Review Article

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DOI:
10.4103/bc.bc_5_21

# Vascular tortuosity in endovascular mechanical thrombectomy

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**Abstract:**

Endovascular mechanical thrombectomy effectively removes occlusive thrombi from the arterial lumen; however, there is little literature supporting the relevance of vascular geometry on surgical outcomes. Critical vessel characteristics including the degree of angulation and tortuosity influence the ability to advance stent retriever devices toward the site of occlusion. Therefore, it is crucial to evaluate the impact of carotid artery catheter pathway accessibility on the thrombectomy outcomes in acute ischemic stroke (AIS) patients. Traditional imaging modalities generate incomplete pictures of the vascular tortuosity and are prone to clinical judgment errors. Recent three-dimensional computed tomography angiography image analysis techniques circumvent these limitations to calculate accurate tortuosity and angulation measurements. These novel images facilitate classifying common anatomical variant patients into groups that may be treated with specially designed catheter devices. Importantly, this image analysis method reveals significant angulation in the common carotid artery and extracranial internal carotid artery that correlates with delays in reaching the occlusion site. Increased age, which is associated with increased risk of stroke, also increases the incidence of severe tortuosity. The semi-automated measurements technique also demonstrate that full 360° arterial loops are present in nearly 3% of catheter pathways and that the overall degree of angulation differs bilaterally. In this review, we examine the utility of this novel image analysis procedure and evaluate the recent literature relevant to neuroendovascular thrombectomy in AIS patients. Three literature databases – PubMed, Embase, and Web of Science were queried for original articles investigating both preclinical and clinical thrombectomy applications.

**Keywords:**

Carotid artery, computed tomography, reperfusion, stent, stroke, thrombolytic, thrombus

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Submission: 03-11-2020
Revised: 02-12-2020
Accepted: 15-12-2020
Published: 30-03-2021

## Introduction: Endovascular Mechanical Thrombectomy

Endovascular mechanical thrombectomy (EVT) utilizes intra-arterial stent retrievers to extract or disintegrate occlusive thrombi in acute ischemic stroke (AIS) patients. A series of randomized controlled trials in 2015 confirmed the effectiveness of EVT compared to traditional thrombolytic treatment with alteplase or reteplase.[1] The HERMES collaboration subsequently validated the relationship between early EVT recanalization and superior outcomes in emergent large-vessel occlusion (ELVO) patients.[2] Together, these novel findings position EVT as a viable stroke treatment.

## Vessel Tortuosity

The lack of data about the prevalence and impact of anatomical variations on the surgical efficacy of EVT limits its clinical applications. Historical studies in other neuroendovascular procedures demonstrate that individual vascular deviations precipitate poor operative outcomes.[3] Previous EVT research generally investigated preoperative characteristics such as landmark identification rather than relevant endovascular features like anatomical variation and vessel tortuosity.[4,5] However, recent evidence suggests that



**How to cite this article:** Farooq J, Lee JY. Vascular tortuosity in endovascular mechanical thrombectomy. Brain Circ 2021;7:3-7.

certain carotid arch variants and increased intracranial vascular torsion decrease EVT effectiveness.[6-8] Vessel tortuosity is challenging to assess preoperatively due to the absence of practical imaging modalities. Traditional approaches to visualize the extracranial carotid artery include digital subtraction angiography (DSA), computed tomography angiography (CTA), and ultrasound. While these procedures provide valuable information about the carotid artery, they lack a three-dimensional (3D) component to assess the degree of tortuousness accurately.[9,10] These techniques only generate limited pictures of patients' vascular anatomy. An alternative method to estimate vessel tortuosity relies on population data from AIS patients treated with EVT. This leverages prevalence data to create specialized catheter systems and 3D models for population-specific anatomical variations. Clinical trials may also utilize population data to tailor study designs toward groups with specific large-vessel variations.

## Endovascular Mechanical Thrombectomy Registry Data

Incomplete information from imaging techniques combined with the lack of robust population data limits the understanding of carotid artery segment variation in ELVO stroke patients [Figure 1]. However, the prospective Bernese registry provides valuable adjunct data on 592 AIS patients treated with stent retriever thrombectomy.[11] This database demonstrates the efficacy of neurovascular interventions, with only 20/592 patients (3%) experiencing catheterization failure from poor cervical artery access.[11] Either an inability or a delay in establishing arterial access exacerbates outcomes in these patients. Importantly, vessel tortuosity and abnormal aortic arch anatomy drive reperfusion failure in approximately one-third of these patients by obstructing the ability to reach the target occlusion.[11]

## Timing of Endovascular Mechanical Thrombectomy

Although the inability to establish arterial access inherently implies a failure to reach the thrombus, this is less clinically significant than delayed access. Complete failure to achieve access is rare, occurring in only 2/100 patients (2%), compared to 30 min or longer delays in 30/100 patients (30%).[12] In each instance of failed access, both the common carotid artery (CCA) and extracranial internal carotid artery (ICA) exhibited tremendous tortuosity, with a full 360° loop in one case.[12] However, delays result in protracted neuroendovascular interventions, which increase the intracranial hemorrhage rate and reduce postoperative functional independence.[13-15]

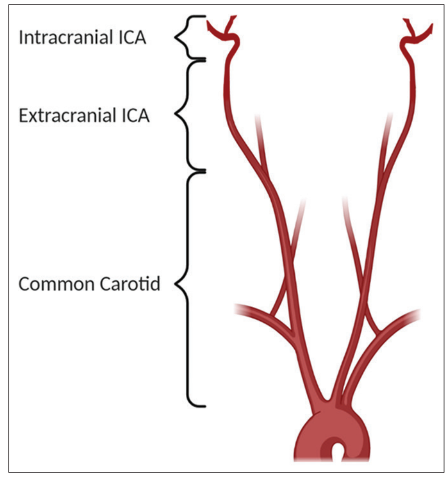


**Figure 1:** The common carotid stretches from the aortic arch to the bifurcation of the internal and external carotids. The extracranial internal carotid internal carotid artery extends to the skull base. The intracranial internal carotid artery ends at its bifurcation into the cerebral arteries

## Historical Measurements of Tortuosity

The diversity in anatomical variations creates unique challenges toward quantifying and qualifying vascular angulation. Without appropriate classification schemas, it is difficult to assess how angulation and tortuosity impact EVT outcomes. Traditional attempts to measure these characteristics in AIS patients utilize coronal and sagittal CTA images to measure the degree of vessel curvature away from the midline of blood flow.[16] To the same effect, evaluation of the significance of tortuosity on thrombectomy outcomes typically relies on CTA and DSA.[6,7] However, 2D image analysis introduces nonnegligible errors that under- or overestimate angulation and tortuosity.

## Novel Measurements of Tortuosity

A recently developed model of measuring vessel tortuosity circumvents the limitations of previous procedures. This technique applies semi-automatic technology to process CTA images based on predefined criteria and generates optimal images for further analysis. The software calculates centerlines that best fit the arterial pathway. This simultaneously minimizes human error and maximizes the accuracy of the centerline generation. Detailed analysis of the carotid artery in these CTA images reveals increases in CCA-brachiocephalic segment tortuosity lengthen access time.[12] It also demonstrates that differences in the vertex to jugular notch height, type two and three aortic arch, and bovine arch, do not extend access times.[12]

## Applications to Neuroendovascular Interventions

This novel technique allows clinicians to categorize anatomical variations accurately in EVT patients.

Beyond its direct applications intraoperatively, this imaging method facilitates designing specialized thrombectomy devices on a population level for patients with common variations. It also creates widespread applications in 3D printing for both resident training and presurgical planning. The semi-automated nature of the CTA image analysis enables future integration with robotic technology to further refine EVT and other neuroendovascular procedures [Figure 2]. It is a practical tool for AIS in ELVO patients that supplements flourishing data on the effectiveness of robot-assisted minimally invasive endovascular procedures.[17] Artificial intelligence and machine learning integration may leverage this technology to calculate ideal access pathways for neuroendovascular interventions in all patients.

## Current Horizons of Endovascular Mechanical Thrombectomy

Imaging analysis and computer modeling demonstrate tremendous potential for predicting EVT safety and outcomes. Coronal computed tomography (CT) image tracing reveals that the course of the middle cerebral artery (MCA) strongly aligns with intraoperative angiography.[18] Utilizing preoperative CT to map out surrounding vasculature informs surgical preplanning and may reduce the risk of vessel perforation. CTA-identified anatomical variations such as bovine aortic arch also correlate with transbronchial catheter insertion success for EVT.[19] Similarly, computer models of MCA occlusion predict certain Circle of Willis (CoW) variants that precipitate compensatory flow deficits compared to normal CoW configurations.[20] Beyond virtual modeling, a recently developed 3D printed test bed enables efficacious EVT testing in cerebrovascular phantoms.[21] This recreates realistic AIS scenarios and allows for advanced surgical training with multiple catheter designs. These findings underscore the intertwined benefits of both preoperative images and anatomical models in neuroendovascular procedures.

Although EVTs' clinical applications are already apparent, the technique is still relatively new and its standard protocols are continuously evolving. Many research efforts attempt to optimize the surgical procedure and stent/catheter design. Transcarotid artery revascularization transiently reverses blood flow intraoperatively to enhance neuroprotection during EVT.[22] Retriever wire supported carotid artery revascularization effectively and safely manages tandem occlusion patients with both extracranial and intracranial ICA lesions.[23] The ongoing thrombectomy in tandem occlusion trial is investigating EVT alone compared to EVT with concomitant extracranial carotid stenting.[24] Application of this dual procedure theoretically increases the success of EVT; however, thrombectomy with contact aspiration demonstrates comparable revascularization rates and shorter operation times than stenting.[25] A unique EVT technique employs simultaneous intermediate aspiration and stenting. This hybrid approach yields quicker and superior first-pass recanalization success than traditional approaches.[26] Several different designs of stents and stent retrievers successfully revascularize occluded vessels, though it remains to be seen which type is most effective.[27,28] Stenting appears advantageous both alongside traditional EVT and as a rescue therapy after thrombectomy failure.[29] Concurrent thrombolytic and dual-antiplatelet treatment also improves outcomes and functional status without increasing hemorrhage risk.[30-32]

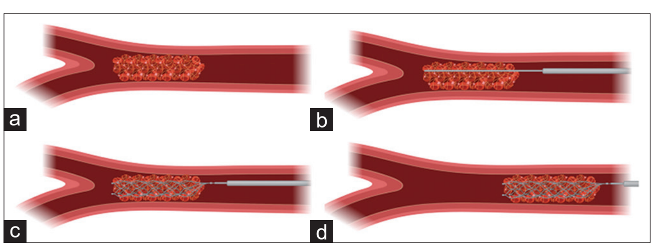


**Figure 2:** Overview of endovascular mechanical thrombectomy. (a) A large clot occludes an artery. (b) The surgeon advances a stent retriever through the clot. (c) The stent retriever inflates. (d) The surgeon retracts the stent retriever-clot complex for removal from the circulation

Timely neuroendovascular access is critical, as delays in reaching the target occlusion worsen ELVO patient outcomes. EVT performed more than 6 h after stroke appears to as safe as recanalization immediately following AIS.[33] Transradial and transfemoral access sites are both viable in EVT for these patients. While transfemoral is more often employed, the transradial site yields similar total procedure time and mean fluoroscopy times.[34-36] Rarely, neither approach is available secondary to obstructive anatomical challenges. Direct carotid artery puncture allows emergent access in these cases and demonstrates relatively high safety and efficacy, with a median time from a puncture to perfusion of only 23 min.[37-39]

Several preclinical patient characteristics predict outcomes and may be valuable in clinical decision-making. Decreased hemoglobin and increased red cell distribution width at admission, both indicators of anemia, independently predict worse functional outcomes after EVT.[40,41] A C-reactive protein level >1.4 mg/L strongly correlates with deterioration in ICA occlusion patients.[42] An elevated glycosylated hemoglobin A1c level predicts cerebral hemorrhage and mortality risk.[43] Significant brain atrophy from anterior circulation strokes also increases mortality after EVT.[44] Other negative predictors include baseline NIH Stroke Scale score, distal clot migration, D-dimer levels, history of transient ischemic attack or stroke, terminal ICA occlusion, number of thrombectomy passes, and age.[45-47] Vascular tortuosity, presents in nearly 40% of patients, and arterial kinks also correlate with worse outcomes, but this is due to thrombectomy failure from the inability to reach the thrombus.[48,49] COVID-19 status also plays a crucial role in EVT outcomes. Infected patients that require mechanical thrombectomy are generally much younger than the mean EVT-patient population, and they present with a hypercoagulable state that precipitates multi-territory infarcts and markedly worse outcomes.[50,51]

Overall, mechanical thrombectomy is a very compelling treatment for AIS patients with ELVO. Its superiority compared to conservative thrombolytic therapy combined with a tremendous potential for continued advancement alongside computerized and imaging enhancements positions EVT as a standard care option for stroke. Refinements to technique and catheter design will further improve clinical and functional outcomes. Future studies are needed to thoroughly elucidate the impact of vascular tortuosity and angulation on surgical success.


### Financial support and sponsorship
Nil.

### Conflicts of interest
Prof. Cesario V. Borlongan is Associate Editor of *Brain Circulation*.


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