Review

Endovascular Revascularization for Basilar Artery Occlusion

Jacky T. Yeung^a Charles C. Matouk^a Ketan R. Bulsara^a Kevin N. Sheth^bDepartments of ^aNeurosurgery and ^bNeurology, Yale School of Medicine, New Haven, Conn., USA**Key Words**

Endovascular revascularization · Basilar artery occlusion

Abstract

Basilar artery occlusion is one of the most devastating neurological conditions known to man. Though rare, patients with clinical syndromes localized to this anatomical region are often referred to acute stroke and endovascular units. Recent studies evaluating the efficacy of endovascular approaches to stroke have focused on anterior circulation syndromes. In this review, we examine the approaches to stroke syndromes due to basilar artery thrombosis. We share the relevant data for intravenous and intra-arterial tissue plasminogen activator as well as mechanical approaches to restoring perfusion in this critical area of the brain.

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Introduction

Acute basilar artery occlusion is a rare stroke syndrome comprising only 3% of all ischemic strokes [1, 2]. Overall, the estimated incidence is approximately 1 patient per 100,000 person-years [3]. Although embolism from cardiac or infectious sources accounts for some acute basilar artery occlusions, the majority is a secondary consequence of atherosclerotic disease [4]. Acute basilar artery occlusion carries an exceptionally high morbidity and mortality rate of 80–90% without active intervention [5, 6]. A majority of reports in the liter-

Kevin N. Sheth, MD, FAHA
Department of Neurology, Yale School of Medicine
PO Box 208018
New Haven, CT 06520-8018 (USA)
E-Mail kevin.sheth@yale.edu

ature demonstrate an improved natural history with aggressive intervention [7]. However, the retrospective nature of a majority of these studies, the heterogeneity of management philosophies, and the rapid evolution of interventional treatment modalities over time make definitive statements regarding a best approach difficult [8–13].

Three neutral trials of endovascular therapy for acute ischemic stroke have recently been published in the *New England Journal of Medicine* (IMS III, Synthesis, and MR-RESCUE) [14–16]. This has dampened the enthusiasm for endovascular therapies. However, patients with acute basilar artery occlusion were not well represented in these studies. Basilar artery occlusion is a devastating pathology that continues to warrant aggressive treatment. For example, in IMS III, only 4 patients with acute basilar artery occlusion underwent intra-arterial (IA) therapy (and thrombolysis in cerebral infarction scores were not reported) [14]. Synthesis did not require patients with posterior circulation strokes to have basilar artery occlusions to be enrolled in the study and randomized to, and receive, endovascular therapy [15]. MR-RESCUE only included patients with anterior circulation strokes [16]. Unlike other stroke syndromes where significant controversy exists as to the role of endovascular therapy, the preponderance of evidence suggests that IA approaches may in fact impart a major survival advantage. In this review, we focus on the different modalities of IA therapy and their efficacy in the management of acute basilar artery occlusion.

Intravenous Therapy

Patients with acute ischemic stroke in the anterior circulation benefit from intravenous thrombolysis (IVT) within 4.5 h after symptom onset [17]. However, due to the devastating nature of basilar artery occlusions, the time to treatment is often extended beyond 4.5 h. More than 67% of basilar artery occlusion patients present >3 h after symptom onset, which is, in part, a reflection of the ill-defined symptoms and the diagnostic difficulties of this disease [18]. As the risk of poor functional outcome is proportional to the time to recanalization therapy, the need to achieve quicker recanalization is underscored [18]. Endovascular therapies have become an attractive modality to achieve this goal.

Endovascular Treatment Options

IA Thrombolysis

The use of IA tissue plasminogen activator (tPA) was first described over 30 years ago [19]. Therefore, it is perhaps surprising that the number of large-scale studies of IA thrombolysis in posterior circulation strokes remains small. In this regard, an Australian multicenter, randomized, controlled trial of IA urokinase in the treatment of acute posterior circulation ischemic stroke administered within 24 h of symptom onset was a foundational study. Only 16 patients were randomized; 8 patients received IA thrombolysis, and 4 of the patients died. Of the survivors, the 4-month modified Rankin Scale (mRS) score was 1 [20]. In the control group, 4 patients died. However, the 4-month mRS score in the stroke survivors was only 3 [20]. Although the study population was too small to draw statistically significant conclusions, the results suggested that IA thrombolytics may be beneficial for patients with acute vertebrobasilar occlusions.

Most other reports are case series that differ in treatment protocol and study methodology, making direct comparisons of study results difficult. In one of the largest case series involving 180 patients with acute vertebrobasilar occlusion treated with IA thrombolysis, complete and partial recanalizations were achieved in 55 and 19% of the cases, respectively

[21]. Recanalization was significantly associated with a favorable outcome and negatively correlated with the volume of thrombus [21]. Neurologic outcome strongly correlated with pretreatment mRS score, age, and coma lasting <4.5 h on univariate testing [21]. However, the duration of brainstem stroke symptoms and coma duration were not significant as independent variables for a favorable neurological outcome in multivariate testing [21]. In other words, the authors could not establish a time window that would exclude selected patients from IA fibrinolysis. This was corroborated in another, smaller study which showed no correlation between admission Glasgow Coma Scale (GCS) and 90-day mRS scores and indicated that equal numbers of patients with the good neurologic outcome of an mRS score of ≤ 1 ($n = 12$) had a GCS score of ≤ 6 or > 6 at presentation [22]. The authors also argued that low GCS scores at presentation should not exclude patients from IA thrombolytic therapy [22].

A meta-analysis including 10 studies and 316 patients demonstrated a recanalization rate of 64%, a mortality rate of 56%, and a 48% absolute risk reduction of death ($p < 0.001$) [23]. A consistent survival benefit was predicted by revascularization (87% nonrecanalized compared with 39% recanalized; $p < 0.001$). Since this meta-analysis included studies with a high degree of heterogeneity (in the timing of interventions, interventional technique, and outcome measurements), differences in neurological outcomes amongst survivors could not be adequately assessed. Notwithstanding these inherent limitations, there was a strong suggestion that IA thrombolytics reduce mortality in patients with acute basilar artery occlusions.

It is unclear at this time how IA therapy compares with IV therapy, due to the lack of randomized controlled trials. In a systematic review of published case series of substantial size reporting the outcome of basilar artery occlusion after IA thrombolysis or IVT, mortality or dependency were equally common between the two routes of medication delivery, i.e., 78% (59 of 76) and 76% (260 of 344), respectively ($p = 0.82$) [9]. The therapeutic windows in the studies were divided into the ultra-acute (within 6 h) and acute (within 12 h) [9]. Outcome scores approximating a 3-month outcome were used, if provided [9]. Although recanalization was achieved more frequently with IA delivery (225 of 344; 65%) than with IVT (40 of 76; 53%; $p = 0.05$), there was no difference in survival rates and positive outcomes (IA vs. IV: 24 and 22%) [9]. It is, therefore, reasonable to argue that IVT be performed in centers without the capability of IA delivery. Interestingly, studies in recent years have looked at the use of IVT to bridge the time gap until IA therapy is initiated [12, 24]. Pfefferkorn et al. [13] showed that initial IVT in a community hospital followed by IA thrombolysis in an interventional neuroradiology center may have higher efficacy than IA thrombolysis alone.

There is a paucity of data in the literature to establish the efficacy of IA thrombolysis in combination with IVT or other modalities such as IA stenting and mechanical thrombectomy in the treatment of acute basilar artery occlusion. The overall rate of symptomatic hemorrhage ranges from 0 to 14% in published studies [9, 22, 25–29]. Considering the poor natural history of the disease, this rate of symptomatic hemorrhage may be acceptable. Moreover, the rates of symptomatic hemorrhage appear to be lower with the more recent mechanical thrombectomy technologies. Multi-institutional randomized trials are needed to fill the many gaps in knowledge concerning IA thrombolysis.

Angioplasty and Stenting

Sundt et al. [30] reported the first intracranial angioplasty performed in a basilar artery. Recanalization of the intracranial vertebral and basilar arteries by angioplasty and/or stenting has since become an increasingly feasible option due to advances in endovascular treatment [31–33]. The focus of this paper is the management of acute thrombotic occlusion of the basilar artery, and we will therefore not focus on the management of intracranial atherosclerosis per se, a subject that is well reviewed elsewhere [34, 35].

Fig. 1. A 63-year-old female with a history of atrial fibrillation, but not anticoagulated, presented with 24 h of ophthalmoplegia, dysarthria, dysmetria, and a fluctuating level of consciousness. A head CT demonstrated an acute right cerebellar stroke and multiple old strokes in the bilateral occipital lobes and left thalamus. The Penumbra Stroke System was successfully used to remove the clot in her basilar artery and achieve complete revascularization.

IA Thrombectomy

Mechanical thrombectomy has been shown to restore patency in large intracranial vessel occlusion in 41–54% of cases [36–39]. This treatment modality represents an alternative for those who fail conventional intravenous tPA therapy. The most common devices reported in the literature include Merci and Penumbra aspiration catheters, the Solitaire, and Trevo stent retrievers.

The Mechanical Embolus Removal in Cerebral Ischemia (MERCI) trial assessed the efficacy of mechanical thrombectomy using the Merci Retrieval System (Concentric Medical Inc.) within the first 8 h of acute ischemic stroke [37]. This prospective, nonrandomized, multicenter trial targeted patients who were ineligible for intravenous tPA therapy. Depending on whether the analysis was based on intention-to-treat or on actual deployment of the device, the recanalization rate ranged from 46 to 48%, with clinically significant procedural complications occurring in 7.1% of patients with large-vessel occlusion. Specifically, 9% of the study population had basilar artery occlusion. Although the study grouped vertebral and basilar artery occlusions in one entity, the rate of recanalization was up to 50%, and the 90-day mortality rate was 50% [37]. Thirty-six percent of the patients in this group had a favorable mRS score of ≤ 2 at 90 days, which may be viewed as a vast improvement compared with reported mortality rates of 83–92% if the vessel fails to open with IA thrombolytic therapy [40, 41]. The Multi MERCI trial was a subsequent iteration that included patients who were also treated with IV tPA [11]. Of note, there were no differences in the rates of intracranial hemorrhage or clinically significant procedural complications seen between those treated with IV tPA and those who were not, suggesting that pretreatment with IV tPA did not affect the safety of the procedure. Thirty-five percent of the patients with posterior circulation occlusion had a favorable outcome with an mRS score of ≤ 2 in 90 days with the L5 Merci system [11].

The Penumbra thrombectomy device works by fragmenting and aspirating the thrombus (a representative case is shown in fig. 1). In a prospective, multicenter, single-arm study, 9 patients with basilar artery occlusion who presented within 8 h of symptom onset had a 38% observed mortality rate compared to the 88% expected mortality rate derived from the existing literature. These early data suggested that the penumbra device may have potential

Fig. 2. A 54-year-old man with hypertension and dyslipidemia presented with nausea and vomiting, fluctuating left-sided weakness, and a fluctuating level of consciousness. A CT angiography demonstrated midbasilar occlusion, likely representing atherosclerotic disease. A Solitaire revascularization device was deployed across the basilar occlusion into the left posterior cerebral artery. Retrieval of the device resulted in complete revascularization of the basilar artery and its distal territories. A focal, severe, midbasilar stenosis was now demonstrable. This was successfully treated by angioplasty alone, using a Gateway PTA Balloon Catheter. A decision was made not to stent the vessel at this time, given the need for acetylsalicylic acid/Plavix in the context of an acute stroke syndrome.

as a treatment for basilar artery occlusion due to thromboembolism [42]. Data concerning the use of the Penumbra device in cases of basilar artery occlusions are often not reported separately from the entire study population [43–45].

The Trevo retriever is a stent retriever that applies a radial retrieval force within the thrombus and entraps the thrombus within the confines of the stent. A microcatheter is placed distal to the thrombus, and a retriever is deployed by unsheathing the microcatheter, resulting in the opening of the stent and radial displacement of the thrombus against the vessel wall, leading to the incorporation of the clot into the stent struts [46]. In an open-label, randomized, controlled trial that compared the efficacy of the Trevo device with that of the Merci device, it was found that 76 patients (86%) in the Trevo group and 54 patients (60%) in the Merci group met the primary endpoint of a thrombolysis in cerebral infarction score of ≥ 2 [46]. The data suggest that the Trevo retriever may be more effective than the Merci retriever in clot retrieval. Compared with the Merci group, more patients in the Trevo group had good long-term functional outcomes at 90 days. In this trial, Trevo and Merci retrievers were used to treat 7 (8%) and 5 patients (6%) with vertebrobasilar strokes, respectively [46].

The Solitaire system is a self-extending, fully retrievable nitinol stent used for mechanical recanalization that is based on the Solitaire AB, which is commonly used for the stent-assisted treatment of intracranial aneurysms (a representative case is shown in fig. 2). In a prospective study by Mourand et al. [47], successful recanalization was achieved in 23 of 31 patients (74%) within the first 24 h after the onset of symptoms. Five symptomatic intracranial hemorrhages were related to the procedure, and symptomatic distal migrations of thrombotic material occurred in 10 cases. A favorable outcome, measured at more than 180 days after the procedure, was observed in 35% of the patients with an overall mortality rate of 32% [47]. Costalat et al. [48] analyzed 16 cases of basilar occlusion that were treated with combined therapy, as part of the Rescue, Combined and Stand-Alone Thrombectomy (RECAST) study for large-vessel occlusions. Six patients had thrombectomy alone, and 10 had combination

Table 1. Summary of previously published literature on different modalities of treatment for basilar artery occlusion

Study	Pa- tients, n	Hours to treat- ment	Mortality, %	Symptomatic hemorrhage, %	Recanalization, %	Good outcome (mRS 0–2), %	Study type	Notes
<i>Angioplasty</i>								
Imai et al. [10]	10	<8.5	40	10	80	20	Retrospective	Data taken from occlusion group; mRS measured at 3 months
BASICS [25]	183		54	1			Prospective, observational	Outcome assessed at 1 month; more benefit for severe stenosis
Jiang et al. [58]	69		13 ^a	1.5			Prospective, database	–
<i>IA thrombolysis</i>								
Lindsberg and Mattle [9]	344		55	8	65	24	Systematic review	–
BASICS [25] ^b	92		23	14	83	30	Prospective, observational	Outcome assessed at 1 month
BASICS [25] ^c	196		49	14	69	11	Prospective, observational	Outcome assessed at 1 month
Renard et al. [26]	16	<9.2	50	0	69	31	Prospective	–
Kashiwagi et al. [27]	18	<4.5	6	6	94	39	Retrospective	With optional percutaneous transluminal angioplasty (n = 8)
Yu et al. [28]	52	<3–48	38	12	77	42	Retrospective	With optional stenting
Chandra et al. [22]	40	<7.2	33	13	83	35	Retrospective	With optional angioplasty and Merci thrombectomy
Jung et al. [29]	106	<5.5	41	1	70	33	Prospective data from registry	With optional mechanical thrombectomy; outcome assessed at 3 months
<i>Mechanical thrombectomy</i>								
Lutsep et al. [59]	27	<5.4	44	19	78	33	Prospective, nonrandomized, multicenter trial	Adjunctive treatments used
Pfefferkorn et al. [60]	26	<6	31	8	85	38	Quasi-experimental	Merci, Penumbra, or Angiojet used in 16/26 patients
Nogueira et al. [46]	88	<8	29 (Trevo) 21 (Merci)	7 (Trevo) 9 (Merci)	86 (Trevo) 60 (Merci)	N/A	Clinical trial	Trevo vs. Merci
Miteff et al. [61]	10	<4	30	10	100	20	Retrospective	IA thrombolysis used
Smith [38]	111	<8	33	9	54 without and 69 with adjunctive therapy	37	Clinical trial	Merci – 27% received IV tPA before the intervention; outcomes assessed at 3 months
Costalat et al. [48]	16	<24	25	2	81	44	Prospective data from registry	Solitaire – 10/16 patients treated with full-dose IV alteplase
Bose et al. [42]	9	<8	38 ^d		100		Prospective, single arm	–

^a Death or major stroke. ^b Mild-to-moderate deficits. ^c Severe deficits. ^d Grouped as posterior circulation.

therapy, which was immediate IVT as a bridging mechanism until the angiographic suite was ready for urgent thrombectomy. The mean recanalization time from symptom onset was 377 min. In these cases, 44% had a discharge NIHSS score of 0–1, 44% had an NIHSS score improvement of >9 points, and the 3-month mortality was 33% [48]. However, the outcome analysis was not made available for basilar artery thrombosis specifically.

Results from the Basilar Artery International Cooperation Study

Most of what we know about outcomes from endovascular interventions for basilar artery occlusion comes from retrospective case series (table 1). The Basilar Artery International Cooperation Study (BASICS) was the first organized, prospective, observational registry of consecutive patients who presented with an acute, symptomatic, and radiographically confirmed basilar artery occlusion that allowed comparisons of outcomes at 1 month between different treatment groups [25]. These treatment groups included (1) antithrombotic treatment only, (2) primary IVT including subsequent IA thrombolysis, and (3) IA therapy,

which comprised thrombolysis, mechanical thrombectomy, stenting, or a combination of these approaches. Overall, 62% of the patients were treated within 6 h of symptom onset. Fifty-two percent of the patients had NIHSS scores of >20 . They confirmed the poor prognosis after basilar artery occlusion, with a third mortality and a third dependency at 1 month. A key finding from this observational study was that there was no statistically significant superiority for any treatment strategy. However, there were trends to suggest that patients with a mild-to-moderate deficit more often had a poor outcome if they were treated with IA therapy rather than with IVT. Conversely, patients with a severe deficit seemed to benefit from both IVT and IA therapy. The absolute risk of death or dependency was 19% (IVT) and 10% (IA therapy) lower than the risk with antithrombotic treatment only [25]. From these data, one could argue that patients with minor symptoms may benefit from anticoagulation-/anti-thrombotic-based strategies alone rather than from aggressive IA interventions. However, an intrinsic flaw of the study lies in grouping patients treated with subsequent IA thrombolysis in the IVT group. It is difficult to assess the effectiveness of IA thrombolysis alone in basilar artery occlusion as IV tPA is the gold standard in the treatment of ischemic stroke, provided that a patient fits the inclusion criteria. It is, therefore, hard to conceive a study that subjects a patient to up-front IA therapy. Also, the current interpretation of the results from the BASICS is limited by the introduction of stent retrievers, which were not available at the time of the study.

Currently, at Yale-New Haven Hospital, the management of patients with acute basilar artery occlusion is based on the severity of symptoms. If the neurological deficits are mild, such as vertigo, nausea, and vomiting, then medical management with IVT is offered, if appropriate. This is corroborated by the BASICS [25]. IV tPA is given up to 4.5 h from symptom onset. If the deficits are more severe, such as hemiparesis, tetraparesis, and a fluctuating level of consciousness, then a more aggressive IA therapy is recommended after the administration of IV tPA. IA tPA is often given with mechanical revascularization as well. As there is little information about reperfusion and hemorrhage in basilar thrombosis, sometimes we perform an MRI to help assess the infarct burden before proceeding with IA delivery. Our center is able to perform acute MRI in a timely manner with the cooperation of the radiology department, which would prioritize stroke patients that may benefit from MRI with acute stroke sequences.

Utility of Pretreatment MRI in Predicting Outcomes

CT is known to be inferior in detecting brainstem ischemia [49–51]. Pretreatment MR diffusion-weighted imaging (DWI) has been shown to be a useful tool for predicting outcomes of basilar artery occlusions. Although some medical centers may not have the capability to perform MRI in a timely manner, there are sufficient data to demonstrate its utility in basilar artery occlusion.

Renard et al. [26] used a 10-point semiquantitative score composed of 1 point for unilateral and 2 points for bilateral involvement of each brainstem level (medulla, pons, and midbrain) and 0.5 points for each region and each side of the thalamus and temporooccipital lobe reflecting the number of acute ischemic brain lesions on DWI. In 16 patients treated with IA tPA, the authors found that a high lesion score was an additional predictor of poor outcome, defined as an mRS score of >2 [26].

Similarly, Cho et al. [52] analyzed baseline clinical and DWI parameters in 29 patients treated with endovascular procedures for acute basilar artery occlusion using a semiquantitative score based on arterial territory segmentation developed by Tatu et al. [53]. This scoring system is a summation of the territories involved: 0–8 in the medulla, 0–6 in the pons, and 0–8 in the midbrain. The total number of involved arterial territories defined the

brainstem DWI lesion score, ranging between 0 and 22 [53]. The outcomes at 3 months were dichotomized according to the mRS score into favorable (score of 0–2) and unfavorable (score of 3–6) [52]. The patients were treated with various IA modalities including tPA, tPA with IV abciximab, tPA with mechanical thrombectomy, or mechanical thrombectomy alone. In multivariate analysis, the brainstem DWI score was the only independent baseline predictor of clinical outcome ($p = 0.026$) [52].

Other pretreatment scores using DWI have also been published. Karameshev et al. [54] tested their score, which is a combination of those of Renard et al. [26] and Cho et al. [52], and showed that it reliably quantified pretreatment ischemic damage and was an independent predictor of functional outcome at 3 months. Similarly, a posterior circulation Acute Stroke Prognosis Early CT Score of ≥ 8 points on early DWI is an independent predictor of a favorable outcome at 3 months in patients with acute basilar artery occlusion [55]. Although there are isolated reports of some functional recovery despite DWI evidence of infarction from basilar artery occlusion, the evidence supports DWI as a useful tool for prognostication. When available, it should be incorporated into future clinical trials and used in everyday practice when considering IA therapy for basilar artery occlusion [56, 57].

Conclusions

Basilar artery occlusion is a devastating disease due to the anatomic nature of the involved vessel. Various modalities of treatment are available, ranging from medical (antithrombotic, antiplatelet, and thrombolytic agents) to more aggressive endovascular interventions. There are many open questions due to the lack of prospective studies. The BASICS did not make a distinction between patients treated with IA thrombolysis or IVT [25]. The role of IA delivery during the early IVT time window will hopefully be elucidated in the upcoming BASICS. There is still a lack of data concerning the impact of bridging IV therapy on recanalization and reperfusion hemorrhage rates. There is also a paucity of prospective data on outcomes based on different interventions, specifically for the treatment of basilar artery occlusion. The newer generation of devices, such as stent retriever and Penumbra MAX systems, might be better than the older devices. The current data suggest that occlusions associated with severe clinical symptoms may benefit from endovascular interventions, while milder impairments may benefit from anticoagulation/antithrombotic treatments. Multicenter, prospective studies are warranted to compare the different treatment modalities.

References

- 1 Savitz SI, Caplan LR: Vertebrobasilar disease. *N Engl J Med* 2005;352:2618–2626.
- 2 Weimar C, Goertler M, Harms L, Diener HC: Distribution and outcome of symptomatic stenoses and occlusions in patients with acute cerebral ischemia. *Arch Neurol* 2006;63:1287–1291.
- 3 Mattle HP, Arnold M, Lindsberg PJ, Schonewille WJ, Schroth G: Basilar artery occlusion. *Lancet Neurol* 2011;10:1002–1014.
- 4 Voetsch B, DeWitt LD, Pessin MS, Caplan LR: Basilar artery occlusive disease in the New England Medical Center Posterior Circulation Registry. *Arch Neurol* 2004;61:496–504.
- 5 Schulte-Altedorneburg G, Mayer TE: Management of acute basilar artery occlusion (in German). *Radiologe* 2007;47:355–358.
- 6 Baird TA, Muir KW, Bone I: Basilar artery occlusion. *Neurocrit Care* 2004;1:319–329.
- 7 Schonewille WJ, Algra A, Serena J, Molina CA, Kappelle LJ: Outcome in patients with basilar artery occlusion treated conventionally. *J Neurol Neurosurg Psychiatry* 2005;76:1238–1241.
- 8 The International Stroke Trial (IST): a randomised trial of aspirin, subcutaneous heparin, both, or neither among 19,435 patients with acute ischaemic stroke. International Stroke Trial Collaborative Group. *Lancet* 1997;349:1569–1581.

- 9 Lindsberg PJ, Mattle HP: Therapy of basilar artery occlusion: a systematic analysis comparing intra-arterial and intravenous thrombolysis. *Stroke* 2006;37:922–928.
- 10 Imai K, Mori T, Izumoto H, et al: Transluminal angioplasty and stenting for intracranial vertebrobasilar occlusive lesions in acute stroke patients. *AJNR Am J Neuroradiol* 2008;29:773–780.
- 11 Smith WS, Sung G, Saver J, et al: Mechanical thrombectomy for acute ischemic stroke: final results of the Multi MERCI trial. *Stroke* 2008;39:1205–1212.
- 12 Nagel S, Schellinger PD, Hartmann M, et al: Therapy of acute basilar artery occlusion: intraarterial thrombolysis alone vs bridging therapy. *Stroke* 2009;40:140–146.
- 13 Pfefferkorn T, Mayer TE, Opher C, et al: Staged escalation therapy in acute basilar artery occlusion: intravenous thrombolysis and on-demand consecutive endovascular mechanical thrombectomy: preliminary experience in 16 patients. *Stroke* 2008;39:1496–1500.
- 14 Broderick JP, Palesch YY, Demchuk AM, et al: Endovascular therapy after intravenous t-PA versus t-PA alone for stroke. *N Engl J Med* 2013;368:893–903.
- 15 Ciccone A, Valassori L, Nichelatti M, et al: Endovascular treatment for acute ischemic stroke. *N Engl J Med* 2013;368:904–913.
- 16 Kidwell CS, Jahan R, Gornbein J, et al: A trial of imaging selection and endovascular treatment for ischemic stroke. *N Engl J Med* 2013;368:914–923.
- 17 Lees KR, Bluhmki E, von Kummer R, et al: Time to treatment with intravenous alteplase and outcome in stroke: an updated pooled analysis of ECASS, ATLANTIS, NINDS, and EPITHET trials. *Lancet* 2010;375:1695–1703.
- 18 Vergouwen MD, Algra A, Pfefferkorn T, et al: Time is brain(stem) in basilar artery occlusion. *Stroke* 2012;43:3003–3006.
- 19 Zeumer H, Hacke W, Ringelstein EB: Local intraarterial thrombolysis in vertebrobasilar thromboembolic disease. *AJNR Am J Neuroradiol* 1983;4:401–404.
- 20 Macleod MR, Davis SM, Mitchell PJ, et al: Results of a multicentre, randomised controlled trial of intra-arterial urokinase in the treatment of acute posterior circulation ischaemic stroke. *Cerebrovasc Dis* 2005;20:12–17.
- 21 Schulte-Altdorneburg G, Hamann GF, Mull M, et al: Outcome of acute vertebrobasilar occlusions treated with intra-arterial fibrinolysis in 180 patients. *AJNR Am J Neuroradiol* 2006;27:2042–2047.
- 22 Chandra RV, Law CP, Yan B, Dowling RJ, Mitchell PJ: Glasgow Coma Scale does not predict outcome post-intra-arterial treatment for basilar artery thrombosis. *AJNR Am J Neuroradiol* 2011;32:576–580.
- 23 Smith WS: Intra-arterial thrombolytic therapy for acute basilar occlusion: pro. *Stroke* 2007;38(suppl):701–703.
- 24 Eckert B, Koch C, Thomalla G, et al: Aggressive therapy with intravenous abciximab and intra-arterial rtPA and additional PTA/stenting improves clinical outcome in acute vertebrobasilar occlusion: combined local fibrinolysis and intravenous abciximab in acute vertebrobasilar stroke treatment (FAST): results of a multicenter study. *Stroke* 2005;36:1160–1165.
- 25 Schonewille WJ, Wijman CA, Michel P, et al: Treatment and outcomes of acute basilar artery occlusion in the Basilar Artery International Cooperation Study (BASICS): a prospective registry study. *Lancet Neurol* 2009;8:724–730.
- 26 Renard D, Landragin N, Robinson A, et al: MRI-based score for acute basilar artery thrombosis. *Cerebrovasc Dis* 2008;25:511–516.
- 27 Kashiwagi J, Kiyosue H, Hori Y, et al: Endovascular recanalization of acute intracranial vertebrobasilar artery occlusion using local fibrinolysis and additional balloon angioplasty. *Neuroradiology* 2010;52:361–370.
- 28 Yu YY, Niu L, Gao L, et al: Intraarterial thrombolysis and stent placement for acute basilar artery occlusion. *J Vasc Interv Radiol* 2010;21:1359–1363.
- 29 Jung S, Mono ML, Fischer U, et al: Three-month and long-term outcomes and their predictors in acute basilar artery occlusion treated with intra-arterial thrombolysis. *Stroke* 2011;42:1946–1951.
- 30 Sundt TM Jr, Smith HC, Campbell JK, Vlietstra RE, Cucchiara RF, Stanson AW: Transluminal angioplasty for basilar artery stenosis. *Mayo Clin Proc* 1980;55:673–680.
- 31 Terada T, Higashida RT, Halbach VV, et al: Transluminal angioplasty for arteriosclerotic disease of the distal vertebral and basilar arteries. *J Neurol Neurosurg Psychiatry* 1996;60:377–381.
- 32 Gupta R, Schumacher HC, Mangla S, et al: Urgent endovascular revascularization for symptomatic intracranial atherosclerotic stenosis. *Neurology* 2003;61:1729–1735.
- 33 Mori T, Kazita K, Chokyu K, Mima T, Mori K: Short-term arteriographic and clinical outcome after cerebral angioplasty and stenting for intracranial vertebrobasilar and carotid atherosclerotic occlusive disease. *AJNR Am J Neuroradiol* 2000;21:249–254.
- 34 Hussain MS, Fraser JF, Abruzzo T, et al: Standard of practice: endovascular treatment of intracranial atherosclerosis. *J Neurointerv Surg* 2012;4:397–406.
- 35 Ozturk AK, Bulsara KR: The evolving paradigm in the management of intracranial atherosclerotic disease. *Int J Vasc Med* 2012;2012:289852.
- 36 Berlis A, Lutsep H, Barnwell S, et al: Mechanical thrombolysis in acute ischemic stroke with endovascular photoacoustic recanalization. *Stroke* 2004;35:1112–1116.
- 37 Smith WS, Sung G, Starkman S, et al: Safety and efficacy of mechanical embolectomy in acute ischemic stroke: results of the MERCI trial. *Stroke* 2005;36:1432–1438.

- 38 Smith WS: Safety of mechanical thrombectomy and intravenous tissue plasminogen activator in acute ischemic stroke. Results of the Multi Mechanical Embolus Removal in Cerebral Ischemia (MERCi) trial, part I. *AJNR Am J Neuroradiol* 2006;27:1177–1182.
- 39 Lu AY, Ansari SA, Nystrom KV, et al: Intra-arterial treatment of acute ischemic stroke: the continued evolution. *Curr Treat Options Cardiovasc Med* 2014;16:281.
- 40 Brandt T, von Kummer R, Müller-Küppers M, Hacke W: Thrombolytic therapy of acute basilar artery occlusion. Variables affecting recanalization and outcome. *Stroke* 1996;27:875–881.
- 41 Bruckmann H, Ferbert A, del Zoppo GJ, Hacke W, Zeumer H: Acute vertebral-basilar thrombosis. Angiologic-clinical comparison and therapeutic implications. *Acta Radiol Suppl* 1986;369:38–42.
- 42 Bose A, Henkes H, Alfke K, et al: The Penumbra System: a mechanical device for the treatment of acute stroke due to thromboembolism. *AJNR Am J Neuroradiol* 2008;29:1409–1413.
- 43 Mpotsaris A, Bussmeyer M, Weber W: Mechanical thrombectomy with the Penumbra 3D Separator and lesional aspiration: technical feasibility and clinical outcome. *Clin Neuroradiol* 2014;24:245–250.
- 44 Kulcsar Z, Berentei Z, Marosfoi M, Vajda J, Szikora I: Thromboembolic complication induced stable occlusion of a ruptured basilar tip aneurysm. Case report and review of the literature. *Interv Neuroradiol* 2010;16:83–88.
- 45 Liu W, Kung DK, Mahaney KB, Rossen JD, Jabbour PM, Hasan DM: Anterior-to-posterior circulation approach for mechanical thrombectomy of an acutely occluded basilar artery using the Penumbra Aspiration System. *World Neurosurg* 2012;77:398.E17–E20.
- 46 Nogueira RG, Lutsep HL, Gupta R, et al: Trevo versus Merci retrievers for thrombectomy revascularisation of large vessel occlusions in acute ischaemic stroke (TREVO 2): a randomised trial. *Lancet* 2012;380:1231–1240.
- 47 Mourand I, Machi P, Milhaud D, et al: Mechanical thrombectomy with the Solitaire device in acute basilar artery occlusion. *J Neurointerv Surg* 2014;6:200–204.
- 48 Costalat V, Machi P, Lobotesis K, et al: Rescue, combined, and stand-alone thrombectomy in the management of large vessel occlusion stroke using the Solitaire device: a prospective 50-patient single-center study: timing, safety, and efficacy. *Stroke* 2011;42:1929–1935.
- 49 Roh JK, Kim KK, Han MH, et al: Magnetic resonance imaging in brainstem ischemic stroke. *J Korean Med Sci* 1991;6:355–361.
- 50 Fiebach JB, Schellinger PD, Jansen O, et al: CT and diffusion-weighted MR imaging in randomized order: diffusion-weighted imaging results in higher accuracy and lower interrater variability in the diagnosis of hyperacute ischemic stroke. *Stroke* 2002;33:2206–2210.
- 51 Tei H, Uchiyama S, Usui T, Ohara K: Posterior circulation ASPECTS on diffusion-weighted MRI can be a powerful marker for predicting functional outcome. *J Neurol* 2010;257:767–773.
- 52 Cho TH, Nighoghossian N, Tahon F, et al: Brain stem diffusion-weighted imaging lesion score: a potential marker of outcome in acute basilar artery occlusion. *AJNR Am J Neuroradiol* 2009;30:194–198.
- 53 Tatu L, Moulin T, Bogousslavsky J, Duvernoy H: Arterial territories of human brain: brainstem and cerebellum. *Neurology* 1996;47:1125–1135.
- 54 Karameshev A, Arnold M, Schroth G, et al: Diffusion-weighted MRI helps predict outcome in basilar artery occlusion patients treated with intra-arterial thrombolysis. *Cerebrovasc Dis* 2011;32:393–400.
- 55 Nagel S, Herweh C, Köhrmann M, et al: MRI in patients with acute basilar artery occlusion – DWI lesion scoring is an independent predictor of outcome. *Int J Stroke* 2012;7:282–288.
- 56 Samaniego EA, Lansberg MG, DeGeorgia M, Venkatasubramanian C, Wijman CA: Favorable outcome from a locked-in state despite extensive pontine infarction by MRI. *Neurocrit Care* 2009;11:369–371.
- 57 Yoo AJ, Hakimelahi R, Rost NS, et al: Diffusion weighted imaging reversibility in the brainstem following successful recanalization of acute basilar artery occlusion. *J Neurointerv Surg* 2010;2:195–197.
- 58 Jiang WJ, Du B, Hon SF, et al: Do patients with basilar or vertebral artery stenosis have a higher stroke incidence poststenting? *J Neurointerv Surg* 2010;2:50–54.
- 59 Lutsep HL, Rymer MM, Nesbit GM: Vertebrobasilar revascularization rates and outcomes in the MERCi and Multi-MERCi trials. *J Stroke Cerebrovasc Dis* 2008;17:55–57.
- 60 Pfefferkorn T, Holtmannspötter M, Schmidt C, et al: Drip, ship, and retrieve: cooperative recanalization therapy in acute basilar artery occlusion. *Stroke* 2010;41:722–726.
- 61 Miteff F, Faulder KC, Goh AC, Steinfert BS, Sue C, Harrington TJ: Mechanical thrombectomy with a self-expanding retrievable intracranial stent (Solitaire AB): experience in 26 patients with acute cerebral artery occlusion. *AJNR Am J Neuroradiol* 2011;32:1078–1081.