



## Topical Review

## What is the Role of Mechanical Thrombectomy in Childhood Stroke?

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## ABSTRACT

**Background:** Like adults, most children have lifelong morbidity after stroke. Revascularization therapies such as intravenous tissue plasminogen activator and mechanical thrombectomy may be options to decrease this morbidity in selected children, although currently there are no evidence-based recommendations to guide treatment. The utility and safety of mechanical thrombectomy in childhood stroke is unknown because of the lack of safety trials, case-controlled trials, and comprehensive retrospective studies. As such, the current rationale for the use of mechanical thrombectomy in childhood is based on extrapolation from adult experience, as well as consensus at individual institutions with many centers deciding care on a case-by-case basis. Nevertheless, the increasing use of recanalization therapies in appropriately selected adults with acute arterial ischemic stroke has led to an increase in consideration and use in childhood, and there are enough case reports and series, as well as experience, to suggest that some children with large vessel occlusion will likely benefit.

**Methods:** We reviewed current literature regarding mechanical thrombectomy in childhood.

**Results:** There are differences between pediatric and adult stroke which may impact safety, efficacy, and individual decision-making, including patient size, pathophysiology of stroke, deficit, experience, and lack of data regarding natural history of stroke in children.

**Conclusions:** Hospitals planning to perform mechanical thrombectomy in children should establish local procedures and guidelines for considering thrombectomy. In our experience, care is best provided through multidisciplinary teams including a pediatric vascular neurologist, neurointerventionalist with pediatric experience, and pediatric neurocritical care.

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## Importance

Recanalization therapies are now the standard of care in appropriately selected adults with acute arterial ischemic stroke (AIS).<sup>1,2</sup> In 2015, publication of a series of five clinical trials established the efficacy of mechanical thrombectomy within six hours of a proximal large vessel occlusion (LVO). These five trials included (1) Multicenter Randomized Clinical Trial of Endovascular Treatment for Acute Ischemic Stroke in the Netherlands (MR CLEAN), (2) Endovascular Treatment for Small Core and

Anterior Circulation Proximal Occlusion with Emphasis on Minimizing CT to Recanalization Times (ESCAPE), (3) Extending the Time for Thrombolysis in Emergency Neurological Deficits - Intra-Arterial (EXTEND-IA), (4) Solitaire with the Intention for Thrombectomy as Primary Endovascular Treatment (SWIFT PRIME), and (5) Randomized Trial of Revascularization with Solitaire FR Device Versus Best Medical Therapy in the Treatment of Acute Stroke Due to Anterior Circulation Large Vessel Occlusion Presenting within Eight Hours of Symptom Onset (REVASCAT).<sup>3-7</sup> In 2018 the treatment window for mechanical thrombectomy for anterior circulation LVO with salvageable penumbra on perfusion imaging was extended to 16 hours in the DEFUSE 3 (Endovascular Therapy Following Imaging Evaluation for Ischemic Stroke 3)<sup>8</sup> and to 24 hours in the DAWN (DWI or CTP Assessment with Clinical Mismatch in the Triage of Wake-Up and Late Presenting Strokes Undergoing Neurointervention with Trevo) trials.<sup>9</sup>

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Like adults, most children have lifelong morbidity after a stroke.<sup>10–12</sup> Revascularization therapies such as intravenous tissue plasminogen activator and mechanical thrombectomy may be options to decrease this morbidity in selected children, although currently there are no evidence-based recommendations to guide treatment. The 2015 American Heart Association stroke guidelines for acute management suggest that the benefits of mechanical thrombectomy are not established in children, but that “endovascular therapy with stent retrievers may be reasonable for some patients less than 18 years of age with acute ischemic stroke who have demonstrated large-vessel occlusion in whom treatment can be initiated (groin puncture) within six hours of symptom onset.”<sup>1</sup> The 2018 American Heart Association stroke guidelines for acute management focusing on the new 16- to 24-hour time window in adults did not, however, address treatment of children in response to these new trials.<sup>13</sup>

Before 2015 the lack of compelling adult mechanical thrombectomy trials led many pediatric vascular neurologists to consider mechanical thrombectomy only rarely, using mechanical thrombectomy in life-threatening situations such as basilar artery occlusion with severe deficit. Although pediatric data are still lacking, given the demonstrated benefit of mechanical thrombectomy in appropriately selected adults, pediatric vascular neurologists have increasingly felt compelled to consider mechanical thrombectomy in selected children who meet adult criteria for intervention. In addition, the extension of the treatment time window to 16 to 24 hours in adults means that children with stroke, who often come to medical attention late, will increasingly present during a timeframe in which an adult would be considered for mechanical thrombectomy. Therefore the pediatric neurologist must make urgent decisions regarding a therapy that is unproven in children but highly effective in adults.

### Current use of mechanical thrombectomy in childhood

Because of the lack of safety trials, case-controlled trials, or comprehensive retrospective studies, the safety and efficacy of mechanical thrombectomy in childhood stroke is unknown. As such, the current rationale for the use of mechanical thrombectomy in childhood is based on extrapolation from adult experience and

consensus at individual institutions, with many centers deciding care on a case-by-case basis. Factors that are often considered include the age and size of child and the anticipated outcome in the absence of intervention. Despite the lack of systematic efficacy and safety data, the use of mechanical thrombectomy in childhood is increasing, and case reports and small series have reported good outcome.<sup>14,15</sup> In a recent review of 29 published cases of mechanical thrombectomy in children with proximal LVO and high pediatric National Institute of Health Stroke Scale scores, there were no major adverse events and the average modified Rankin scale at follow-up was less than 1. Three quarters of cases achieved thrombolysis in cerebral infarction 2b/3 recanalization.<sup>14</sup> However, publication bias in case reports with positive outcomes is common in the medical literature<sup>16</sup> and is particularly problematic for rare diseases such as LVO in childhood on which controlled studies are unlikely to ever be performed.

There are sufficient case reports and case series, as well as experience, to suggest that some children with LVO will likely benefit from mechanical thrombectomy.<sup>14,15,17</sup> It is also possible that there is a yet-unrecognized benefit in maintaining patent arteries rather than relying on collateral circulation over the decades of life after stroke. Nevertheless, there are critical differences between adult and childhood AIS that may limit extrapolation from adult data to children (Table 1).

Stroke accounts for most acute neurological deficit in adults, and although somewhat limited in sensitivity and specificity, LVO prediction instruments are available for triage for adult stroke.<sup>18</sup> In contrast, childhood stroke is relatively rare, its diagnosis is often delayed, and half of children with acute neurological deficit suggestive of stroke will actually have a mimic.<sup>19,20</sup> Most LVO in adults are presumed to be cardioembolic in origin, and approximately 10% are because of large artery atherosclerosis.<sup>21</sup> The etiologies of LVO in children are unknown. As approximately one third to one half of all childhood strokes occur secondary to a cerebral arteriopathy,<sup>22</sup> cerebral arteriopathies with secondary LVO may be prevalent in children. At this time it remains unclear how arteriopathies with associated LVO would respond to mechanical thrombectomy, but, theoretically, there is an increased risk of hemorrhage in a diseased vessel undergoing mechanical thrombectomy. In addition, cerebral

**TABLE 1.**  
Key Differences in Adult Versus Childhood Stroke

Variable	Experience in Adults	Experience in Children
Diagnosis	Stroke accounts for most acute neurological deficit in adults	Stroke is less common than in adults Half of children with acute neurological deficit suggestive of stroke will have a mimic
Etiology	Most LVOs in adults are cardioembolic in origin, and approximately 10% because of large artery atherosclerosis	The etiologies of LVO in children include thromboembolic events such as congenital heart disease and cervical artery dissection but may also be associated with intracranial arteriopathies
Predictive value of NIHSS	In adults, initial NIHSS predicts outcome	The predictive value of the PedNIHSS within first hours of stroke onset has not been systematically studied
Perfusion imaging	Perfusion-based imaging can be used to identify patients most likely to benefit	The efficacy of perfusion-based imaging has not been established in children
Collaterals	Poor collateral status is associated with poor outcome, and mechanical thrombectomy may benefit some adults with minor strokes because of LVO	Children often have robust collaterals, and the incidence of early neurological deterioration with LVO is unknown
Anterior versus posterior circulation	Most strokes occur in the anterior circulation, and most mechanical thrombectomy trials are for anterior circulation stroke	In childhood, up to half of all strokes are in the posterior circulation
Vessel size	Cerebral vessel size approaches adult size by age five years	Children aged <5 have smaller vessels that may not accommodate adult devices
Incidence of vasospasm	Vasospasm is reported in 3% of adults undergoing mechanical thrombectomy	Vasospasm is reported in childhood mechanical thrombectomy, and the incidence and significance are not known
Infrastructure	Primary and comprehensive stroke centers	Formal infrastructure does not exist

Abbreviations:

LVO = Large vessel occlusion

NIHSS = National Institutes of Health Stroke Scale

arteriopathies may be associated with collaterals, whose protective role in childhood AIS is likewise unclear.

Computed tomography (CT) or magnetic resonance imaging (MRI) perfusion-based imaging can be used to identify adults most likely to benefit from mechanical thrombectomy and was crucial in studies showing efficacy of mechanical thrombectomy. Perfusion imaging can identify salvageable tissue in childhood AIS<sup>23</sup>; however, the limits of this imaging technique in children are not known, including the extent to which stenosing arteriopathies—which are common in childhood AIS—can interfere with interpretation.

Poor collateral status in adults is associated with a larger ischemic core at baseline and worse outcome after treatment.<sup>24</sup> Early neurological deterioration can occur in adults with minor clinical strokes and LVO, and early thrombectomy may benefit these patients.<sup>25</sup> In contrast, children often have robust collaterals, particularly if stroke is associated with a progressive arteriopathy,<sup>26</sup> and the incidence of early neurological deterioration with LVO is unknown.

Most mechanical thrombectomy trials in adults have enrolled anterior circulation strokes, as these are most common in adults. In childhood, up to half of all strokes are in the posterior circulation and half of these are dissections,<sup>27</sup> which may increase risk of mechanical thrombectomy. In adults, mechanical thrombectomy is often pursued in basilar artery occlusion, as untreated basilar artery occlusion results in death or severe disability in 80% to 90% of cases.<sup>28</sup> Outcome following basilar artery occlusion is better in children than adults, and good outcomes can occur without intervention.<sup>29</sup>

There are features unique to childhood AIS that may increase procedural risk. Children with stroke often have comorbidities such as sickle cell, congenital heart disease, and severe thrombophilia, which increase the risk of interventions, including anesthesia and procedural-related thrombosis. Cerebral vessel size as assessed on cerebral catheter angiography does not approach adult size until age five years,<sup>30</sup> so stent-vessel size mismatch can occur. Vasospasm is reported in 3% of adults undergoing mechanical thrombectomy.<sup>31</sup> Vasospasm has been reported in pediatric mechanical thrombectomy,<sup>15,32,33</sup> and based on anecdote may occur more often than in adults. It has been suggested that the increased risk of vasospasm in childhood mechanical thrombectomy is because of large stent size relative to vessel size,<sup>32</sup> and smaller stents have been suggested as a solution.<sup>34</sup> However, arterial vasospasm may not always be because of mechanical factors. For example, younger adults with subarachnoid hemorrhage have a higher incidence of angiographic and symptomatic vasospasm than older adults,<sup>35,36</sup> suggesting an age-related susceptibility.

Primary and comprehensive stroke centers across the United States have extensive guidelines and infrastructure to rapidly diagnose and provide acute care to adults with stroke.<sup>37</sup> Although the Thrombolysis in Pediatric Stroke trial created an initial group of pediatric stroke centers,<sup>38</sup> the use of mechanical thrombectomy in children faces many barriers including separate pediatric and adult hospitals, adult interventionalists who are located at an adult center without the capability to optimally treat young children, and a lack of oversight and guidelines to promote quality measures in treating children with stroke.

### Risks of mechanical thrombectomy

In adults the risk of significant complications secondary to mechanical thrombectomy is estimated to be about 15%. These include access-site complications, intracranial hemorrhage, extracranial bleeding, arterial dissection and other vascular injury, distal or new arterial territory embolization, vasospasm, and device malfunction.<sup>39</sup>

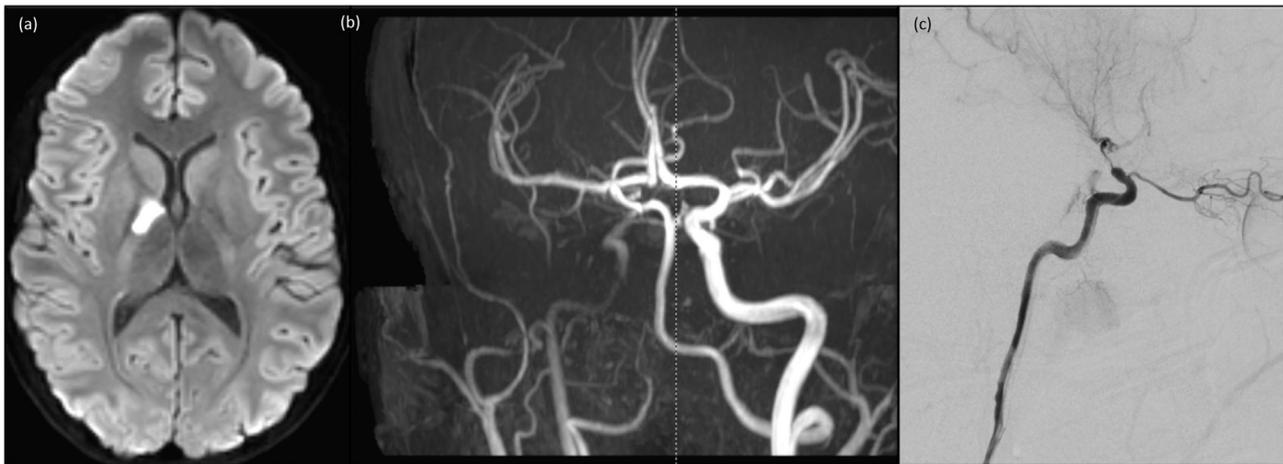
Children who undergo mechanical thrombectomy are often brought to adult stroke centers, where inadequate knowledge of medical comorbidities in children may result in inappropriate decision making by adult providers. Medically complex children, who often carry a higher risk of complications with anesthesia and other aspects of the procedure, risk further injury with improperly trained providers who do not understand the disease processes. The importance of collaterals in childhood stroke and the need to maintain robust cerebral perfusion may not be recognized. In hospitals without a pediatric stroke team to assist, decisions may be driven by an adult protocol, without involvement of the pediatric service. Stroke syndromes common in childhood but not in adults, such as progressive arteriopathies and focal cerebral arteriopathies, may mimic the appearance of a thrombus on imaging but may not be amenable to mechanical thrombectomy. Dissection, another common childhood stroke syndrome, may result in an occlusion on imaging, which may be confused as a thrombus. In adults, although treatment insular middle cerebral artery (MCA) (M2) occlusions has not been fully evaluated in a randomized controlled trial, in a single institution experience, the treatment was found to be safe and effective,<sup>40</sup> and may be pursued in some patients.<sup>41</sup> Involvement of the M2 segment is common in children, often secondary to arteriopathy; however, it is unknown if children would be a good candidate for M2 mechanical thrombectomy. The variable etiologies and potential ability for recovery in the developing brain make decisions about thrombectomy in childhood stroke particularly challenging (Figs 1 and 2).

Bringing a child to the interventional radiology suite can be slow because of lack of established procedures, need for transfer to a hospital able to provide mechanical thrombectomy, and the need for anesthesia. Comprehensive adult stroke centers are incentivized to continue quality improvement of stroke care, as part of accreditation, whereas there is no pediatric stroke accreditation for children's hospitals, and resources for process improvement are often minimal. Although many adults can complete mechanical thrombectomy with conscious sedation, most children will require general anesthesia, which can further delay both the procedure and recanalization. On the other hand, children usually have very straight vessels, so once the procedure begins, accessing the clot with the mechanical thrombectomy device is typically faster and easier than in adults with vessel tortuosity and atherosclerosis.

### Neuroimaging before mechanical thrombectomy

Most children's hospital stroke pathways use MRI brain and MR angiogram of the head and neck as the preferred imaging modality because of the high likelihood of the presentation of a stroke mimic.<sup>42</sup> For children with contraindications to MRI, CT head with CT angiography of the head and neck may be a viable option. The amounts of contrast and radiation a child would receive during a CT angiography of the head and neck and a mechanical thrombectomy should be considered, especially in a child with renal compromise. The presence of robust collaterals in the setting of an occluded vessel may sway a decision not to pursue mechanical thrombectomy if it appears that the child is perfusing well.

The role of perfusion imaging, on either CT or MRI, has not been studied in childhood AIS, and there are no data to support its use in patient selection. CT perfusion imaging is used in adult studies and in most centers for adults who present outside the six-hour window; however, CT perfusion requires significant radiation and contrast, as well as accurate timing of the bolus of contrast with the scan. It may be difficult to time the scan appropriately to get useful results, particularly in children with higher heart rates and in those with congenital or acquired heart disease and abnormal cardiac function. Stenosing arteriopathies such as moyamoya and focal



**FIGURE 1.** (A) This is a previously healthy 15-year-old boy presented with left face, arm, and leg weakness about five hours from his last known normal function. Initial NIHSS was 3; however, symptoms continued to worsen while in the emergency department, with an increase in NIHSS to 6. MRI brain shows acute infarct in right internal capsule and globus pallidus on diffusion weighted imaging. (B) MR angiogram brain with right internal carotid artery occlusion, thought to be secondary to thrombus. (C) He was taken to the interventional radiology suite for thrombectomy but initial angiogram showed greater than 90% stenosis of supraclinoid right internal carotid artery, concerning for a focal cerebral arteriopathy. Thrombectomy was aborted and child was taken back to the pediatric ICU for medical management. At time of discharge he had a mild left hemiparesis. ICU = Intensive care unit; MRI = Magnetic resonance imaging; NIHSS = National Institute of Health Stroke Scale.

cerebral arteriopathy may also interfere with interpretation of perfusion-based imaging. Misguided attempts at mechanical thrombectomy in children with such conditions may incur significant complications. Although it requires more time and preparation, MRI perfusion imaging may be necessary to obtain adequate imaging for optimal decision making. Some centers are also using stroke volume measurements to select patients, but this is labor-intensive and requires local expertise.

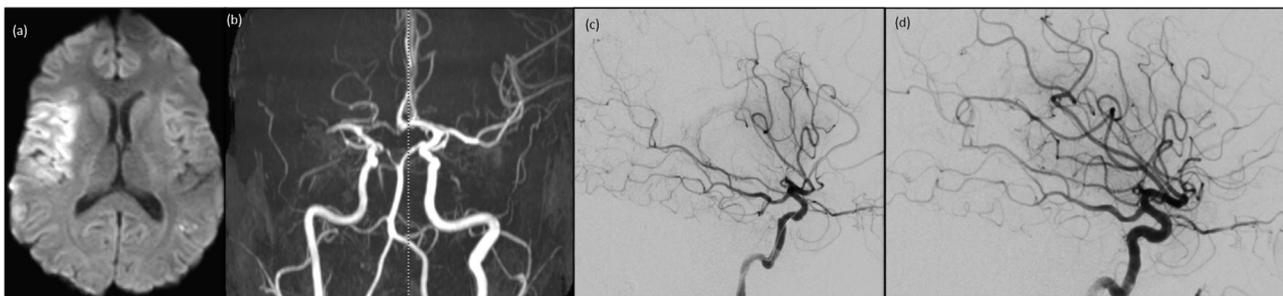
### Individual clinical decision making

No evidence-based guidelines exist for mechanical thrombectomy in childhood AIS. Institutional guidelines may include interdisciplinary consensus-based guidelines for consideration of mechanical thrombectomy in children. Consensus-based recommendations from the Hospital for Sick Children published in 2017, before publication of the DAWN AND DEFUSE 3 trials, excluded children with stroke onset more than six hours earlier, children with infarcts greater than one third of the MCA territory, and all children less than five years of age.<sup>15</sup> Some centers have extrapolated evidence from adult trials to consider thrombectomy in children with LVO up to 24 hours. Other factors

considered include M2 occlusions, National Institute of Health Stroke Scale, multiple strokes, bilateral MCA stroke, low Alberta Stroke Program Early CT score, prestroke disability, age, stroke size, and medical comorbidities. Criteria for mechanical thrombectomy differ, even among well-established pediatric stroke centers, reflecting the paucity of evidence on which recommendations are based. In the absence of evidence-based guidelines, the clinical impression of the treating team will be crucial, and the use of mechanical thrombectomy in a given child will usually depend on speculation regarding the potential benefits and risks based on extrapolation from adult studies (Table 2). Factors that should be considered include age, deficit, time since stroke onset, and anticipated outcome in the absence of intervention. Decisions may be impacted by pediatric experience, use of adult pathways in adult hospitals, and regional and hospital infrastructure.

### Mechanical thrombectomy procedure

A neurointerventionalist whose primary stroke experience is in treating adults is likely to treat most children undergoing mechanical thrombectomy. Ideally the neurointerventionalist will have sufficient expertise in treating children to safely transfer the



**FIGURE 2.** (A) 16-year-old girl with history of multiple autoantibodies including antilupus anticoagulant and ADAMTS13 inhibitor presents with left face, arm, and leg weakness and numbness. She did not receive IV tPA because of thrombocytopenia secondary to newly diagnosed thrombotic thrombocytopenic purpura. Initial NIHSS was 11. MRI brain shows acute infarct in right insula, frontal, parietal, and temporal cortices, and underlying white matter on diffusion weighted imaging. (B) MRA brain with right MCA occlusion at the distal M1. (C) Initial angiogram showed a right MCA occlusion just distal to anterior temporal artery. (D) A solitary stent retriever was used to remove thrombus. After thrombectomy angiogram shows complete recanalization of the MCA, grade TIC1 3. The etiology of her stroke was thought to be secondary to her hypercoagulable state. She was also found to have several venous clots in her extremities, although no patent foramen ovale found on transthoracic echocardiogram. She made a full recovery back to her prior baseline. IV tPA = Intravenous tissue plasminogen activator; MCA = Middle cerebral artery; MRI = Magnetic resonance imaging; NIHSS = National Institute of Health Stroke Scale; TIC1 = Thrombolysis in cerebral infarction.

**TABLE 2.**  
Extrapolation From Adult Mechanical Thrombectomy Guidelines

American Heart Association 2018 Guidelines for Use of Mechanical Thrombectomy <sup>41</sup>	Potential Impact on Decision for Pediatric Thrombectomy
<p>Patients aged <math>\geq 18</math> years. All thrombectomy trials were done in adults</p> <p>&lt;6 hours from last known normal</p> <p>Prestroke modified Rankin score of 0-1</p> <p>Occlusion of the internal carotid or middle cerebral artery segment</p> <p>NIHSS score <math>\geq 6</math></p> <p>ASPECTS of <math>\geq 6</math></p> <p>Treatment can be initiated within six hours of symptom onset</p>	<p>Mechanical thrombectomy may be challenging in very young children because of vessel size. Very small children may have increased risk of peripheral or central artery injury with instrumentation because of smaller vessels. Vessel size approaches adult size by age 5</p> <p>Modified Rankin score is a measure of how much independence an adult has with activities of daily living. Young children are dependent on adults for many activities of daily living</p> <p>Care should be taken to consider a pediatric specific differential diagnosis for stroke in children. Some LVOs—such as seen in cardioembolic stroke from congenital heart disease—are likely to respond to thrombectomy in a predictable manner, as they have a pathophysiology that is similar to adult stroke. Others—such as focal cerebral arteriopathies—may be less predictable in their response to thrombectomy, as this pathophysiology is rarely seen in adults with stroke</p> <p>Calculating a PedNIHSS in a child can be difficult, especially in younger children</p> <p>Children with mild deficit may be assumed to have good recovery without intervention, whereas children with severe deficit may be considered more likely to benefit for mechanical thrombectomy</p> <p>ASPECTS is typically measured on a CT head. Modified Pediatric ASPECTS can be derived from MRI<sup>43</sup></p> <p>Children often present outside the window for acute stroke treatment. Some children's hospitals require a transfer to adult stroke centers in which transport time should be considered in decisions regarding thrombectomy</p>
<p>&gt;6 hours from last known normal</p> <p>Prestroke modified Rankin score of 0-1</p> <p>Occlusion of internal carotid or middle cerebral artery segment</p> <p>In selected acute stroke patients within six-16 hours of last known normal who have an LVO in the anterior circulation and meet other DAWN or DEFUSE 3 eligibility criteria, mechanical thrombectomy is <i>recommended</i></p> <p>In selected acute stroke patients within six-24 hours of last known normal who have LVO in the anterior circulation and meet other DAWN eligibility criteria, mechanical thrombectomy with a stent retriever is <i>reasonable</i></p> <p>Treatment can be initiated within six-24 hours of symptom onset</p>	<p>See aforementioned</p> <p>See aforementioned</p> <p>The measurement of infarct volumes in the DAWN trial required the use of specialized software that is not validated in children and unavailable in most pediatric stroke centers. More likely to be available in children is the use of manual measurements of stroke volume performed by an experienced radiologist, using the DAWN criteria: (1) NIHSS <math>\geq 10</math> and infarct volume &lt;31 mL using DWI, or (2) NIHSS <math>\geq 20</math> and infarct volume of 31-51 mL using DWI</p> <p>The impact of collaterals in childhood stroke on this timeframe has not been studied</p>

## Abbreviations:

ASPECTS = Alberta Stroke Program Early CT score

DWI = Diffusion weighted imaging

LVO = Large vessel occlusion

MRI = Magnetic resonance imaging

NIHSS = National Institute of Health Stroke Scale

technique. The application of adult techniques will require adapting the technique to the different etiologies in childhood, the likely increased risk of vasospasm, and in the very young, smaller arterial size. Parents or guardians should be informed that safety and efficacy of mechanical thrombectomy in children with stroke has not been established. Supportive care should be discussed as an alternative to mechanical thrombectomy.

Most mechanical thrombectomy experience in treating adults, including in major trials, is with the stent retriever–based technique in combination with a balloon guide catheter.<sup>44</sup> Appropriately, most cases reported in the child population use this technique. As the average size of the MCA by age five is 94% that of an adult, the common 4 mm diameter stent retriever is appropriate for most cases aged  $\geq 5$ .<sup>30</sup> For smaller vessels, 3 mm diameter stent retrievers are available.<sup>34</sup> In addition, stent retrievers are not necessarily limited to use in vessels with their specified diameter as they will only open to the size of the vessel. The key issue is the outward force of the stent retriever when deployed at a certain vessel diameter.

Proactive measures may decrease the risk of vasospasm. Use of a stent retriever includes waiting three to five minutes after deployment to allow the stent retriever to engage the clot. During this time, intra-arterial calcium channel blocker could be administered through either the guide catheter or, if used, an aspiration catheter (distal access catheter). As anesthesia monitored care is recommended in pediatric cases, any resultant

drop in blood pressure will be promptly managed. In adults, some operators routinely administer a calcium channel blocker during the stent retriever deployment.

The stent retriever is optimally used in conjunction with a balloon guide catheter. Adult size catheters are intentionally large to provide more effective aspiration. Typical sizes range in the order of 8F—likely too large for the common femoral arteries of younger children. Fortunately, the generally very straight anatomy of younger children allows for options other than typical guide catheters. As an example, a number of distal access catheters are available, which can be used as the guide catheter with a stent retriever or in a contact aspiration technique.

Special consideration should be given to the etiologies of progressive arteriopathies and focal cerebral arteriopathies, which are common in children but not in adults. The care team should be aware that the appearance of stenosis may be confused with thrombus on cross-sectional imaging potentially leading to attempt at mechanical thrombectomy. Fortunately, the distinction between thrombus and stenosis can be made at catheter angiography. However, an *in situ* thrombus caused by an underlying stenosis usually cannot be distinguished from an embolus. In adults, this not-uncommon circumstance because of atherosclerosis is usually not known before the mechanical thrombectomy. The mechanical thrombectomy is performed in a usual manner and only once the clot is removed is the underlying stenosis identified. Additional steps may be needed to prevent reocclusion.

The use of a stent retriever involves first crossing the occlusion using a small microcatheter and microwire combination (diameter less than two thirds of a millimeter). The stent retriever is then deployed in the clot including in any underlying stenosis. The stent retriever opens and engages the clot and is subsequently dragged through the lesion. It is prudent to assume the process is traumatic to an underlying stenosis and that the etiologies encountered in children may be more susceptible to injury than those in adults. The technique of contact aspiration avoids the use of a stent retriever.<sup>45</sup> After the lesion is crossed by the microcatheter/microwire combination, a catheter with diameter just smaller than the occluded vessel is advanced to the proximal end of the thrombus and connected to aspiration. After a minute, the catheter is removed and often the clot along with it. In this manner, the thrombus is aspirated while the only manipulation of the arterial lesion is that of traversing with the microcatheter/microwire combination. When injury to an underlying lesion is a potential concern, it may be appropriate to begin with this less traumatic technique.

General anesthesia will be necessary for all children except perhaps older teenagers. In this regard, recent adult studies that compare general anesthesia with conscious sedation and show no outcome difference are reassuring.<sup>46–48</sup> Given the importance of collaterals in pediatric stroke, maintaining adequate perfusion pressure throughout the procedure is critical.

Postprocedure care will be similar to that for adults, with emphasis placed on neurological assessment and puncture site monitoring. Postprocedure neuroimaging, either head CT or head MRI, should be obtained to assess possible hemorrhagic complications.

### Future directions

The overwhelming evidence for increased functional outcomes for selected adults who receive mechanical thrombectomy will lead to an increase in consideration and use in childhood, and programs must be prepared to consider mechanical thrombectomy while optimizing safety. Mechanical thrombectomy is not standard of care in children and should be performed only by teams with experience in treating childhood stroke. Ideally, before attempting mechanical thrombectomy, hospitals should establish local procedures and guidelines for considering thrombectomy, as in the use of tissue plasminogen activator for children.<sup>38</sup> In our experience, multidisciplinary teams that include a pediatric stroke neurologist, a vascular neurologist, and a neurointerventionalist are most capable of establishing these local guidelines and making real-time decisions about mechanical thrombectomy treatment.

Continued quality improvement should include the collection of standardized outcome data on children with AIS, including children with poor outcomes, so that complications can be better understood. Future literature about the safety of thrombectomy in children is greatly needed. Initial data will likely be retrospective, but the expanded time windows for mechanical thrombectomy may lead to a successful prospective trial in children. At the very least, uniform data from a prospective registry should be sought.

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