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ORIGINAL RESEARCH

Mechanical embolectomy for treatment of large vessel acute ischemic stroke in children

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ABSTRACT

Background and purpose The three largest adult stroke trials investigating mechanical embolectomy retrieval devices in acute stroke (the Merci, Multi Merci and Penumbra Pivotal Stroke Trials) excluded children. There is a need to expand the literature on mechanical embolectomy in large vessel pediatric arterial ischemic stroke. This paper reports the use of two mechanical embolectomy devices cleared by the Federal Drug Administration (FDA) in four consecutive cases.

Methods Our pediatric stroke database from 2002 to the present was reviewed retrospectively. Patients were included if they were diagnosed with an acute large vessel occlusion, were <18 years of age and underwent recanalization with a device cleared by the FDA. Clinical and radiographic results were abstracted from medical record review. The Pediatric National Institutes of Health Stroke Scale (PedNIHSS) score at presentation and at discharge and a pediatric-modified Rankin Scale (Ped-mRS) at approximately 90 days were scored retrospectively based on documented examinations.

Results Four patients aged 4–17 years with a PedNIHSS score at presentation ranging from 2 to 17 points underwent mechanical embolectomy for reperfusion of the basilar artery (n=3), M1 segment of the right middle cerebral artery (n=1) and right internal carotid artery terminus (n=1). Thrombolysis in cerebral infarction (TICI) grade 3 was achieved in four vessels and TICI grade 2A was achieved in one vessel; there was one asymptomatic intraparenchymal hemorrhage. Intra-arterial tissue plasminogen activator was administered in two vessels. The PedNIHSS score at discharge ranged from 0 to 16 points and the Ped-mRS score at approximately 90 days ranged from 0 to 3 with 75% achieving a Ped-mRS score of ≤2.

Conclusion Mechanical embolectomy using the Merci and Penumbra systems may be a feasible therapeutic option in the treatment of large vessel pediatric arterial ischemic stroke.

INTRODUCTION

The incidence of pediatric stroke is estimated to be 2–13/100 000 children per year. Pediatric arterial ischemic stroke makes up a subset of these cases with an estimated incidence of 0.63–7.9/100 000 per year.[1–3] Mortality in childhood stroke remains low with an estimated case death rate of 2–11%, but is offset by lifelong morbidity which is reported to be between 68% and 74%.[4 5] Sequelae of pediatric stroke can manifest as deficits in motor function, language, ability to learn, behavior and social skills.[6 7] While most cases of arterial ischemic stroke in children are classified as idiopathic, known etiologies include focal cerebral arteriopathy, infection, cardiac disease, sickle cell disease, moya moya, arterial dissection, vasculitis and metabolic derangement.[8] The most common presenting symptom of stroke in young children is seizure or hemiparesis, with seizures heralding the index stroke 20–48% of the time.[9] Moreover, hemiparesis as a symptom of stroke may be extremely difficult to recognize in a young child and can be attributed to other causes. Because symptoms often mimic more common medical conditions such as migraine headache, diagnosis and medical intervention may be delayed.[10] This often limits treatment options to endovascular measures.

The American College of Chest Physicians, Royal College of Physicians and American Heart Association[11] have each established guidelines to aid the pediatric specialist in the treatment of large vessel pediatric arterial ischemic stroke (LVPAIS). These current guidelines are based on consensus and expert opinion with no specific recommendations on mechanical embolectomy.[4] One potential reason for this is the lack of data on the use of embolectomy devices cleared by the Federal Drug Administration (FDA) in children and adolescents. In the Merci, Multi Merci and Penumbra single-arm trials, which concluded that their respective devices were safe and effective, patients aged <18 years were excluded. Owing to the scarcity of data, pediatric specialists and interventionalists are forced to extrapolate data from adult trials, postulating that safety and efficacy of mechanical embolectomy in children parallels that in adults. Data on the use of FDA-cleared devices off label in the setting of LVPAIS are limited to one case report and one small case series.[12 13] The aim of this paper is to broaden the current base of knowledge by describing our early experience in using mechanical embolectomy devices in LVPAIS.

METHODS

Patient selection

Our pediatric stroke database was reviewed retrospectively from 2003 to 2010 and four pediatric patients who underwent mechanical revascularization for arterial ischemic stroke were identified. Patients were included if they had a large vessel occlusion, were less than 18 years of age and underwent revascularization using an FDA-cleared mechanical embolectomy device. Adjunctive use of thrombolytics was permitted. Prior to endovascular

therapy, all patients underwent evaluation by a pediatric neurologist (HJF).

Endovascular procedure and post-treatment management

All patients were placed under general anesthesia before treatment and underwent common femoral arterial puncture for vascular access. A 5 or 6 Fr vascular sheath was chosen for vascular access in children and a 7 Fr or larger vascular sheath was used in adolescents. During procedures a normotensive blood pressure was sought. A baseline activated clotting time was established in three of the four patients and all patients were anticoagulated with heparin. Thrombolytics were administered as an adjunct in one case. The Merci retriever (Concentric Medical, Mountain View, California, USA), Penumbra system (Penumbra, Alameda, California, USA) or both were employed in each case to achieve revascularization. Following revascularization, patients were transferred to a pediatric intensive care unit and managed by a pediatric intensivist and a pediatric stroke neurologist (HJF). All patients underwent follow-up imaging with MRI to assess the extent of their infarction.

Angiographic analysis

The location of vessel occlusion, grade of collateral flow[14] and perfusion following embolectomy were reported. Success of revascularization was based on the thrombolysis in cerebral infarction (TICI) grading system proposed by Higashida *et al* in 1993.[14] We defined successful revascularization as a TICI score of 2a or better. In addition to grading reperfusion, Higashida *et al* also proposed a grading system for quantifying cerebral collateral blood flow at the time of occlusion. We reported collateral flow using this grading system, as collateral flow has been shown to correlate with stroke volume and may affect patient outcome.[15 16]

Outcome assessment

A pediatric stroke neurologist (HJF) involved in the clinical care of all four cases reviewed all available medical records and retrospectively graded initial stroke severity and clinical outcomes using a validated pediatric adaptation of the National Institutes of Health Stroke Scale (PedNIHSS)[17] and a previously published but not validated pediatric adaptation of the modified Rankin Scale (Ped-mRS).[18]

The Ped-mRS is graded as follows: 0, normal; 1, neurologic deficit but no impairment on daily activities; 2, neurologic deficit that interferes with daily activities, some functional use of affected limb(s); 3, able to walk or sit up, very limited functional use of limb, still can perform basic daily activities; 4, unable to resume daily activities, no use of affected limb(s); 5, completely dependent on care giver; 6, death. The PedNIHSS was graded prior to endovascular therapy and at the time of the patient's discharge from hospital. The clinical evaluation closest to 90 days was used to approximate the 90-day Ped-mRS score.

RESULTS

Demographics and risk factors

Four children underwent revascularization of five large vessel occlusions using mechanical embolectomy clot retrieval devices for treatment of arterial ischemic stroke between 2003 and 2010 at our institution. The patients were aged 4–17 years (median 13 years). Three of the patients presented acutely without a precipitating event. One patient had a history of posterior circulation transient ischemic attacks and two remote posterior circulation infarcts prior to acute presentation with a basilar artery (BA) occlusion.

Risk factors for stroke in our series included infection, trauma, cardiac disease and prior endovascular surgery. The etiology for arterial ischemic stroke was suspected in each of the four patients. A cardioembolic source was documented as the cause in patient 1 (figure 1) and highly suspected in patient 3, and artery-to-artery embolic events were suspected in the other two patients. Biomarkers for hypercoagulability were measured in all cases and found to be abnormal in two patients. The details are summarized in table 1.

Intervention and angiographic outcome

Imaging findings, NIHSS, time to arterial puncture, time to reperfusion, collateral grade, retrieval devices, angiographic outcome and clinical outcome are summarized in tables 2 and 3. Diffusion MRI/MRA (magnetic resonance angiography) imaging was obtained in two of the four patients. In patient 4 a dense artery sign was present on non-contrast CT scanning and an MRI was performed showing areas of restricted diffusion in the pons. In patient 2 (figure 2) a non-contrast CT scan with a dense artery sign was deemed sufficient by the pediatric neurologists in the context of the clinical examination to proceed to angiography. No perfusion imaging was obtained prior to endovascular therapy.

Time of onset of stroke to time of arterial puncture and time of onset of stroke to reperfusion for each vascular occlusion was recorded in hours and minutes. The median time of stroke onset to arterial puncture was 8 h 23 min (range 4–20 h). Time of stroke onset to reperfusion of the occluded vessel ranged from 5 h 40 min to 22 h 24 min (median 9 h 20 min). No intravenous tissue plasminogen activator (tPA) was administered prior to embolectomy. In patient 1, 8 mg and 6 mg of intra-arterial tPA was given at 5 h 8 min in the BA and at 6 h 11 min in the right middle cerebral artery (MCA) M1 segment, respectfully.

The Merci mechanical retriever system was used in isolation in two patients and in the other two patients both systems were employed. Different variations of the Merci retriever were used in each case, dictated by the latest available design at the time of the intervention and the operator's preference. The 0.032 inch Penumbra system was used exclusively in our pediatric cohort based on size recommendations by the manufacturer.

The Merci device was successful in removing embolus in four of the five vessels. The only failure occurred in a right internal carotid artery (ICA) terminus occlusion in patient 1. In this particular case only a single pass was made at the discretion of the neuroradiologist before committing to the use of a 0.032 inch Penumbra system that was successful in establishing TICI grade 3 perfusion. The 0.032 inch Penumbra aspiration system was successful in recanalizing one of two vessels in our series. The Penumbra system was only employed in anterior circulation occlusions after at least one pass with the Merci device. No failures in revascularization occurred after establishing intent to treat and TICI grade 3 reperfusion was achieved in 80% of vessel recanalizations.

Intravenous heparin was administered as a single bolus at the beginning of the procedure in 75% of cases to target an activated clotting time of 200 s. In patient 3, a heparin drip was initiated at the outside facility and continued during the intervention at the discretion of the operator. Only one patient received antiplatelet medication. A single dose of 325 mg acetylsalicylic acid was administered prior to transfer. No IIB/IIIA inhibitors were given.

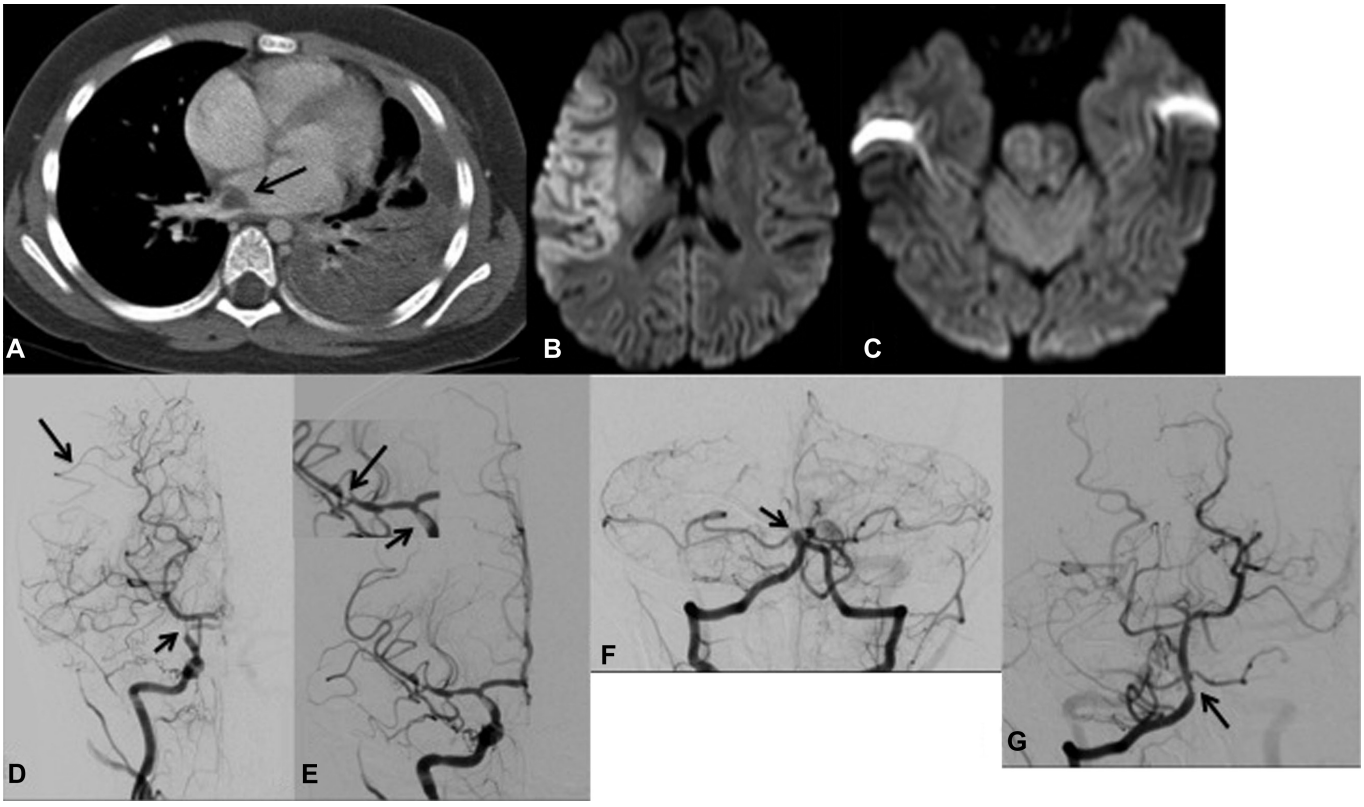

Figure 1 A 4-year-old girl with H1N1 viral pneumonia complicated by left lower lobe streptococcal pneumonia and empyema. (A) Chest CT scan with contrast showing filling defect (arrow) consistent with thrombus in the left atrium. (B) Diffusion-weighted imaging showing restricted diffusion in right frontal and posterior temporal lobes and basal ganglia. (C) Diffusion-weighted imaging showing restricted diffusion in the pons. (D) Anteroposterior (AP) Townes angiogram, right internal carotid artery (ICA) injection, showing an occlusion of the distal right ICA (small arrow) and robust temporal lobe pial collaterals from the posterior circulation (large arrow). (E) AP Townes angiogram after embolectomy, right ICA injection, showing re-established flow through the distal right ICA. Thrombus is seen as a filling defect in the distal right ICA (small arrow) and spasm of a proximal M2 segment (long arrow). (F) AP Townes angiogram, left vertebral artery (VA) injection, showing occlusion of the proximal basilar artery (BA) (small arrow). (G) AP Townes angiogram, right VA injection, showing re-establishment of flow in the BA. There is no reflux or washout of contrast from the left VA (arrow), consistent with occlusion.

Clinical outcome

The PedNIHSS score on admission ranged from 2 to 17 points (median 8.5) which improved to a score ranging from 0 to 16 (median 3) at discharge. The Ped-mRS at approximately 90 days ranged from 0 to 3, with a score of ≤2 being achieved in 75% of cases. Patient 1 had a Ped-mRS score of 3 at 30 and 90 days. In this patient the NIHSS score failed to improve significantly secondary to a worsening motor examination despite an improving mental examination.

DISCUSSION

The use of mechanical embolectomy in LVPAIS has become more appealing as we have realized that there is an increase in time from stroke onset to therapy in the pediatric literature despite improved awareness in the medical community.[8] In our series we encountered a range in time from stroke onset to arterial puncture of 4–20 h and a mean time from stroke onset to arterial puncture of 10 h 11 min. This is significantly different from the mean time of stroke onset to arterial puncture of 4 h

Table 1 Patient demographics, risk factors, abnormal laboratory values and suspected etiology

Patient	Presentation/neurologic examination	Risk factor(s)	Abnormal hematologic laboratory values	Suspected etiology
1	Agitated/bilateral HP (Lt>Rt), dilated Rt pupil (6 mm), Rt gaze, clonus BLE	H1N1/streptococcal pneumonia, streptococcal bacteremia	–	C: Lt atrial thrombus*
2	Awake/Lt HP, Lt FD	H/O right ECA fistula embolization	Lipoprotein A 97 (<75), protein C 71% (76–146%)	A: Stump embolus from dilated Rt ECA
3	Awake, vertigo, diplopia/INO, 6th NP	2.7 mm PFO	–	C: Cardiac embolus
4	Rt arm and tongue numbness, diplopia/INO	H/O C-spine trauma with undiagnosed dens fracture resulting in repetitive trauma to VA, bilateral VA FMD with H/O Rt VA dissection, recurrent posterior fossa strokes	+MTHFR†	A: Arterial thrombus

*Definite etiology.
†Homozygous.
A, arterial; BLE, bilateral lower extremity; C, cardiac; ECA, external carotid artery; FD, facial droop, FMD, fibromuscular dysplasia; H/O, history of; HP, hemiparesis; INO, internuclear ophthalmoplegia; Lt, left; MTHFR, methylenetetrahydrofolate reductase; NP, nerve palsy; PFO, patent foramen ovale; Rt, right; VA, vertebral artery.

Table 2 Imaging findings, retrieval device and angiographic outcome

Patient	Pre-procedure imaging modality	Pre-procedure imaging findings	Site of occlusion	Embolectomy device (number of passes)	TICI score	Post-procedure MRI findings
1	MRI/MRA	RD in Rt>Lt pons, Rt MCA territory, Rt BG	Mid-BA, Rt ICA terminus	Merci 2.5 mm firm, BA (2); Merci 2.5 mm firm, Rt ICA (1); 0.032 inch Penumbra, Rt ICA	3 (BA); 2A (Rt ICA)	RD in Rt>Lt pons, Rt MCA territory, Rt BG
2	NCCT	Hyperdense Rt MCA	Rt M1 segment	L4 Merci (1); 0.032 inch Penumbra; Merci 2.5 mm soft (1)	3	RD in Rt BG
3	NCCT CTA MRI	Multiple foci of RD Rt pons, focus of RD Lt PMJ	Mid-BA	Merci X6 (1)	3	Multiple foci of RD, Rt pons, focus of RD Lt PMJ
4	NCCT MRI	Multiple foci of RD bilateral pons, focus of RD Lt cerebellar hemisphere	Mid-BA	Merci K mini (1)	3	Multiple foci of RD bilateral pons, focus of RD Lt cerebellar hemisphere

BA, basilar artery; BG, basal ganglia; CTA, CT angiogram; ICA, internal carotid artery; Lt, left; MCA, middle carotid artery; NCCT, non-contrast CT; PMJ, pontomedullary junction; RD, reduced diffusion; Rt, right.

18 min reported in the Pivotal Penumbra, Merci and Multi Merci trials and probably reflects the many mimics and non-specific presentation of LVPAIS.[19] This increase in time to therapy was confirmed in a recent study by Rafay *et al* which found that 68% of children with stroke present to hospital within 3 h of symptom onset, qualifying them for intravenous tPA; however, only 20% of these same patients were diagnosed with stroke within 6 h, limiting therapeutic options.[10] Moreover, like other tertiary centers, many of the children with stroke are referred to our facility because of inexperience in treating pediatric stroke in the community, and the transfer time adds to the overall time to endovascular therapy. These clinical challenges can make it quite difficult to render definitive care in a relevant period of time when intravenous or intra-arterial thrombolysis may be a feasible therapeutic option.

The two FDA-cleared devices for retrieval of emboli and thrombus currently on the market are the Merci and Penumbra systems, and these two systems were used exclusively in our study. The Merci retrieval device is a corkscrew-shaped nitinol wire which engages the clot for retrieval into a guide catheter. This is facilitated with proximal occlusion of flow by inflating a balloon on the guide catheter transiently during clot retrieval. In our series, the use of the balloon guide catheter was limited to larger children because of the size of the catheter (available in 7–9 Fr only).

The Penumbra system uses a specifically designed system to macerate and then aspirate the embolus. As the catheter is moved distally through the embolus or thrombus it is cleared periodically with a separator wire under a constant vacuum. The decision as to which device to use in our study was based on device availability at the time of the procedure, clinical experience and operator preference. There was a bias towards using the Merci device first in our series, reflecting its availability in earlier cases before the advent of the Penumbra system and the operator's comfort level with the device.

The size of device used in our series was tailored to the size of the target vascular anatomy. The Merci device was sized to the target vessel diameter. The choice of firm or soft was based on operator experience and preference. The size of the Penumbra system was based on the manufacturer's recommendations. Penumbra recommends using a 0.032 inch system in vessels of 2.0–3.0 mm, which was why we chose to use this size in patients 1 and 2.

We achieved success in recanalization with both devices, but a comparison between the devices is difficult for several reasons. First, this is a limited study based on a small number of patients and device successes and failures may be under-represented in such a small cohort. Second, there was crossover between the devices, making it difficult to make a fair comparison between systems. One device could have facilitated the re-establishment of blood flow even though the device was not successful in primarily recanalizing the vessel. Lastly, the established selection bias by the operator in making the decision to abandon one device in favor of the other, was not controlled for in this study, affecting the success of each device.

In our series we achieved a 100% recanalization rate and encountered a 25% rate of intracranial hemorrhage, which is comparable with the rate of 27–35.5% in published adult mechanical embolectomy trials.[20 21] The asymptomatic hemorrhage in our series occurred in the right basal ganglia in patient 2, and was suspected with the development of a small arterial to venous shunt noted on digital subtraction angiography (DSA) following reperfusion. In the same patient there was contrast staining of the angular cortex on post-procedural non-contrast CT scanning without definitive subarachnoid hemorrhage (SAH) being noted. However, an adjacent flair signal abnormality in the subarachnoid space was seen on the MRI scan, suggesting a focal SAH had occurred. The etiology of this SAH, if real, is unclear. In this case, the Merci devices were deployed in the proximal M2 segment and we postulate that traction with this device could have led to a small avulsion hemorrhage of more distal insular perforators. The location of Merci deployment and lack of focal vessel abnormality on DSA would argue against a dissection as the etiology of the

Table 3 NIHSS, time to arterial puncture, time to reperfusion, collateral grade and outcome

Patient	PedNIHSS (P)	Time to arterial puncture	Time to reperfusion	Collateral grade	PedNIHSS (D)	Ped-mRS (90 days)
1	17	4 h	5 h 40 min (BA), 6 h 36 min (right ICA)	1 (BA), 2 (right ICA)	16	3
2	12	7 h 30 min	9 h 20 min	3	3	1
3	2	9 h 15 min	10 h	2	0	0
4	5	20 h	22 h 24 min	1	3	0

BA, basilar artery; D, discharge; ICA, internal carotid artery; Ped-mRS, pediatric modified Rankin Scale; PedNHISS, pediatric National Institutes of Health Stroke Scale; P, presentation.

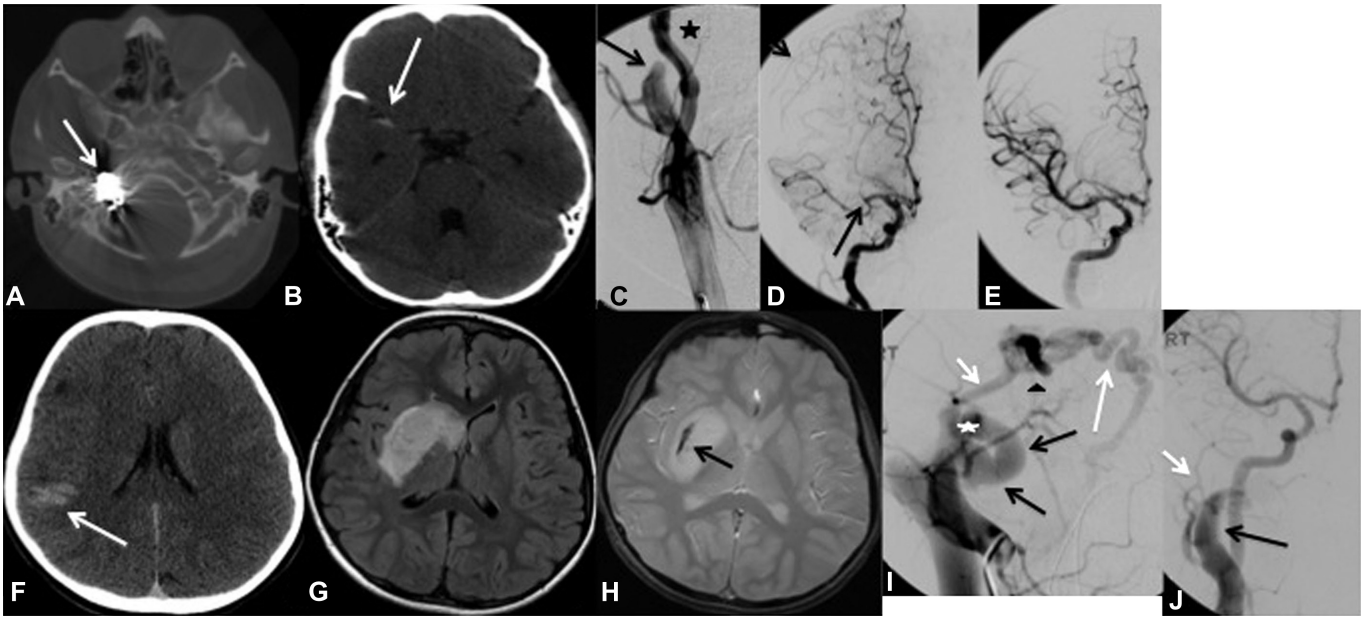

Figure 2 A 10-year-old boy presented with an acute left hemiparesis and facial droop. (A) Non-contrast CT (NCCT) scan showing coils (arrow) in the location of the right hypoglossal canal. (B) NCCT scan showing a hyperdense sign in the right middle cerebral artery (MCA) (arrow). (C) Digital subtraction angiogram (DSA), right common carotid artery (CCA) injection, right anterior oblique (RAO) projection, showing enlarged patulous proximal external carotid artery (ECA) and internal maxillary artery ending in a blind pouch (arrow). The nest of coils seen in (A) is subtracted from the image (asterisk). (D) DSA, right internal carotid artery (ICA) injection, anteroposterior (AP) projection, showing an occlusion of the distal right M1 segment (large arrow). Pial collaterals are seen from the right anterior cerebral artery (small arrow) retrogradely filling the right MCA territory. (E) DSA, right ICA injection, AP projection, showing re-establishment of blood flow in the right MCA. (F) NCCT scan within 24 h following reperfusion showing contrast staining of the parenchyma (arrow) in the right temporal lobe. (G) T2-weighted flair image showing increased signal in the head of the caudate, globus pallidus and putamen. (H) T2-weighted GRE image showing a linear low signal (arrow) in the right putamen reflecting a small intraparenchymal hemorrhage. (I) Outside Hospital (OSH) DSA from 2007, obtained following stroke intervention, injection right ECA, RAO projection, showing an ascending pharyngeal artery (APA) to internal jugular vein fistula (asterisk). The APA is dilated and patulous (black arrows). Blood is shunted into the intraparietal sulcus (small white arrow), cavernous sinus (arrowhead) and superior ophthalmic vein (large white arrow). (J) DSA from 2007, right CCA injection, AP projection, following treatment of the fistula showing a large patulous right ECA and APA (black arrow) over twice the size of the ICA. This appearance is similar to the current DSA, demonstrating lack of autoregulation over time. In comparison, the internal maxillary artery is small (white arrow).

SAH. Short-term follow-up demonstrated complete resolution of the suspected SAH and no increase in size of the intraparenchymal hemorrhage. Reperfusion occurred 9 h 20 min after the onset of symptoms, and the absence of thrombolytics in this case may have lessened the chance of a symptomatic hemorrhage.

Although we did not experience a symptomatic hemorrhage in our study, this is probably the result of undersampling given our small cohort. If we assume a risk of symptomatic hemorrhage of 10–11% as demonstrated in adult embolectomy trials,[20 22] we would require a cohort of at least 11 patients to expect to see one symptomatic hemorrhage.

Others have described the use of mechanical embolectomy devices in children. Tsivgoulis *et al*[13] described a case of a right ICA terminus occlusion in a 6-year-old boy that was recanalized with the use of a Merci device. No hemorrhage was reported on short-term follow-up (table 4). Grunwald *et al*[12] described the use of the Penumbra system in two pediatric patients without hemorrhage. One case involved a distal left ICA occlusion in a 7-year-old boy with clot propagation into the left M1 segment. The patient presented with right hemiplegia and recanalization was achieved within 10 min of arterial puncture. The second case involved a 16-year-old comatose girl with a BA occlusion. She underwent recanalization within 2 min after microcatheter

Table 4 Comparison of published pediatric mechanical embolectomy cases

	Current study	Grunwald *et al*[12]	Tsivgoulis *et al*[13]
Age (n)	4–17 (4)	7–16 (2)	6 (1)
Mean NHISS at baseline	9	31	17
Mean change from baseline in NIHSS at discharge	−3.5	−19.5	−11
Location of occlusion	Anterior circulation (n=2) Posterior circulation (n=3)	Anterior circulation (n=1) Posterior circulation (n=1)	Anterior circulation (n=1)
Device	Merci/Penumbra	Penumbra	Merci
Asymptomatic hemorrhage	1	0	0
Symptomatic hemorrhage	0	0	0
Mean mRS at 90 days	1*	Not reported	1

*Pediatric mRS.
mRS, modified Rankin Scale; NHISS, National Institutes of Health Stroke Scale.

placement. In both cases, they were successful in achieving thrombolysis in myocardial infarction 3 reperfusion scores with the use of a 0.41 inch Penumbra system. In the BA occlusion, the authors administered intra-arterial thrombolytics at 8 h as adjunctive therapy to mechanical embolectomy. They also chose to use a larger Penumbra system which may have partially influenced the differences in recanalization times between their study and ours.

In the cases by Tsivgoulis *et al*, Grunwald *et al* and in our study, thrombolytics were used in specific cases as adjunctive therapy. Typically, the dosage and timing of thrombolytics in these cases is based on extrapolated data from adult trials[23] without pediatric-specific guidelines.[4 24] Dosing of thrombolytics is complicated by differences in concentrations of endogenous tPA and plasminogen activator inhibitor-1 in children compared with adults, making it difficult to extrapolate safe and effective dosing of fibrinolytics in children from adult data.[25] Although still undefined, the safety of thrombolytics in children has been supported in a recent review by Arnold *et al*. They evaluated all reported pediatric cases of intravenous and intra-arterial thrombolysis in large vessel occlusions.[26] Dosing was heterogeneous, but no symptomatic hemorrhage was detected and only two asymptomatic hemorrhages were identified when thrombolytics were administered within 8 h. The data from this review are in agreement with our own experience and those reported by Grunwald *et al* and Tsivgoulis *et al* [12 13] However, while these data are promising, the lack of current dosing guidelines for intravenous or intra-arterial tPA in children highlights the theoretical advantage of mechanical embolectomy.

The etiology of stroke encountered in our population did not differ from those reported elsewhere[4 9 25–28] and included vessel injury, prior surgery, patent foramen ovale and infection leading to cardiac thrombus formation. The decision to treat in each case was collectively made by the neurointerventionalist and the pediatric neurology service on an individual basis and was based on stroke severity and location of the vascular occlusion. We did not base our decision to treat on perfusion imaging because, to our knowledge, no prospective studies have validated the prognostic ability of imaging to predict outcome and complete stroke volume in pediatric patients and thereby exclude them from interventional therapy. We limited our window of therapy to 6 h for intra-arterial thrombolytics and 8 h for embolectomy in anterior circulation occlusions based on current adult data. However, we did not limit our mechanical embolectomy therapy to an established time window for BA occlusions.

Both patients with BA occlusions presented with low NIHSS scores more than 8 h after symptom onset. The potential lethality, unclear natural course and potentially poor outcome of these lesions[29] played a primary role in our decision to treat. We were particularly concerned about the potential for propagation of thrombus leading to deterioration in clinical examination and worsened outcome. Both of our patients with isolated BA occlusions did well following embolectomy, even with a prolonged ischemic interval between time of symptom onset and therapy. This may be related to acute establishment of robust collateral flow.

Our data suggest a benefit to timely revascularization in LVPAIS, demonstrating an improvement in standard stroke outcomes. However, this conclusion must be interpreted with caution in the absence of a control cohort. The two patients presenting with a low NIHSS score in our series returned to baseline by the time of discharge with a mean improvement in their NIHSS score of 2. Both were independent with mRS scores of 0 at 90 days. The other two patients with more severe neurologic deficits also improved but differed in their degree of improvement and stroke burden documented by MRI. Patient 2 presented with an NIHSS score of 12, which improved to 3 at discharge, and a mRS score of 1 at 90 days. Patient 1 presented with an NIHSS score of 17 which only minimally improved to 16 at discharge. Her score reflected an improvement in mental status but regression in motor function. Her mRS score of 3 remained unchanged at 30 and 90 days. She was younger and had a more extensive area of ischemia including involvement of both anterior and posterior circulation and the cortical and deep gray structures. Both younger age and simultaneous involvement of cortical and deep gray structures have been shown to predict a worse outcome in children.[7]

Others have echoed our findings. Grunwald *et al*[12] also described significant improvement in one of their patients who presented with an NIHSS score of 26 which improved to 0 at discharge and a modest improvement in their other patient from an NIHSS score of 36 to 23 at discharge. They did not report post-treatment imaging findings, mRS scores or functional outcome. Tsivgoulis *et al*[13] reported improvement in their patient from an NIHSS score of 15 to 9 at 24 h and further improvement in the NIHSS score to 2 and an mRS score of 1 at 3 months.

This study has several limitations. First, it is based on a small sample size, reflecting the incidence of large vessel ischemic stroke in the pediatric population. Second, it was retrospective without a control group, representing a bias towards endovascular therapy. Finally, availability and past experience influenced the operator's choice of device and there were no guidelines regarding the number of attempts that could be made with a particular embolectomy device before considering it a failed attempt at recanalization. The variability in the operator's choice of device, lack of a control group and small sample size limits the strength of any conclusion that can be drawn from these data. However, the objective of this study was not to prove safety or superiority but to introduce a concept that may be further evaluated with future collaborative efforts.

In conclusion, mechanical embolectomy using the Merci or Penumbra systems for the treatment of LVPAIS may be a safe and potentially effective therapeutic option. It has the advantage of avoiding uncertain dosing regimens of thrombolytic agents in children. It may also be used beyond the typical therapeutic window of thrombolytics, as is often the case in the pediatric age group. These results should be viewed with caution given the context of the study. Future work should focus on the limitations of mechanical embolectomy in children and defining treatment windows using a cooperative effort in view of the low incidence of the disease.

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