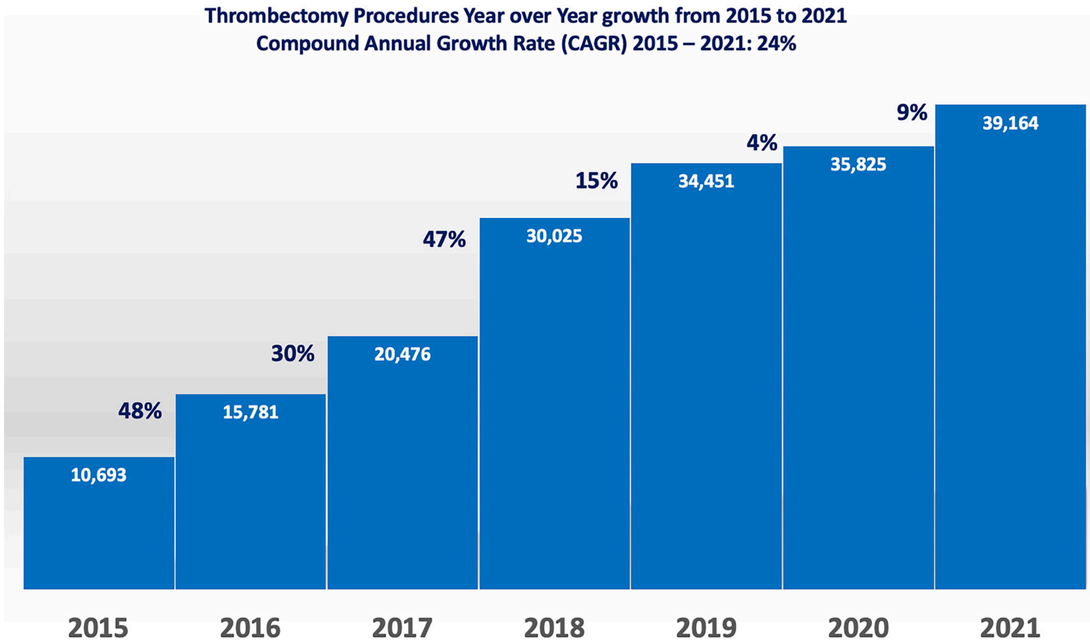

Figure 2 Estimates of mechanical thrombectomy procedures per year. The percentages above the bars show the growth rate from the previous year.

MT procedures. The per capita rate shows a lower MT volume per population in the western USA compared with the east.

Figure 4A shows MT procedures as a proportion of all patients with AIS and patients with underlying vascular occlusions. The percentage of all patients with AIS undergoing MT increased from 2% in 2015 to 5% in 2021. For patients with a vascular occlusion, MT procedures increased from 8% in 2015 to 27% in 2021 (figure 4). MT as a percentage for all LVOs and M2 occlusions are shown separately.

Using the 2021 MT numbers as a baseline, figure 5 shows the projected MT estimates for the next 6 years at year-over-year growth rates of 5%, 10% and 15%, respectively, with a likely growth rate between 5% and 10%. The proportion of patients with AIS undergoing MT could double from 5% in 2021 to 10% in 2028 if MT volume grows at 10% per year (figure 4B).

DISCUSSION

Our data indicate a steep growth in MT procedures in the first few years (2015–2018) and relative flattening of the curve in recent years (2019–2021). This incidentally coincides with the onset of the COVID-19 pandemic. The impact of the pandemic

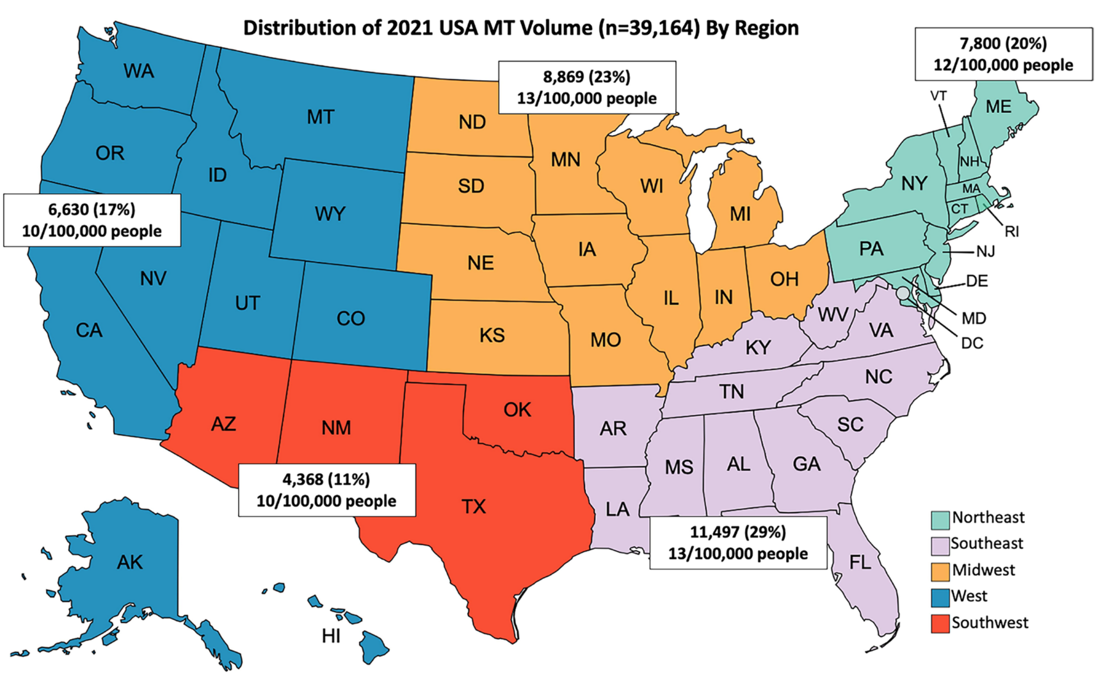

Figure 3 Distribution of 2021 mechanical thrombectomy (MT) procedures in the USA by region. The estimated MT procedures for each region are shown with the percentage of the total 2021 MT volume in parentheses. The rate of these procedures for the population in each region is listed as MT procedures per 100 000 people.

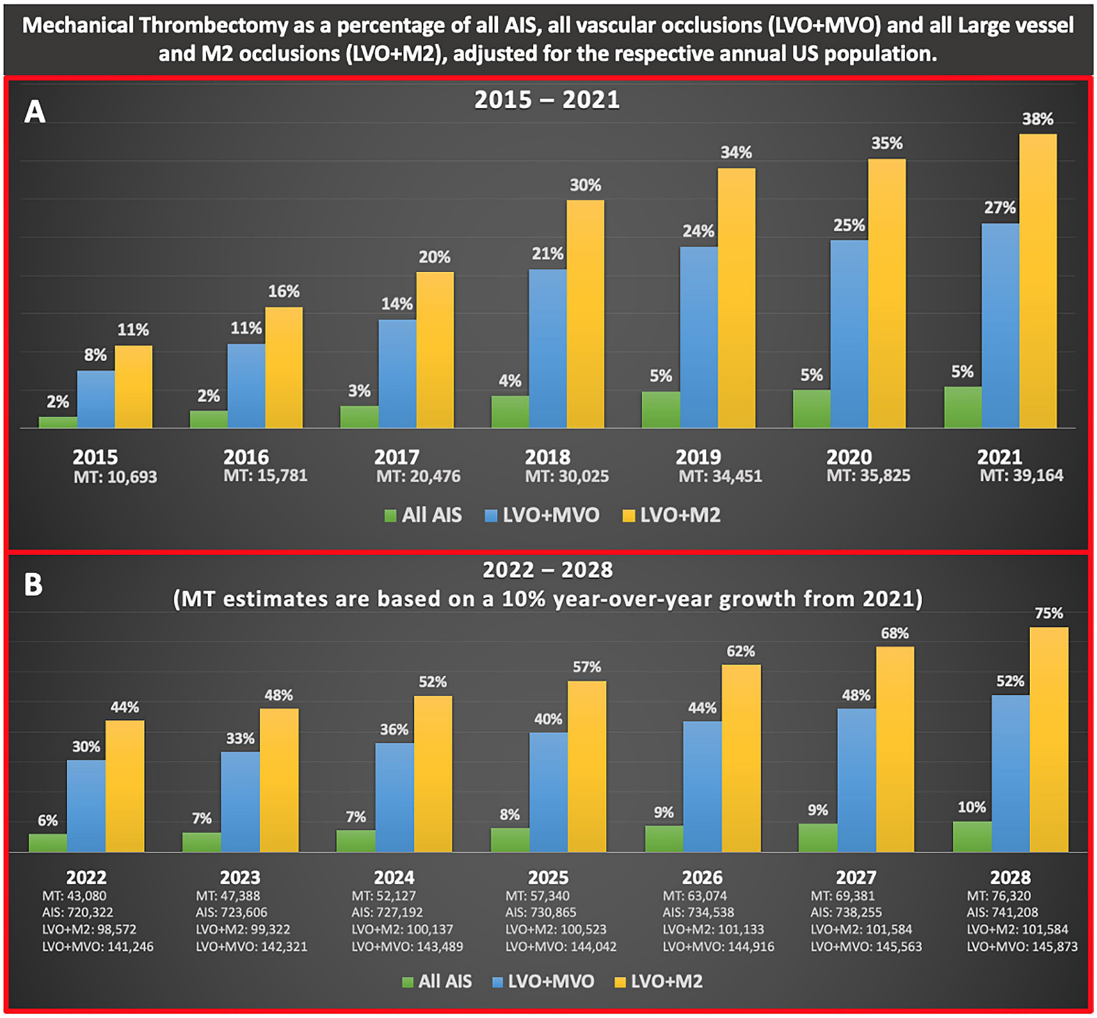

Figure 4 Annual mechanical thrombectomy (MT) procedures in the USA as a percentage of all acute ischemic stroke (AIS), all large and medium vessel strokes (LVO+MVO) and all large vessel (LVO) and M2 occlusions. The disease incidence is adjusted for the expected year-over-year change in the US population. (A) Data presented from 2015 to 2021 with MT estimates derived from the methodology described in this paper. (B) Future estimated growth in MT procedures from 2022 to 2028 based on a 10% annual growth rate from the 2021 MT volume.

on the epidemiology of AIS is difficult to quantify because the literature is mixed. One recent meta-analysis showed an increased risk of ischemic stroke,[7] other studies describing regional experiences in emergent stroke care showed a decline in acute stroke admissions and reperfusion rates,[8] while another regional study did not show any differences in the treatment metrics between pandemic and pre-pandemic cases.[9] A few studies showed a disruptive effect of the pandemic on stroke care[10] with a significant decline in acute stroke presentations.[11 12] Other studies have shown an increased incidence and severity of LVOs in patients with COVID-19.[13–16] It is reasonable to assume that there was some disruptive effect of COVID-19 on acute stroke care, but it may be a stretch to attribute the entire decrease in MT growth since 2018 to the pandemic. Supply chain issues related to a shortage of iodinated contrast[17 18] have impacted radiology departments throughout the country, but there are no reports—and it is unlikely—that this affected emergent care.

One possible explanation for the recent decline in growth is that the initial rapid adoption of MT after 2015 captured the 'low hanging fruit'. There had been a significant slump in endovascular stroke care following the publication of the negative MT trials in 2013,[19 20] but from an infrastructure perspective many centers maintained comprehensive endovascular capabilities, neurointerventional staffing, and established referral pathways. Once the efficacy of endovascular stroke therapy was proven, these centers rapidly geared up to treat large vessel strokes. With time, other centers opened up and MT procedures not only grew as a whole but care was distributed among more hospitals. The relatively sluggish growth in the last 3 years may be due to some degree of market saturation and the need for different measures to overcome the logistical barriers in providing endovascular care. Similar trends were observed in cardiology following the revolution in percutaneous coronary interventions (PCI). The Global Registry of Acute Coronary Events (GRACE) showed that, from 1999 to 2006, primary PCIs for patients with ST-elevation myocardial infarction (STEMI) grew at about 30% for the first 2 years, 19% for the next 2 years, and fell to an average of 9% for the 2 years after that.[21] In the same Registry, only 30% of patients admitted for acute coronary syndrome (ACS) received a PCI in the first 12 hours.[22] The highest reported percentage of patients with ACS receiving a primary PCI is 75%.[23] A more recent paper reported a primary PCI rate of 46% for patients with STEMI.[24]

We estimate 718 191 (95% CI 661 483 to 791 121) AIS per year, which is higher than the AHA estimate perhaps because we adjusted it for population growth. LVOs or MVOs are estimated

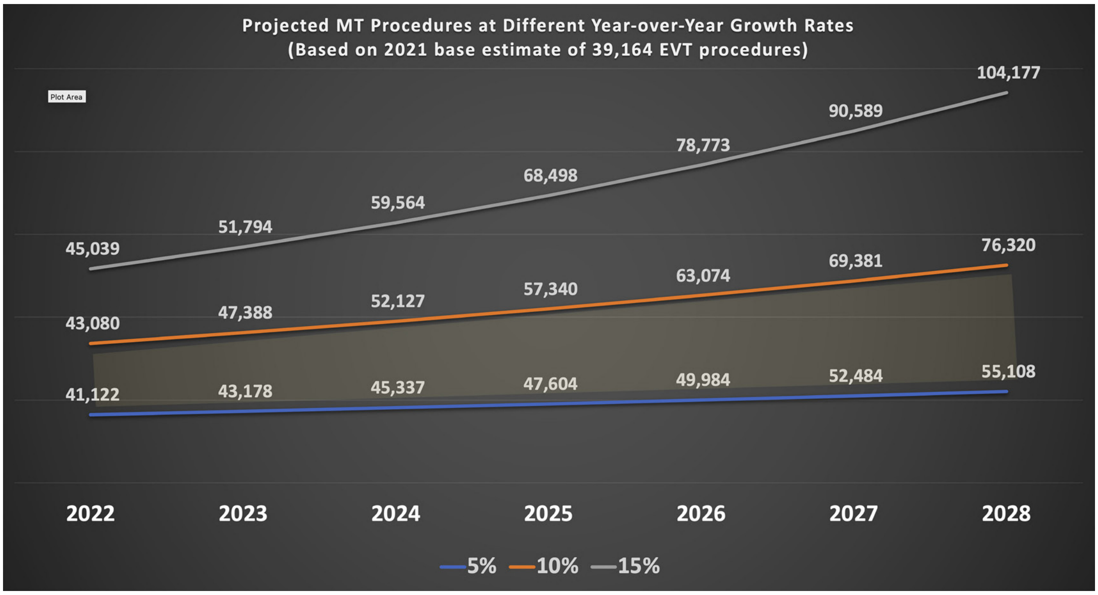

Figure 5 Future annual mechanical thrombectomy (MT) estimates projected at different year-over-year growth rates. The 2021 MT numbers of 39 164 are used as the base estimate for 2022.

to be around 144 000 per year. The proportion of disease treated is an important metric when determining the penetration of a treatment. The percentage of STEMI cases treated by acute coronary interventions can serve as a guide for MT infiltration in LVOs and MVOs. Figure 3 indicates that the proportion of all AIS and vascular occlusion strokes treated with MT has been increasing. The 2021 MT numbers represent almost 40% of all LVOs+M2 occlusions and 27% of all LVOs and MVOs. We have included M2 occlusions with LVOs as proximal M2 occlusions are currently being treated at most centers. If acute coronary interventions are a guide, then it is unlikely that MT will capture more than 60–70% of all treatable strokes. About 75 000 annual MT procedures represent 75% of all M1, M2, ICA-T and BA occlusions and 50% of all LVOs and MVOs. Endovascular treatment of 75% of all vascular occlusions gives about 110 000 annual MT procedures but this is probably an unlikely target, at least in the next several years. These percentages are independent of the infarct core size, which means that inclusion of large core strokes may not have a meaningful impact on the percentage of disease treated.

Inclusion of small and medium vessel strokes could help expand the MT numbers faster but does not significantly change the market cap of MT procedures, even accounting for the change in annual population. A variable that could increase the overall disease burden is the growth in the population aged >60 years, which accounts for the bulk of AIS. Expansion of MT in this population could be enhanced by acute detection, efficient transfer and early arrival at stroke centers. Endovascular stroke care may have pushed past the initial organic growth following the sudden surge in demand. Future growth may require a sustained methodical approach targeting infrastructure and workflow barriers in acute endovascular stroke care.

Study limitations

The incidence of AIS and LVOs and MVOs can vary georgraphically. The data presented here are from counties in a rural setting in the traditional 'stroke belt'. As such, our estimates likely represent the upper limits of the total disease burden. It is possible that smaller hospitals or those in an urban environment have different rates, so universal application of these statistics could be misleading unless other variables are homogenously taken into account and similar methodology is followed. We have mitigated these variations by following previously published methodologies for population studies and have provided our own detailed methodology so others can replicate if needed. We have also provided individual rates of vascular occlusion by location, allowing for permutations of LVOs or MVOs based on varying definitions of the occlusion sites. Our calculation of the MT estimates is dependent on the accuracy of procedural coding and data availability from different federal sources. As such, inherent inaccuracies are possible and an analysis based on other data sources may yield different numbers. We hope that the detailed description of our methodology will help critical evaluation of the data and any replication if desired.

CONCLUSION

We estimate 718 191 (95% CI 661 483 to 791 121) AIS per year in the USA, of which 21% (95% CI 15% to 29%) have an underlying vascular occlusion (LVOs: 11%, MVOs: 10%). The majority (63%) of the AIS are estimated in the ≥65 year age group. There has been a relative flattening of the MT growth curve in recent years compared with the initial rapid growth. Almost 40 000 MT procedures were performed in 2021, accounting for 5% of all AIS and 27% of all AIS with an underlying vascular occlusion. A double digit year-over-year growth over the next 10 years is probably unlikely, but a 5–10% growth may be possible given the current trajectory. Factors that could escalate the growth curve are a heightened focus on the ageing population, inclusion of distal and medium vessel occlusions if a benefit is shown in trials, improved early detection methods, workflow efficencies and neuroprotective therapies that may retard infarct growth or improve treatment outcomes. These efforts may lead to MT volumes in the USA of between 67 000 and 76 000 by 2028.

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