Review

A review of endovascular treatment for medium vessel occlusion stroke

Johanna Maria Ospel 1,2 and Mayank Goyal 2,3

ABSTRACT
Medium-vessel occlusions (MeVOs), that is, occlusions of the M2/3 middle cerebral artery, A2/3 anterior cerebral artery, and P2/3 posterior cerebral artery segments, account for 25%–40% of all acute ischemic stroke cases. Clinical outcomes of MeVO stroke with intravenous thrombolysis, which is the current standard of care, are moderate at best. With improving imaging technologies and a growing literature, MeVOS are increasingly recognized as a target for endovascular treatment (EVT). For the time being, there is limited but promising evidence for the safety and efficacy of MeVO EVT, and many neurointerventionists are already routinely offering EVT for MeVO stroke, despite the lack of clear guideline recommendations. In this article, we review the evidence on endovascular treatment for MeVO stroke and summarize the available literature on current imaging strategies, commonly used EVT selection criteria, EVT techniques, and outcome assessment for MeVO stroke.

In acute ischemic stroke, blockage of an intracranial artery leads to interruption of blood supply of the brain parenchyma with subsequent ischemia and infarction unless blood flow is restored quickly. Acute ischemic stroke has traditionally been divided into large-vessel occlusion (LVO) stroke, that is, acute stroke due to occlusion of proximal arteries of the anterior circulation (the terminal intracranial internal carotid artery (ICA), M1, or A1 segment), and non-LVO stroke. Around 35%–40% of acute ischemic stroke cases occur due to LVO, while 25%–40% are caused by medium-vessel occlusions (MeVOS). Although it is commonly assumed that outcomes of MeVO strokes are better compared with LVO strokes, due to the more distal occlusion location and less extensive ischemia, cohort studies suggest that outcomes are frequently poor, despite best medical management. Over the past few years, several randomized trials have proven the safety and efficacy of endovascular treatment (EVT) in LVO stroke, while for patients with MeVOS, there is currently no high-level evidence for EVT. But given the high efficacy of EVT in LVO stroke and the substantial morbidity associated with MeVO, EVT is now increasingly performed for MeVO stroke.

DEFINITION OF MEDIUM-VEssel OCCLUSIONS
In a recent publication, MeVOS have been defined as occlusions of the M2, M3, A2, A3, P2, or P3 segment. That being said, the distinction between LVOs and MVOs is often challenged. For example, there are various ways to define the border between the M1 segment, which is considered a “large vessel”, and the M2 segment of the middle cerebral artery. Furthermore, because M2 occlusions, particularly those affecting the dominant branch, can cause clinical symptoms identical to M1 occlusions, some authors include M2 occlusions in their definition of LVO. Given the variability in anatomy and clinical symptoms, a multidimensional definition based on morphological features (ie, vessel anatomy and size) and clinical deficits (ie, symptoms that are commensurate with the occluded vessel) may be preferred over a purely anatomical definition.

PRIMARY AND SECONDARY MEOVS
Not all MeVOS are the same: MeVOS can be classified based on their underlying mechanism as either primary or secondary MeVOS. “Primary” MeVOS occur de novo, with etiologies similar to LVOs. “Secondary” MeVOS occur when clot migration or fragmentation of a LVO occurs. This can happen spontaneously or iatrogenically, after intravenous thrombolysis or during EVT. Secondary MeVOS may either represent embolization to new territory, or embolization to distal territory, if they are located within the territory of the proximal occlusion. Another, rare subtype are “concurrent MeVOS”, that is, MeVOS that occur simultaneously with other occlusions. They are likely part of an “embolic shower” or could be due to fragmentation of a more proximal occlusion.

PREVALENCE AND CLINICAL COURSE OF MEVO STROKE
Although it is commonly assumed that outcomes of MeVO strokes are better compared with LVO strokes, due to the more distal occlusion location and less extensive ischemia, a recent analysis from the INTERRSeCT and PRove-IT cohort studies has shown that one out of four patients with MeVO stroke does not achieve functional independence (modified Rankin Scale (mRS) 0–2) at 90 days with current best management, including intravenous thrombolysis if indicated. An excellent outcome (mRS 0–1) is only achieved by half of the patients with MeVO stroke (online supplemental figure 1). These somewhat sobering results emphasize the need for a more effective therapy. Given the overwhelming efficacy of endovascular treatment (EVT) in LVO strokes, it might seem obvious to expand this treatment to MeVO patients as well. Many neurointerventionists already routinely offer EVT in MeVO strokes, particularly in the case of M2
occlusions, but there is no randomized evidence for MeVO EVT, and it is possible that due to the smaller vessel size, MeVO EVT may yield an increased risk of procedural complications. Therefore, the question whether EVT is truly beneficial in the setting of MeVO stroke or not, remains to be answered. Furthermore, the smaller vessel caliber and more distal occlusion location of MeVOS compared with LVOs warrant changes in EVT technique and technology.

In the following, we review the existing literature on treatment indications, imaging selection criteria, and treatment techniques for MeVO EVT as well as clinical outcomes following MeVO EVT. We conclude with an outlook on open questions and ongoing developments.

**SEARCH STRATEGY**

We searched the electronic databases Medline/PubMed, Google Scholar, and EMBASE using the search terms stroke, thrombectomy, endovascular, aspiration, mechanical, small, distal, medium, M2, M3, A2, A3, P2, and P3. We included original research studies, systematic reviews, and meta-analyses which: reported angiographic and/or clinical outcomes of patients with MeVO stroke treated with EVT; included at least five patients; and were published in English. Bibliographies of identified manuscripts were screened for additional relevant studies. The literature search is up-to-date as of 23 November 2020. Tables 1 and 2 provide an overview of the studies and systematic reviews that were identified during the literature search.

**IMAGING PROTOCOLS – HOW TO IMAGE MEVO STROKE?**

Baseline imaging can facilitate EVT treatment decision making in MeVO stroke, or enrolment in a randomized EVT MeVO trial for that matter, by answering the following questions:

1. Is there evidence of intracranial hemorrhage? Just as with LVO stroke, hemorrhagic stroke needs to be ruled out prior to treatment.
2. Is there an acute MeVO? EVT can only be initiated if a target occlusion is visualized.
3. Does that MeVO explain the patient’s deficit (clinical-anatomical correlation, particularly important for secondary MeVOS and concurrent MeVOS in the setting of multiple occlusions)? Right-sided hemiparesis, for example, can be well-explained by a left-sided M2 occlusion, while left-sided hemi-paresis cannot.
4. Is the occlusion likely to recanalize with intravenous thrombolyis? Smaller, permeable thrombi may resolve with intravenous thrombolysis which may influence EVT decision-making.
5. Is the MeVO amenable to safe and fast recanalization using EVT? How technically challenging an operator perceives EVT for a certain MeVO and the availability of dedicated EVT tools designed for MeVOS will also influence the treatment decision and help to set the expectations of the patient and the medical team right.

Since EVT has been established as standard of care in 2015, non-invasive neurovascular imaging (CTA or less frequently MR angiography) is recommended for all acute ischemic stroke patients, and should thus be obtained in all MeVO patients. In the past, detection of MeVOS on non-invasive imaging has been challenging, but innovative imaging techniques such as multiphase CTA (including color-coded mCTA maps) and CT perfusion have rendered fast and reliable MeVO detection possible (online supplemental figure 2). Determining the presence of salvageable brain tissue is more challenging in MeVOS compared with LVOs. Established EVT imaging selection criteria that are currently used in LVO stroke, namely Alberta Stroke Program Early CT Score (ASPECTS) ≥6, intermediate to good collaterals, and currently established perfusion mismatch/core criteria (eg, ischemic core on rCBF maps)18–21 will likely be of little use in MeVO stroke. Due to the more distal occlusion, the ischemic territory will be smaller, and as such, ASPECTS will be generally higher and areas with severe hypoperfusion (“core”) smaller. When assessing collateral status, one would have to assess collaterals solely within the affected territory downstream to the MeVO, which can be challenging, especially in the ACA and PCA territory. So far, no standardized methodology has yet been established. Due to the relative insensitivity and high inter-rater reliability of NCCT in detecting early ischemic changes, and because detecting MeVOS on conventional CTA/MRA images is difficult at times, advanced imaging protocols (CTP and MRI) are often used.

However, accurately determining infarct core and penumbra in MeVO stroke may be challenging or not possible at all, as recent literature suggests that we currently lack the ability to precisely delineate infarct “core” with routinely used imaging methods.22 More importantly, delineating ischemic core and penumbra may not even be necessary, as past early time window LVO trials failed to show any volume cut-off below which EVT was no longer beneficial, and current EVT guidelines for LVO patients in the early time window therefore exclusively rely on NCCT ASPECTS to estimate the degree of irreversible tissue damage. That being said, using ASPECTS in MeVO stroke may be problematic, since the anterior and posterior cerebral artery territories are not represented at all, and even in middle cerebral artery MeVOS, the ASPECTS range will be relatively small, since the internal capsule, lentiform, and caudate are unlikely to be affected, and of the cortical 6 regions, only few will be affected. Thus, for a typical M3 occlusion, ASPECTS may be either 8, 9, or 10.

Most of the MeVO EVT studies we identified used a CT-based imaging protocol, and approximately half of them included CT perfusion as part of the standard protocol, regardless of the time frame, and some reported MRI-based protocols with DWI±PWI sequences (table 2). Studies that relied only on NCCT and single-phase CTA were mostly subgroup analyses from randomized LVO trials and LVO registries,23 24 that is, M2 occlusions were a small minority of all cases. Many studies simply transferred the perfusion thresholds and ASPECTS cut-offs that are used for LVO strokes to their MeVO patient sample, which may be suboptimal for MeVO patient selection. Only a few studies adapted imaging selection criteria and used, for example, a higher ASPECTS cut-off.28 29 Table 3 provides an overview of different MeVO imaging paradigms. Future studies should aim to develop MeVO-specific imaging selection criteria for EVT.

**CLINICAL EVT SELECTION CRITERIA FOR MEVO EVT**

Just as there are no uniform imaging criteria for EVT patient selection in MeVO strokes, there is also no consensus on clinical selection criteria. Several MeVO EVT studies used an NIHSS threshold of ≥6, as it is currently recommended for LVO strokes. However, a recent analysis from prospective cohort studies has shown that 1/3 of MeVO stroke patients have a baseline NIHSS <6. One study specifically stated that they included patients “with NIHSS ≥6 or disabling deficit”, and another one lowered the NIHSS cut-off of 5 instead of 6, which seems more appropriate, considering that one out of three patients with untreated supposedly “mild” strokes (NIHSS <5) will not be functionally independent at 90 days.31 Indeed, in a recent survey, most physicians stated that they would offer EVT for
<table>
<thead>
<tr>
<th>First Author/Year</th>
<th>Study type</th>
<th>N with MeVO</th>
<th>EVT</th>
<th>NIHSS (median/mean)</th>
<th>ASPECTS (median/mean)</th>
<th>Imaging modality used</th>
<th>Treatment criteria</th>
<th>MeVO type</th>
<th>Technique used</th>
<th>Anesthesia</th>
<th>Angiographic outcome</th>
<th>Clinical outcome</th>
<th>sICH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Romano et al 2020</td>
<td>MC</td>
<td>44</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>NCCT+CTA (±DWI if onset unknown)</td>
<td>NIHSS≥6 Pre-stroke mRS 0–2 ASPECTS≥6 Absence of large infarction DWI-clinical mismatch Contraindication to IV tPA</td>
<td>M2, M3/M4</td>
<td>DA</td>
<td>GA, CS</td>
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<td>mRS 0–2: 71%</td>
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<tr>
<td>Haussen et al 2020</td>
<td>SC</td>
<td>137</td>
<td>18</td>
<td>8/9</td>
<td>8</td>
<td>NCCT+CTA+CTP</td>
<td>M2, M3 Any ACA Any PCA</td>
<td>DA, SR</td>
<td>TICI 2b/3: 84% (SR) vs 69% (DA)</td>
<td>TICI 3: 58% (SR) vs 46% (DA)</td>
<td>TICI 3: 58% (SR) vs 46% (DA)</td>
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<td>Adhuneyasskul et al 2020</td>
<td>MC</td>
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<td>15/17</td>
<td>9</td>
<td>9</td>
<td>NCCT+CTA</td>
<td>M2</td>
<td>DA, SR</td>
<td>TICI 2b/3: 90% (SR) vs 77% (DA)</td>
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<td>10</td>
<td>NCCT+CTA+CTP</td>
<td>M2</td>
<td>SR, CS</td>
<td>TICI 2b/3: 95%</td>
<td>TICI 3: 7%</td>
<td>mRS 0–2: 46% mRS 0–1: 26% mRS 0–7%</td>
<td>7%</td>
<td></td>
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<td>Compagne et al 2019</td>
<td>MC</td>
<td>244</td>
<td>14</td>
<td>9</td>
<td>9</td>
<td>NCCT+CTA</td>
<td>M2</td>
<td>DA, SR, IA tPA</td>
<td>–</td>
<td>TICI 2b/3: 57%</td>
<td>mRS 0–2: 46% mRS 0–1: 26% mRS 0–7%</td>
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<tr>
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<td>RCT</td>
<td>79</td>
<td>13.4</td>
<td>8</td>
<td>8</td>
<td>NCCT+CTA+CTP</td>
<td>M2</td>
<td>DA, SR, CS, GA</td>
<td>TICI 2b/3: 84% (SR) vs 7% (DA)</td>
<td>TICI 3: 55% (SR) vs 54% (DA)</td>
<td>TICI 3: 42% (SR) vs 35% (DA)</td>
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<td>Oureshi et al 2017</td>
<td>RCT</td>
<td>34</td>
<td>16</td>
<td>–</td>
<td>–</td>
<td>NCCT+CTA</td>
<td>M2, A, combinations</td>
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<td>TICI 2b/3: 97%</td>
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<td>TICI 3: 43%</td>
<td>mRS 0–2: 53% mRS 0–1: 38%</td>
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<td>14.1</td>
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<td>NCCT+CTA+CTP</td>
<td>M2, A, combinations</td>
<td>DA</td>
<td>TICI 2b/3: 83%</td>
<td>TICI 3: 43%</td>
<td>mRS 0–2: 59%</td>
<td>mRS 0–1: 36% mRS 0: 14%</td>
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<td>9</td>
<td>9</td>
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<td>M2</td>
<td>SR, IA tPA</td>
<td>TICI 2b/3: 78%</td>
<td>–</td>
<td>TICI 3: 43%</td>
<td>mRS 0–2: 69% mRS 0–1: 36% mRS 0: 14%</td>
<td>6%</td>
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<td>Navia et al 2016</td>
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<td>12.5</td>
<td>–</td>
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<td>NCCT+CTA+CTP</td>
<td>M2, M3, P2, A2</td>
<td>DA</td>
<td>TICI 2b/3: 100%</td>
<td>TICI 3: 83%</td>
<td>mRS 0: 100% mRS 0–1: 60% mRS 0: 20%</td>
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<td>Menon et al 2019</td>
<td>RCT</td>
<td>67</td>
<td>14</td>
<td>9</td>
<td>9</td>
<td>NCCT+CTA+CTP</td>
<td>M2</td>
<td>SR</td>
<td>TICI 2b/3: 59%</td>
<td>–</td>
<td>TICI 3: 43%</td>
<td>mRS 0–2: 58% mRS 0–1: 37% mRS 0: 19%</td>
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<td>Coutinho et al 2016</td>
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<td>9</td>
<td>NCCT+CTA+CTP</td>
<td>M2</td>
<td>SR, CS, GA</td>
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<td>TICI 3: 43%</td>
<td>mRS 0–2: 60% mRS 0–1: 50%</td>
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<td>SC</td>
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<td>M2</td>
<td>Any ACA, Any PCA</td>
<td>DA, SR</td>
<td>TICI 3: 83%</td>
<td>TICI 3: 45%</td>
<td>mRS 0–2: 30% mRS 0–1: 13%</td>
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<th>First Author Year</th>
<th>Study type</th>
<th>N with MeVO EVT</th>
<th>NIHSS (median/mean)</th>
<th>ASPECTS (median/mean)</th>
<th>Imaging modality used</th>
<th>Treatment criteria</th>
<th>MeVO type</th>
<th>Technique used</th>
<th>Anesthesia</th>
<th>Angiographic outcome</th>
<th>Clinical outcome</th>
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<td>M2</td>
<td>DA, SR</td>
<td>–</td>
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<td>mRS 0–2: 49%</td>
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<td>Altenbernd et al 2018</td>
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<td>ASPECTS ≥8</td>
<td>M2, M3</td>
<td>DA, GA</td>
<td>TICI 2b/3: 100%</td>
<td>mRS 0–2: 95% mRS 0–1: 86% mRS 0: 35%</td>
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<td>Crockett et al 2019</td>
<td>SC</td>
<td>14</td>
<td>8</td>
<td>9</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>A2, A3, P2, M3, SCA</td>
<td>DA</td>
<td>TICI 2b/3: 100%</td>
<td>mRS 0–2: 63% mRS 0–1: 50% mRS 0: 43%</td>
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<td>Bhogal et al 2017</td>
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<td>106</td>
<td>12</td>
<td>9</td>
<td>NCCT+CTA or MRI</td>
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<td>M2</td>
<td>SR</td>
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<td>mRS 0–2: 55% mRS 0–1: 45% mRS 0: 24%</td>
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<td>30</td>
<td>16</td>
<td>9</td>
<td>NCCT+CTA</td>
<td>Symptom onset ≤6 hour or CTP mismatch if symptom onset 6–24 hour NIHSS ≥6 ASPECTS ≥6</td>
<td>M2</td>
<td>DA, SR, combination</td>
<td>CS, GA</td>
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<td>mRS 0–2: 50% mRS 0–1: 23% mRS 0: 17%</td>
<td>7%</td>
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<td>Griebl et al 2019</td>
<td>SC</td>
<td>52</td>
<td>12</td>
<td>–</td>
<td>NCCT+CTA</td>
<td>NIHSS ≥6 or aphasia Absence of large infarction</td>
<td>M2</td>
<td>DA</td>
<td>GA</td>
<td>TICI 2b/3: 91% TICI 3: 65%</td>
<td>mRS 0–2: 56%</td>
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<td>16</td>
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<td>–</td>
<td>–</td>
<td>M2, M3, Any ACA Any PCA</td>
<td>SR, combination</td>
<td>CS, GA</td>
<td>TICI 2b/3: 50% (SR) vs 64% (combination) TICI 2b/3: 34% (SR vs 51% (combination)) mRS 0–2: 53 (SR vs 51% (combined)) mRS 0–2: 13% (SR vs 2% (combined))</td>
<td>13% (SR vs 2% (combined))</td>
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<td>Haussen et al 2020</td>
<td>SC</td>
<td>22</td>
<td>17</td>
<td>8</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>M2</td>
<td>Combination</td>
<td>TICI 2b/3: 84% TICI 3: 64%</td>
<td>mRS 0–2: 40%</td>
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<tr>
<td>Pfiff et al 2016</td>
<td>SC</td>
<td>30</td>
<td>18</td>
<td>9</td>
<td>DWI+MRAn+ PWI or NCCT+CTA+CTP</td>
<td>Symptom onset ≤6 hour NIHSS ≥6 ASPECTS ≥6</td>
<td>A2, A3, A4</td>
<td>SR</td>
<td>CS, GA</td>
<td>TICI 2b/3: 73%</td>
<td>mRS 0–2: 37%</td>
<td>0%</td>
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<tr>
<td>Szyman et al 2020</td>
<td>MC</td>
<td>15</td>
<td>13</td>
<td>10 (pcASPECTS)</td>
<td>–</td>
<td>–</td>
<td>SCA, AICA, PICA</td>
<td>SR, DA, combination, IA tPA</td>
<td>–</td>
<td>TICI 2b/3: 88% TICI 3: 31% mRS 0–2: 50% mRS 0–1: 29% mRS 0: 7%</td>
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</table>

Note: MC = multi center, SC = single center, EVT = endovascular treatment, MeVO = medium vessel occlusion stroke, NIHSS = National Institutes of Health Stroke Scale, pcASPECTS = posterior circulation Alberta Stroke Program Early CT Score, CT = computed tomography, NCCT = non-contrast head CT, DWI = diffusion weighted imaging, CTP = CT perfusion, DA = direct aspiration, SR = stent retriever, IA tPA = intra-arterial alteplase, CS = conscious sedation, GA = general anesthesia, SCA = superior cerebellar artery, AICA = anterior inferior cerebellar artery, PICA = posterior inferior cerebellar artery, TICI = Thrombolysis in Cerebral Infarction Score, mRS = modified Rankin Score, sICH = symptomatic intracranial hemorrhage.
LVO patients with low NIHSS. Whether a patient is eligible for intravenous thrombolysis or not also seems to play an important role in MeVO EVT decision-making. More than 50% of physicians would perform EVT in M3, A2, and P2 occlusions if the patient is ineligible for intravenous thrombolysis, but when intravenous thrombolysis can be safely administered, the willingness to proceed with EVT is substantially lower. For now, until randomized trial data become available, the decision to treat or not to treat a MeVO will remain a subjective one that is given the relatively modest ICH rates. But over the last few decades, numerous authors reported promising results of primary aspiration as the first-line treatment for M2 stroke compared with DA. Although randomized trials show equivocal results, both SR and DA are effective and safe with high functional independence. There may be a slightly increased risk of ICH.

### Table 2: Systematic reviews and meta-analyses that were identified during the literature search

<table>
<thead>
<tr>
<th>First Author Year</th>
<th>Study type</th>
<th>Research question</th>
<th>Main findings</th>
<th>N with MeVO EVT</th>
<th>NIHSS (median/mean)</th>
<th>N of studies</th>
<th>N with MeVO EVT</th>
<th>NIHSS (median/mean)</th>
<th>MeVO type</th>
<th>Technique used</th>
<th>Angiographic outcome</th>
<th>Clinical outcome</th>
<th>sICH</th>
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<tbody>
<tr>
<td>Pham et al 2018**</td>
<td>MA</td>
<td>What are the rep</td>
<td>Both SR and D</td>
<td>12</td>
<td>835</td>
<td>14</td>
<td>9</td>
<td>Modify M2 SR (n=612) vs DA (n=223)</td>
<td>TICI 2b/3: 81% (SR) vs 87% (DA)</td>
<td>mRS 0–2: 60% (SR) vs 75% (DA)</td>
<td>6% (SR) vs 3% (DA)</td>
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<tr>
<td></td>
<td></td>
<td>ureperfusion rates in M2 occlusions treated with SR vs DA?</td>
<td>AR</td>
<td>DA being performed sooner after onset of stroke compared with SR EVT</td>
<td>TICI 3: 54% (SR) vs 57% (DA) (I²=37%)</td>
<td>mRS 0–1: 40% (SR) vs 66% (DA) (I²=52%)</td>
<td>6% (SR) vs 3% (DA) (I²=40%)</td>
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<td>Saber et al 2018**</td>
<td>MA</td>
<td>What are the a</td>
<td>M2 EVT is t</td>
<td>12</td>
<td>1080</td>
<td>14</td>
<td>–</td>
<td>M2 SR, DA TICI 2b/3: 81% (I²=20%)</td>
<td>mRS 0–2: 59% (I²=61%)</td>
<td>19% (I²=75%)</td>
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<td>M2 SR, DA TICI 2b/3: 81% (I²=20%)</td>
<td>mRS 0–2: 59% (I²=61%)</td>
<td>19% (I²=75%)</td>
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<td>Kim et al 2019</td>
<td>MA</td>
<td>What are the a</td>
<td>M2 EVT is t</td>
<td>8</td>
<td>650</td>
<td>–</td>
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<td>M2 SR, DA TICI 2b/3: 69% (I² not provided)</td>
<td>mRS 0–2: 63% (I² not provided)</td>
<td>6% (I² not provided)</td>
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<td>M2 SR, DA TICI 2b/3: 69% (I² not provided)</td>
<td>mRS 0–2: 63% (I² not provided)</td>
<td>6% (I² not provided)</td>
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<td>Chen et al 2017</td>
<td>SR</td>
<td>What is the evi</td>
<td>M2 EVT results in high functional independence with</td>
<td>8</td>
<td>630</td>
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<td>–</td>
<td>M2 SR, DA TICI 2b/3: 78% (I² not provided)</td>
<td>mRS 0–2: 63% (I²=52%)</td>
<td>19% (I²=75%)</td>
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<td>dence for M2</td>
<td>modest ICH rates. But given the relatively favorable</td>
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<td>M2 SR, DA TICI 2b/3: 78% (I² not provided)</td>
<td>mRS 0–2: 63% (I²=52%)</td>
<td>19% (I²=75%)</td>
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Note: MA = meta-analysis, SR = stent retriever, DA = direct aspiration, EVT = endovascular treatment, (s)ICH = (symptomatic) intracranial hemorrhage, TICI = Thrombolysis in Cerebral Infarction Score, mRS = modified Rankin Score.

### THROMBECTOMY TECHNIQUE – HOW TO PERFORM EVT IN MEVO STROKE?

Several challenges emerge when performing EVT for MeVOS stroke. For the time being, we don’t know how high the risk of vasospasm and dissection is when the catheter size matches or exceeds the vessel diameter, which can happen with large-bore aspiration catheters in MeVOS. Medium-sized vessels can be too small to harbor a regular-sized distal access catheter (DAC), as most of the currently used DACs are 5–6F in diameter. Another problem is the DAC often gets stuck at the ledge of a bifurcation point such, such as the M1 bifurcation, but there are wedge-shaped microcatheters available to overcome this ledge effect. Furthermore, using a primary combined approach (ie, the combination of stent retriever, DAC, and balloon guide catheter), and advancing the system in a tri-axial manner, as it is commonly done for LVOs, may not be possible because of insufficient catheter length and diameter discrepancies. For example, using a longer DAC to access an M3 occlusion may not allow for a small enough and long enough microcatheter capable of deploying a stent. Thus, currently, the microwire and microcatheter are often introduced without a DAC. Once the microcatheter is in place, the stent can be deployed and the microcatheter removed before the distal access catheter is navigated to the site of occlusion (so-called “blind exchange mini-pinning technique”). However, this is probably a transient problem, as many of the newer stent retrievers can be deployed through a 0.017 microcatheter and more microcatheters are now available in 160 cm length. On the other hand, numerous authors reported promising results of primary aspiration as the first-line approach in MeVO stroke, which may constitute an equally effective alternative to stent retriever-based techniques. A comprehensive and unbiased comparison of different MeVO EVT techniques is currently not possible, since most studies are small, focus on specific devices, and a comparator group is often lacking. Furthermore, the literature on MeVO EVT techniques is biased, with onset-to-treatment times being on average much shorter in studies that used primary aspiration compared with those in which stent retrievers were used. Of note, MeVO EVT techniques and technologies are constantly evolving, and with MeVOS increasingly being targeted by neurointerventionalists, it is likely that treatment devices that are specifically tailored to MeVOS will be developed in the near future.

A substantial number of LVOs are treated without the use of general anesthesia (GA). Although randomized trials show equivalent or even better outcomes with GA vs conscious sedation,
Ischemic stroke

Table 3  Overview of different MeVO stroke imaging protocols

<table>
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<tr>
<th>MeVO stroke imaging protocols</th>
<th>Studies in which the protocol was used</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| NCCT+CTA                     | Romano et al 2020<sup>37</sup> (+DWI if symptom onset unknown)  
Atchaneeyasakul et al 2020<sup>46</sup>  
Compagne et al 2019<sup>13</sup>  
Qureshi et al 2017<sup>48</sup>  
Sarraj et al 2016<sup>14</sup>  
Menon et al 2019<sup>24</sup> (CTP/MRI was available in some patients)  
Coutinho et al 2016<sup>50</sup>  
Bhogal et al 2017<sup>52</sup> (either NCCT+CTA or MRI)  
De Castro Afonso et al 2019<sup>48</sup>  
Grieb et al 2019<sup>40</sup> | ► Wide availability  
► Inexpensive  
► Fast  
► Robust against patient motion  
► No post-processing needed  
► Option to use multiphase CTA, including color-coded time-variant mCTA maps and mCTA-derived CTA-like maps<sup>43</sup><sup>48</sup> | ► If single-phase CTA is used MeVOS may be missed<sup>49</sup>  
► Little information about collateral status if single-phase CTA is used  
► Current ASPECTS thresholds for LVO EVT are probably not optimal for MeVO EVT  
► ASPECTS does not capture ischemic changes in ACA and PCA MeVO stroke |
| NCCT+CTA + CTP               | Haussen et al 2020<sup>a</sup>  
Jiang et al 2019<sup>9</sup>  
Vargas et al 2017<sup>17</sup>  
Navia et al 2016<sup>28</sup>  
Menon et al 2019<sup>24</sup> (CTP/MRI was available in some patients)  
Coutinho et al 2016<sup>50</sup> (CTP/MRI was available in some patients)  
Grossberg et al 2018<sup>46</sup>  
Altenbernd et al 2018<sup>18</sup>  
Pfaff 2016<sup>40</sup> (either NCCT+CTA + CTP or DWI+MRA + PWI) | ► Higher information content compared with NCCT+CTA only  
► Estimates for ischemic penumbra and “core” volumes, also for ACA and PCA MeVO stroke  
► Does not exclusively rely on ASPECTS for ischemic “core” assessment  
► Option to use either single or multiphase CTA | ► Unavailability or limited availability of CTP in smaller hospitals  
► Limited accuracy of “core” and penumbra estimates due to variability in post-processing mechanisms  
► Susceptibility to patient motion |
| MRI (DWI-MRI±PWI)           | Romano et al 2020<sup>37</sup> (NCCT + CTA; DWI only if symptom onset unknown)  
Menon et al 2019<sup>24</sup> (CTP/MRI was available in some patients)  
Bhogal et al 2017<sup>52</sup> (either NCCT+CTA or MRI)  
Pfaff 2016<sup>40</sup> (either NCCT+CTA + CTP or DWI+MRA + PWI) | ► DWI: Highest sensitivity for acute small infarcts  
► PWI: Estimates ischemic penumbra and “core” volumes, also for ACA and PCA MeVO stroke | ► Limited availability of MRI and particularly PWI in many hospitals  
► Contraindications  
► Limited accuracy of PWI “core” and penumbra estimates due to variability in post-processing mechanisms  
► Susceptibility to patient motion  
► Various pitfalls in MRI interpretation due to artifacts (e.g. slow flow, metal artifacts due to dental fillings, etc.) |

NCCT = non contrast head CT, CTA = CT angiography, CTP = CT perfusion, DWI = diffusion-weighted imaging, MRA = MR angiography, PWI = perfusion-weighted imaging, ACA = anterior cerebral artery, PCA = posterior cerebral artery, LVO = large vessel occlusion, ASPECTS = Alberta Stroke Program Early CT Score

It is important to note that deficits such as isolated abulia (due to A2/3 occlusion), alexia and agraphia (due to M2/3 occlusions), or quadrantanopia (due to P2/3 occlusion) are not well captured in the NIHSS and mRS. Not only are those scales limited in their granularity, they are also heavily focused on motor function and thus unable to capture the more subtle personality changes and domain-specific impairment that often play a dominant role in MeVO stroke-related disability.

Angiographic outcomes

In most MeVO EVT studies, angiographic outcomes are reported as “successful reperfusion”, that is, TICI 2b/3, analogous to reperfusion assessment in LVO stroke, although several studies reported TICI 3 and/or TICI 2c/3 reperfusion in addition to TICI 2b/3 rates (table 1). Reporting successful reperfusion (TICI 2b/3) only is problematic, given that MeVOSs in the anterior and posterior cerebral artery territory are not reflected in TICI at all, and patients with distal M2 or M3 occlusions will frequently have TICI 2b at baseline. There is currently no satisfactory reperfusion grading system tailored to MeVO stroke. Crockett et al made an interesting attempt in this regard: in addition to the “regular” TICI, they used a modified TICI, which focused solely on the territory affected by the MeVO, with a scoring system identical to the standard TICI system (1, 2a, 2b, 2c, 3). Figure 1 shows a proposed modified eTICI scoring system for...
Ischemic stroke

Ischemic stroke an anterior, middle, and posterior cerebral artery MeVOS. The key difference to the conventional eTICI score is hereby the “denominator”, that is, the territory downstream of the occlusion that serves as a comparator.

Safety outcomes

Accurate and consistent reporting of safety outcomes is crucial when performing MeVO EVT, since the risk of complications is probably higher compared with LVOs, due to the relatively smaller vessel size and more distal occlusion location. Symptomatic intracranial hemorrhage (sICH) was the most consistently reported complication type in MeVO EVT studies (table 1), although many reported asymptomatic hemorrhage, vasospasm, and extracranial complications as well. In two studies, sICH rates ranged from 10%–11%,25 42 while the prevalence in other studies was below 8%, which is only slightly higher compared with LVOs.5

OUTCOMES FOR EVT IN PRIMARY VS. SECONDARY MEVOS

Most of the literature published on MeVO EVT does not distinguish between primary and secondary MeVOS. But in particular the effect of “rescue” EVT in procedure-related secondary MeVOS is of great interest for neurointerventionalists, since peri-procedural embolization of clot fragments is a common phenomenon. Embolization causing anterior cerebral artery occlusion, for example, has been observed in more than 10% of LVO EVT procedures,43 especially in cases with terminal ICA occlusion, in which the clot segment extending into the ACA might get “guillotined off” by the distal aspiration catheter or stent retriever.44 Since the infarcted area will often be larger in secondary MeVOS, one would assume clinical outcomes to be worse compared with primary MeVO strokes. However, Grossberg et al, who reported post-EVT outcomes for primary and iatrogenic (EVT-induced) secondary MeVOS separately, found similar recanalization results and even slightly better clinical outcomes in patients with secondary MeVOS, despite more severe symptoms at baseline.45 Future studies on MeVO EVT should aim to capture information on MeVO types, and report results stratified for primary vs secondary MeVOS.

CONCLUSION AND OUTLOOK

With improving imaging technologies and a growing body of literature, MeVOS are being increasingly recognized as a target for EVT. Outcomes with intravenous thrombolysis, which is the current standard of care, are moderate at best and many patients are not eligible for thrombolytic treatment at all. At the present time, there is limited but promising evidence for the safety and efficacy of MeVO EVT. Many interventionists are already routinely treating primary as well as secondary MeVOS, that is, emboli into distal vessels during EVT for LVO stroke. However, standardized imaging protocols, treatment indication criteria, and unbiased comparisons of different EVT techniques for MeVOS are lacking. At the same time, imaging tools and particularly MeVO EVT techniques are rapidly evolving. A randomized controlled trial seems unavoidable in order to establish MeVO EVT as standard of care.

Twitter Johanna Maria Ospel @johanna_ospel and Mayank Goyal @mayank_G0

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Contributors Both authors were involved in drafting and critical revisions of the manuscript.

Figure 1  Suggested modified eTICI classification for MeVOS in the anterior (MeVO-A-TICI: A), middle (MeVO-M-TICI: B) and posterior (MeVO-P-TICI: C) cerebral artery. Blue overlays in (A1), (B1), and (C1) indicate the “denominator”, that is, the territory downstream of the occlusion that serves as a comparator. Complete reperfusion of the territory marked in blue would correspond to an eTICI score of 3. Reperfusion contained to territory marked with red overlays in (A2), (B2), and (C2) would indicate a MeVO-A-TICI, MeVO-M-TICI, and MeVO-P-TICI score of 2A, that is, reperfusion of less than 50% of the initially affected territory. Reperfusion contained to territory marked with yellow overlays in (A3), (B3), and (C3) would indicate an MeVO-A-TICI, MeVO-M-TICI, and MeVO-P-TICI score of 2B, that is, reperfusion of 50%–90% of the initially affected territory. Reperfusion contained to territory marked with red overlays in (A4), (B4), and (C4) would indicate an MeVO-A-TICI, MeVO-M-TICI, and MeVO-P-TICI score of 2C, that is, near-complete reperfusion/reperfusion of less than 90%–99% of the initially affected territory.
What constitutes the M1 segment of the middle cerebral artery (MCA)?


