Endovascular Treatment for Posterior Circulation Stroke: Ways to Maximize Therapeutic Efficacy

Seong-Joon Lee, Ji Man Hong, Jong S. Kim, Jin Soo Lee

Department of Neurology, Ajou University School of Medicine, Suwon, Korea
Department of Neurology, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea

The efficacy of endovascular treatment (EVT) in patients with posterior circulation stroke has not been proven. Two recent randomized controlled trials failed to show improved functional outcomes after EVT for posterior circulation stroke (PC-EVT). However, promising results for two additional randomized controlled trials have also been presented at a recent conference. Studies have shown that patients undergoing PC-EVT had a higher rate of futile recanalization than those undergoing EVT for anterior circulation stroke. These findings call for further identification of prognostic factors beyond recanalization. The significance of baseline clinical severity, infarct volume, collaterals, time metrics, core-penumbra mismatch, and methods to accurately measure these parameters are discussed. Furthermore, their interplay on EVT outcomes and the potential to individualize patient selection for PC-EVT are reviewed. We also discuss technical considerations for improving the treatment efficacy of PC-EVT.

Keywords: Cerebral infarction; Posterior circulation; Endovascular treatment; Mechanical thrombectomy; Basilar artery occlusion; Vertebrobasilar artery occlusion

Introduction

Endovascular treatment (EVT) based on mechanical thrombectomy (MT) has become the gold standard for treatment of large-vessel occlusion (LVO) of the anterior circulation. In posterior circulation LVO, EVT was associated with improved functional outcomes in a large prospective multicenter registry, and successful reperfusion was associated with favorable outcomes in multiple studies (Table 1) and a recent systematic review. While we wait for positive results of two recent randomized controlled trials (RCTs), two RCTs failed to show a therapeutic efficacy of EVT. A meta-analysis showed that compared with anterior circulation EVT (AC-EVT), outcomes of EVT for posterior circulation stroke (PC-EVT) were unfavorable, with higher rates of futile recanalization (poor outcomes despite successful recanalization). Such data highlight the issue of patient selection, which may be key to the success of PC-EVT.

Moreover, efforts to expand EVT indications for patients who will benefit from this potentially powerful treatment should also be sought. For AC-EVT, these efforts have resulted in the success of late-window trials, based on the selection of patients through clinical-core mismatch or core-penumbra mismatch. A recent RCT also showed the benefit of AC-EVT for larger infarcts based on the Alberta Stroke Program Early Computed Tomography Score (ASPECTS) 3–5. Efforts to expand EVT to patients with a low National Institutes of Health Stroke Scale (NIHSS) score are also under evaluation, along with efforts to expand to patients with distal vascular occlusion. All these efforts should eventually be pursued in PC-EVT.

In this paper, we first review recent RCTs on PC-EVT. We then discuss the prognostic factors of PC-EVT and how to apply
Table 1. Studies evaluating the effect of reperfusion on outcomes

| Author (published year) (study period) | Study design | No. of patient | Artery | Clinical outcomes | Significance of reperfusion |
|---------------------------------------|--------------|----------------|--------|------------------|---------------------------|
| Mokin et al. (2016) (2011–2015)       | Multicenter retrospective | 100 | VBAO | 3-mo mRS 0–2 | Successful recanalization is a predictor of good outcome. |
| Bouslama et al. (2017) (2005–2015)    | Two center retrospective | 214 | VBAO | 3-mo mRS 0–2 | Reperfusion predicts good outcomes (aOR, 10.80; 95% CI, 1.36–85.96). |
| Gory et al. (2018) (2010–2016)        | Multicenter ETIS registry | 100 | BAO | 3-mo mRS 0–2 | Reperfusion predicts good outcome (aOR, 5.64; 95% CI, 1.32–24.06). |

VBAO, verteobasilar artery occlusion; mRS, modified Rankin Scale; aOR, adjusted odds ratio; CI, confidence interval; ETIS, Endovascular Treatment in Ischemic Stroke; BAO, basilar artery occlusion.

them to maximize clinical benefits and expand therapeutic indications. We also describe the technical aspects of PC-EVT.

RCTs of EVT for vertebrobasilar artery occlusion

Four RCTs have so far been published or presented regarding the efficacy and safety of EVT for acute stroke due to vertebrobasilar artery occlusion (VBAO) (Table 2). The Basilar Artery Occlusion Endovascular Intervention Versus Standard Medical Treatment (BEST) was a multicenter randomized open-label trial with a blinded outcome assessment in patients presenting within 8 hours of VBAO at 28 centers in China between 2015 and 2017. The primary outcome was a modified Rankin Scale (mRS) score of ≤3 at 90 days, assessed on an intention-to-treat basis. The primary safety outcomes were sICH and mortality at 90 days. While a sample size of 344 was originally calculated, only 131 (66 endovascular and 65 medical) patients were enrolled due to excessive crossovers and a progressive drop in per center recruitment. In the control group, 22% of the patients ended up receiving EVT, while 5% of the intervention group ended up receiving medical therapy only. The primary outcome was achieved in 42% of the patients in the EVT group and 32% in the medical care group, failing to reach statistical significance (adjusted odds ratio [aOR], 1.74; 95% confidence interval [CI], 0.81 to 3.74). The rates of symptomatic intracranial hemorrhage (sICH) and mortality did not differ between the groups. However, in secondary prespecified analyses, EVT compared to medical treatment alone was associated with a higher rate of mRS 0–3 at 90 days in both per-protocol (44% vs. 25%; aOR, 2.90; 95% CI, 1.20 to 7.03) and as-treated (47% vs. 24%; aOR, 3.02; 95% CI, 1.31 to 7.00) populations.

The Basilar Artery International Cooperation Study (BASICS) trial was performed at 23 centers in seven countries and enrolled patients presenting within 6 hours of stroke due to basilar artery occlusion (BAO). The original inclusion criteria were patients aged <85 years and NIHSS scores of ≥10. However, due to slow enrollment, the inclusion criteria were expanded to include patients aged ≥85 years, NIHSS score <10, and those with contraindications for intravenous thrombolysis. The primary outcome was a mRS score between 0 and 3 at 90 days. The primary safety outcomes were sICH and mortality at 90 days. A total of 300 patients were enrolled (154 in the EVT group and 146 in the medical care group). The primary outcome was achieved in 46.4% of the patients in the EVT group and 24.3% in the medical care group. The sICH and mortality rates did not differ between the groups.

The results of two more RCTs are expected to be positive, and preliminary data presented at the 2022 European Stroke Organization Conference are promising (Table 2). The Basilar Artery Occlusion Chinese Endovascular (BAOCHI) trial enrolled VBAO patients who presented between 6 and 24 hours after onset between 2016 and 2022. In contrast to BEST and BASICS, the BAOCHI trial utilized a clinical severity criteria of NIHSS >6 and imaging-based inclusion criteria of Posterior Circulation Acute Stroke Prognosis Early Computed Tomography Score (PC-ASPECTS) ≥6, and a pons midbrain index of ≤2. In the interim analysis including 212 of the originally planned 318 patients, the rates of favorable outcomes (mRS score between 0 and 3 at 90 days) were significantly higher in the intervention arm (46.4% vs. 24.3%; aOR, 2.92; 95% CI, 1.56 to 5.47). The Endovascular Treatment for Acute Basilar Artery Occlusion (ATTENTION) was a prospective, open, blinded-endpoint RCT that enrolled 342 BAO patients who presented within 12 hours of onset in 36 Chinese stroke centers between 2021 and 2022. The ATTENTION trial had both a clinical severity criterion of NIHSS >10, and an imaging-based inclusion criterion using PC-ASPECTS. Successful reperfusion rates were as high as 93%, and favorable outcomes were achieved in 46% of the intervention arm and 22.8% of the control arm (adjusted risk ratio [aRR], 2.1; P<0.001).
Several factors should be discussed regarding the failure of the BEST and BASICS. First, the inclusion criteria may not have been tailored to maximize EVT outcomes (it was also expanded in BASICS owing to slow recruitment). For the maximal efficacy of reperfusion therapy, there should be a large penumbral area relevant to clinical severity, while the extent of the infarct core should be limited.

### Table 2. Randomized clinical trials

| Protocols | BEST | BASICS | BAOCH | ATTENTION |
|-----------|------|--------|-------|-----------|
| Inclusion period | 2015–2017 | 2011–2019 | 2016–2022 | 2021–2022 |
| Onset to treatment | Within 8 hr | Within 6 hr | 6–24 hr | Within 12 hr |
| Occlusion location | Basilar artery | Basilar artery | Basilar artery or both intracranial vertebral artery | Basilar artery |
| Clinical severity criteria | None | NIHSS ≥10 (later deleted) | NIHSS ≥6 | NIHSS ≥10 |
| Imaging-based inclusion criteria | - | - | PC-ASPECTS ≥6 and pons midbrain index of ≤2 | Age <80, PC-ASPECTS ≥6; age ≥80, PC-ASPECTS ≥8 |
| Imaging-based exclusion criteria | ICH, significant cerebellar mass effect, acute hydrocephalus, or extensive bilateral brainstem ischemia | ICH, extensive bilateral brainstem infarction; cerebellar mass effect; or acute hydrocephalus | Complete bilateral thalamus or brainstem infarction cerebellar mass effect |
| IV thrombolysis | Within 4.5 hr of last seen well | Within 4.5 hr of estimated onset | Before randomization | Within 4.5 hr of last seen well |
| Intracranial stenting | Allowed | Allowed | Allowed | Allowed |
| Primary efficacy endpoint | Proportion of patients with mRS score of 0–3 at 3 months | Intention-to-treat analysis |

| Subjects | | | | |
|---|---|---|---|
| Screened | 288 | 424 | |
| Enrolled/target sample size | 131/344 | 300/300 | 212/318 | 340 |
| Crossover rate (%) | 13 | 3 | 2.3 | |

| Results | | | | |
|---|---|---|---|
| Number | Intervention | Control | Intervention | Control | Intervention | Control | Intervention | Control |
| Age (yr) | 66 (50–74) | 65 | 154 | 146 | 110 | 107 | 226 | 114 |
| Atrial fibrillation | 18 (27) | 10 (15) | 44 (29) | 22 (15) | |
| NIHSS, median | 32 (18–38) | 26 (13–37) | 21 | 22 | 20 (15–29) | 19 (12–30) | |
| IV thrombolysis | 18 (27) | 21 (32) | 121 (79) | 116 (80) | 15 (13.6) | 23 (21.5) | |
| Atherosclerotic etiology | 37 (56) | 32 (49) | |

| Outcomes | | | | |
|---|---|---|---|
| Time from onset-to-EVT | 114 min (66–150) | 4.4 hr (3.3–6.2) | |
| Successful reperfusion | 45 (71) | 63 (72) | 93.3% |
| 3-mo mRS 0–3* | 28 (42) | 21 (32) | 68 (44) | 55 (38) | 51 (46.4) | 26 (24.3) | 46% | 22.8% |
| 3-mo mRS 0–2 | 22 (33) | 18 (28) | 54 (35) | 44 (30) | |
| 3-mo mortality† | 22 (33) | 25 (38) | 59 (38) | 63 (43) | 34 (30.9) | 45 (42.1) | 36.7% | 55.3% |
| PC-ASPECTS score at 24 hours | 6 (4–7) | 6 (4–8) | 8 (6–9) | 8 (6–9) | |

Values are presented as median (interquartile range), number (%), or mean±standard deviation. BEST, Basilar Artery Occlusion Endovascular Intervention Versus Standard Medical Treatment; BASICS, Basilar Artery International Cooperation Study; BAOC-HE, Basilar Artery Occlusion Chinese Endovascular; ATTENTION, Endovascular Treatment for Acute Basilar Artery Occlusion; NIHSS, National Institutes of Health Stroke Scale; ICH, intracranial hemorrhage; PC-ASPECTS, Posterior Circulation Acute Stroke Prognosis Early Computed Tomography Score; IV, intravenous; mRS, modified Rankin Scale; EVT, endovascular treatment.

*BEST trial, adjusted odds ratio, 1.74 (95% confidence interval [CI], 0.8–3.7) for the intervention arm; BASICS trial, relative risk, 1.2 (95% CI, 0.92–1.50); BAOC-HE trial, adjusted odds ratio, 2.92 (95% CI, 1.56–5.47); ATTENTION, adjusted risk ratio, 2.1 (P<0.001); †BEST trial, odds ratio, 0.88 (95% CI, 0.37–1.64) for the intervention arm; BASICS trial, relative risk, 0.87 (95% CI, 0.68–1.12).

Several factors should be discussed regarding the failure of the BEST and BASICS. First, the inclusion criteria may not have been tailored to maximize EVT outcomes (it was also expanded in BASICS owing to slow recruitment). For the maximal efficacy of reperfusion therapy, there should be a large penumbral area relevant to clinical severity, while the extent of the infarct core should be limited. The inclusion criteria of both studies seemed permissive to large infarct volumes only excluding in-
tracranial hemorrhage, extensive bilateral brainstem infarction, cerebellar mass effect, or acute hydrocephalus. Accordingly, the probability of futile recanalization may have increased.\footnote{Lee et al.} Furthermore, there were no clinical severity criteria for BEST, and NIHSS scores ≥10 in the BASICS criteria were later discarded.\footnote{Lee et al.} Initially, the BASICS investigators assumed a primary outcome rate of 40% in the EVT group and 30% in the medical group, which was modified to 46% and 30%, respectively, taking into account the results of AC-EVT trials and slow recruitment. The observed primary outcome rate of 44.2% in the EVT group was largely comparable to the predicted rate; however, the rate of 37.7% in the medical group was higher than predicted. In a subgroup of patients with an NIHSS score of ≥10, which was the initial severity criterion, the primary outcome rate was 39% (48/123) in the EVT group and 27% (31/119) in the medical group, with an absolute difference of 12%. However, in patients with an NIHSS score <10, the primary outcome rate was higher in the medical group (80%, 24/30) than in the EVT group (65%, 20/31), reaffirming the importance of clinical severity criteria.\footnote{Lee et al.}

The second issue was the high crossover rate and drops in the average rate of valid recruitments per center. This occurred because of resistance to conservative treatment by family members in the BEST trial and perhaps in BASICS also. Therefore, a large number of patients were treated outside the trial (29% of screened patients in the BASICS and 55% of screened patients in the BEST trial),\footnote{Lee et al.} potentially causing bias.

The positive results of the ATTENTION and BAOCHÉ trials emphasize the importance of patient selection. Both trials applied specific patient selection criteria composed of baseline neurological severity and infarct volumes estimated by PC-ASPECTS and the pons midbrain index. These factors are discussed further in the following sections.

**PC-EVT versus AC-EVT**

Many studies have compared the outcomes of PC-EVT and AC-EVT.\footnote{Lee et al.} Overall, the reported clinical severity measured by the NIHSS was similar between the groups. However, a lower rate of IV thrombolysis and longer interval from stroke onset-to-recanalization were mostly observed in PC-EVT than in AC-EVT,\footnote{Lee et al.} likely due to delays in diagnosis or need for general anesthesia in real-world practice. Recanalization rates were comparable,\footnote{Lee et al.} while one study reported longer procedure duration for BAO and a trend toward more frequent procedural complications.\footnote{Lee et al.} A meta-analysis comparing PC-EVT and AC-EVT including seven studies showed that PC-EVT was associated with a lower rate of functional independence at 90 days (odds ratio [OR], 0.72; 95% CI, 0.57 to 0.90), higher rate of mortality (OR, 2.03; 95% CI, 1.30 to 3.18), and lower rate of sICH (OR, 0.54; 95% CI, 0.29 to 0.99).\footnote{Lee et al.} Rates of futile recanalization were higher for PC-EVT in multiple studies,\footnote{Lee et al.} with age, stroke severity, maneuver count, and intracranial stenting identified as predictors of futile recanalization.\footnote{Lee et al.} Such differences between PC-EVT and AC-EVT urge us to closely consider the prognostic factors associated with PC-EVT as proper patient selection is essential to reduce futile recanalization.

Another neglected issue is the etiology (or pathogenesis) of stroke. LVO stroke patients undergoing EVT have different etiologies, such as cardiac embolism (CE-LVO), intracranial atherosclerotic (ICAS) thrombosis, and artery-to-artery embolism.\footnote{Lee et al.}

Upon comparison of the etiology-related outcomes between PC-EVT and AC-EVT, PC-EVT group tend to be younger, had CE-LVO less frequently, and had a longer onset-to-recanalization time.\footnote{Lee et al.} The relatively longer onset-to-door time in the PC-EVT group may be attributed to symptoms including dizziness, diplopia, and visual dimness that were not considered as serious neurologic symptoms.\footnote{Lee et al.}

The relatively delayed onset-to-puncture time in the PC-EVT group was most striking in patients with CE-LVO. Although the NIHSS score was highest in CE-LVO patients in the AC-EVT group, it was similar among the three etiologies in the PC-EVT group. Although CE-LVO in the AC-EVT group produced abrupt and severe motor dysfunction associated with sudden middle cerebral artery or internal carotid occlusion, CE-LVO in the PC-EVT group typically occluded the distal basilar or posterior cerebral arteries. This is less likely to cause severe motor dysfunction, thereby delaying the initiation of the EVT decision.\footnote{Lee et al.}

**Prognostic factors and EVT indications**

As discussed above, the careful selection of optimal candidates for PC-EVT is important. In this regard, the prognostic factors of PC-EVT, which may generally be identifiable before the procedure, are discussed below as follows: baseline neurological severity, infarct volumes, collateral circulation, time from onset-to-EVT, and core-penumbra mismatch. In each section, discussions on wider or expanded indications are incorporated. Good clinical outcomes were defined as 3-month mRS 0–2 and favorable outcomes as mRS 0–3 in this review.

**Baseline neurological severity**

Baseline severity: can we treat the lower extreme? Although an NIHSS score ≥6 has been recommended for AC-EVT, evidence regarding the clinical severity threshold for PC-
EVT has not been well studied. While BASICS failed to demonstrate the EVT efficacy in the overall participants, possible benefits were observed in patients who had an NIHSS score ≥10, whereas the chances of achieving favorable outcomes in those with NIHSS score <10 tended to be higher in the medical management group (65% vs. 80%). The lower margin criterion for clinical severity in the BASICS is supported by the BASICS cohort, which showed that in patients with a mild-to-moderate deficit (vs. severe deficits, defined as coma, tetraplegia, or a locked-in state), direct comparison of intra-arterial therapy and intravenous thrombolysis showed an absolute increase in the risk of death or dependence by 20% with intra-arterial therapy. For patients with low NIHSS scores, EVT complications, such as distal thrombus migration resulting in Willisian collateral failure, may be devastating. In addition, these patients may have well-developed collaterals, and may be more responsive to intravenous thrombolysis.

Thus, EVT for patients with low NIHSS scores in the posterior circulation should be selectively performed, e.g., when early neurological deterioration (END) is expected. Patients who experience END are often treated with EVT beyond the traditional therapeutic time window, and they are likely to benefit the most from preemptive EVT before clinical deterioration. This issue is important because the END rate in patients with VBAO was over 30% in those with a low NIHSS score in a retrospective study. However, data regarding predictors of END are limited, and potential factors predictive of END that need to be validated include high blood pressure, shorter onset-to-door times, incomplete occlusions, larger infarct cores, and poorer collaterals.

The second issue is the safety of EVT in VBAO patients with low NIHSS scores. The posterior circulation may be more prone to Willisian collateral failure during procedure, resulting in critical END. In VBAO with low NIHSS, it is likely that the critical Willisian collateral flow involving the basilar top is partially spared, and manipulation of the thrombus may hamper this. The procedural issues for PC-EVT are discussed in detail in the following sections. It should be noted that the ATTENTION trial enrolled patients with NIHSS ≥10, and BAOCHE a severity of NIHSS ≥6.

Baseline severity: can we treat the higher extreme?

It is also an issue whether a very high NIHSS score or coma is an appropriate indication for PC-EVT. Higher NIHSS scores were consistently associated with worse PC-EVT outcomes (Table 3). However, a high NIHSS score is generally not considered a contraindication to EVT. The outcomes of comatose patients undergoing EVT have not been reported uniformly. The data from the Endovascular Treatment in Ischemic Stroke (ETIS) cohort showed that comatose presentation was associated with worse long-term outcomes (mRS 0–3, 11% vs. 54%, P < 0.0001) and higher mortality (64% vs. 34%, P < 0.0001) than non-comatose presentation. In contrast, in a single center study performed in Finland, 20.4% of comatose patients had a favorable outcome after EVT, contesting the futility of EVT in this population. Furthermore, data from the Endovascular Treatment for Acute Basilar Artery Occlusion Study Registry (BASILAR) showed a more than 5-fold increase in the likelihood of achieving favorable functional outcome at 90 days with EVT for severe BAO classified as an NIHSS score ≥21. Accordingly, it is the authors’ opinion that patients should not be deprived of treatment opportunity due to severe symptoms alone. Studies evaluating the effect of clinical severity on outcomes are summarized in Table 3.

### Baseline infarct volumes

**CT-based measurements**

While a small baseline infarct core, for which the ASPECTS was most widely used, was emphasized in AC-EVT, recent RCTs for PC-EVT did not have an infarct volume criterion. However, multiple studies have shown that baseline infarct volume was associated with outcomes and responsiveness to PC-EVT (Table 4).

PC-ASPECTS was developed as a tool to measure infarct volume based on noncontrast computed tomography (CT) or CT angiography source images (CTASI). Owing to the regional eloquence of the brainstem over the cerebellum, a weighted scale was applied. One point is subtracted for early ischemic changes on noncontrast CT or hypointenentation on CTASI in the left or right thalamus, cerebellum, or posterior cerebral artery (PCA) territory, respectively, and 2 points each for early ischemic change (noncontrast CT) or hypointenentation (CTASI) in any part of the midbrain or pons. In the original report, PC-ASPECTS score on CTASI but not noncontrast CT predicted functional independence with a cutoff value of ≥8 in BAO patients. Its utility was further confirmed in the BASICS registry that included patients with BAO, in which a point of ≥6 was associated with favorable outcomes (aRR, 3.1; 95% CI, 1.2 to 7.5) compared with those with PC-ASPECTS of <6. The pons midbrain index is another scoring system that assesses the ischemic changes localized to the pons and midbrain in CTASIs. From an early report, the index has been measured with hypointenentation degrees in the medulla, pons, midbrain, thalami, cerebellum, occipital lobes, inferior parietal lobes, and mid-
dle temporal lobes: 0, no hypoattenuation; 1, <50% hypoattenuation; and 2, >50% hypoattenuation. Only the pons and midbrain scores were associated with death and disability. The authors proposed a combined pons midbrain index of ≥3 as a cutoff point.

Magnetic resonance imaging–based measurements
Because CT evaluation of the brainstem is limited by bone artifacts or partial volume effect,59 studies have used diffusion-weighted magnetic resonance imaging (DWI) for infarct volume measurements.62 PC-ASPECTS measured by DWI53 has been used in various cohort data.62,63 In a retrospective study
Table 4. Studies evaluating the effect of infarct volume on outcomes

| Author (year) (study period) | Study design | No. of patient | Modality | Evaluated index | Main study findings |
|-----------------------------|--------------|----------------|----------|-----------------|---------------------|
| CT-based measurements       |              |                |          |                 |                     |
| Puetz et al. (2008) (2001–2006) | Single center retrospective | 130 Vertebrobasilar ischemia and 46 BAO | CTASI | PC-ASPECTS | PC-ASPECTS ≥8 associated with favorable outcome (RR, 12.1; 95% CI, 1.7 to 84.8) |
| Puetz et al. (2011) (2002–2007) | Multicenter BASICS registry | 78 BAO | CTASI | PC-ASPECTS | PC-ASPECTS ≥6 associated with favorable outcome (RR, 3.1; 95% CI, 1.2–7.5) |
| Schaefer et al. (2008) (2003–2006) | Single center retrospective | 16 EVT | CTASI | Pons midbrain index | Combined pons/midbrain score of ≥3 associated with mortality |
| Pallesen et al. (2016) (2002–2007) | Multicenter BASICS registry | 158 BAO | CTASI | PC-ASPECTS | Among comatose patients, a Pons midbrain index <3 related to reduced mortality (aRR, 0.66; 95% CI, 0.46–0.96) |
| MRI-based measurements      |              |                |          |                 |                     |
| Tei et al. (2010) (2004–2008) | Single center retrospective | 132 Posterior circulation infarction | DWI | PC-ASPECTS | PC-ASPECTS predictive of unfavorable functional outcomes (aOR, 0.40; 95% CI, 0.23–0.67) |
| Son et al. (2015) (2011–2014) | Single center retrospective | 35 BAO EVT | DWI | PC-ASPECTS | Good vs. poor outcomes, mean PC-ASPECTS (7.8±1.6 vs 5.4±1.8, P=0.001) |
| Yoon et al. (2015) (2010–2015) | Single center retrospective | 50 BAO EVT | DWI | PC-ASPECTS | PC-ASPECTS predictive of good outcomes (aOR, 1.85; 95% CI, 1.012–3.397) |
| Gory et al. (2018) (2010–2017) | Multicenter ETIS registry | 117 BAO EVT | CT or DWI | PC-ASPECTS | Lower PC-ASPECTS predictive of mortality (aOR, 1.71; 95% CI, 1.19–2.44) |
| Luo et al. (2018) (2012–2016) | Single center retrospective | 69 BAO EVT | DWI | PC-ASPECTS | PC-ASPECTS ≥6 associated with good clinical outcome (aOR, 7.335; 95% CI, 1.495–36.191) |
| Guillaume et al. (2019) (2010–2017) | Multicenter ETIS registry | 95 BAO EVT | DWI | PC-ASPECTS | Association between imaging-to-reperfusion time and good outcomes for patients with PC-ASPECTS <8 (aOR, 0.4 per 30 min; 95% CI, 0.18–0.85), compared with those with PC-ASPECTS ≥8 |
| Mourand et al. (2014) (2009–2011) | Single center retrospective | 31 BAO EVT | DWI | BSS | BSS <3 associated with good outcomes (OR, 9.92; 95% CI, 1.75–56.30) |
| Yang et al. (2018) (2012–2016) | Single center retrospective | 50 BAO EVT | DWI | BSS | DWI BSS ≥2 predictive of favorable outcome (aOR, 12.4; 95% CI, 2.5–61.2) and >3 associated with mortality (aOR,7.9; 95% CI, 1.4–45.8) |
| Raymond et al. (2018) (2004–2016) | Single center retrospective | 89 Medical and EVT | DWI | Proposed MRI criteria for EVT exclusion | Bilateral thalamus >50% brainstem >20 cc of cerebellum |
| Lee et al. (2020) (2011–2016) | Multicenter ASIAN KR registry | VBAO EVT Derivation: 71 Validation: 32 | DWI | Infract volume | DWI volume <10 mL predictive of good outcomes (aOR, 19.3; 95% CI, 3.0–126.4) |

CT, computed tomography; BAO, basilar artery occlusion; CTASI, computed tomography angiography source image; PC-ASPECTS, Posterior Circulation Alberta Stroke Prognosis Early Computed Tomography Score; RR, risk ratio; CI, confidence interval; BASICS, Basilar Artery International Cooperation Study; EVT, endovascular treatment; aRR, adjusted risk ratio; MRI, magnetic resonance imaging; DWI, diffusion-weighted MRI; aOR, adjusted odds ratio; ETIS, Endovascular Treatment in Ischemic Stroke; BSS, brainstem score; ASIAN KR, Acute Stroke due to Intracranial Atherosclerotic occlusion and Neurointervention Korean Retrospective; VBAO, vertebrobasilar artery.

Involving 31 patients undergoing PC-EVT, DWI correlated well to outcomes with high inter-rater reliability, with a score of ≥8 resulting in a positive predictive value of 90% and negative predictive value of 100% for the prediction of favorable outcomes. A similar score, the brainstem score (BSS), is a DWI-based semi-quantitative 12-point system in which each brainstem level (medulla, pons, and midbrain) is evaluated separately. One point was assigned for each unilateral high-intensity lesion at the brainstem level (medulla, pons, and midbrain) that occupied less than half of the area; 2 points were given if the lesion occupied more than half of the area. The brainstem DWI lesion score ranges from 0 to 12. In patients undergoing PC-EVT, DWI BSS ≤2 was an independent predictor of good outcomes, while DWI BSS >3 was predictive of high mortality. Currently, the PC-ASPECTS (DWI or CT) score is most widely used for the pre-procedural infarct volume assessment. It has
Good collateral circulation and better clinical outcomes

The collateral circulation of the posterior circulation has been evaluated using catheter angiography or noninvasive methods (Table 5). The American Society of Interventional and Therapeutic Neuroradiology/Society of Interventional Radiology (ASITN/SIR) grade (range 0–4) could be applied to the posterior circulation. In the Endovascular Stroke Treatment (ENDOSTROKE) study, a 1 step increase in the ASITN/SIR grade was associated with an increased good outcome (OR, 2.12; 95% CI, 1.11 to 4.06) and successful reperfusion (OR, 3.09; 95% CI, 1.51 to 6.31) in BAO patients treated with EVT. The collateral scores can also be noninvasively evaluated using the posterior circulation collateral score (PC-CS) or Basilar Artery on Computer Tomography Angiography (BATMAN) score. The PC-CS is a 10-point grading system in which each patent posterior inferior cerebellar artery, anterior inferior cerebellar artery, and superior cerebellar artery is allocated 1 point. Identification of a posterior communicating artery (PCoA) was allocated 1 point if its diameter was smaller than the ipsilateral P1 segment and 2 points if its diameter was equal or larger than this segment. Fetal variants of PCA were not included in this score. This score was evaluated in the BASICS registry. When the PC-CS was trichotomized to poor (PC-CS, 0–3), intermediate (PC-CS, 4–5), and good (PC-CS, 6–10) collateral scores, a poor PC-CS was associated with lower risk of death (aOR, 0.210; 95% CI, 0.059–0.752).
and good (PC-CS, 6–10) collaterals, patients with a good PC-CS compared to those with a poor PC-CS were less likely to have poor outcome (aRR, 0.74; 95% CI, 0.58 to 0.96). The BATMAN score is a 10-point computed tomographic angiography-based grading system that incorporates thrombus burden and presence of collaterals. For a patent segment of each P1 PCA, vertebral arteries (considered as 1 segment), proximal BA, middle BA, and distal BA, one point was allocated. For each patent PComA that had continuity with BA through P1 segment, two-point was given if the diameter was ≥1 mm and patent PComA that had continuity with BA through P1 segment, one point was assigned if it was <1 mm. In case of patent fetal-type PComA, 3-point was allocated in each side. When tested in BAO patients presenting within 24 hours, the BATMAN score was significantly associated with outcomes, and it had greater accuracy than PC-CS.

Collateral status influenced by etiology

Some factors may influence the impact of collaterals on the outcomes. First, it may be influenced by occlusion etiology. In the analysis of the ASIAN KR registry, which included VBAO patients undergoing EVT, collateral scores were not predictive of outcomes. There was abundance of ICAS-related occlusions in this Asian cohort, which was associated with poor outcomes. Chronic longstanding ICAS may be associated with higher collaterals, diluting the impact of collaterals on outcomes. Second, in proximal occlusions, the impact of collaterals seems less obvious. In vertebral artery (VA) or proximal basilar occlusions causing critical perfusion failure, the basilar top may be more frequently spared, resulting in higher collateral scores. However, this does not seem to guarantee favorable outcomes for proximal occlusions.

In contrast, in another more recent Korean cohort in which underlying ICAS-related occlusion was not associated with outcomes, both the BATMAN score and PC-CS were associated with good outcomes in univariate analysis. PC-CS ≥6 was associated with good outcomes (OR, 3.79; 95% CI, 1.05 to 13.66) in multivariate analysis, while a BATMAN score ≥6 was not. Thus, the two study results showed a possible interaction between collaterals and etiology on outcomes.

Collaterals via posterior communicating artery

The PComA collateral status is emphasized in both the PC-CS and BATMAN grades. The presence of PComA is generally considered to be associated with favorable clinical outcomes. However, the significance of fetal PComA is controversial. A positive association between the presence of fetal-type PComA and good outcomes has been reported, claiming that PComA acts as a safeguard against ischemic insult. In contrast, when limited to the top of the basilar artery stroke, mostly caused by an embolism, the presence of fetal-type PComA was associated with poorer outcomes, due to inaccessibility of retrograde flow from P1 segment to the basilar artery, and the thrombus to be lodged in the basilar top, causing downward thrombus extension. From the perspective of EVT, there is a chance that fetal PComA may complicate EVT results by producing lower rates of reperfusion due to the absence of collateral flow and a smaller vertebrobasilar artery diameter.

Time from onset to treatment

In AC-EVT, the emphasis of onset-to-EVT time is diminishing with the recognition that the therapeutic time window can be modified by collateral status, or selection of patients by clinical–core or core–penumbra mismatch. Once an EVT candidate is selected, interest is focused on the time from imaging-to-reperfusion. However, in the analysis of real-world AC-EVT data in patients who presented within 8 hours, shorter onset-to-puncture time was associated with better functional outcomes, and its relationship slope was steeper in the 30 to 270 minutes than in the 271 to 480 minutes timeframe. Despite the inconsistent results (Table 6), the onset-to–EVT time is intuitively correlated with infarct growth in PC-EVT. A recent multicenter study utilizing the Get With The Guidelines–Stroke nationwide United States registry, which included 3,015 BAO patients, showed that onset-to-EVT time <6 hours was significantly associated with lower in-hospital mortality (aOR, 0.55; 95% CI, 0.45 to 0.68) and sICH (aOR, 0.52; 95% CI, 0.32 to 0.84) rates, and a higher rate of independence at discharge (aOR, 2.21; 95% CI, 1.66 to 2.95) than those with >6 hours. The fastest decline of good outcomes per hour occurred within 6 hours of symptom onset. Regarding late-window treatment, imaging-based patient selection utilizing the core–penumbra mismatch concept is currently less established in PC-EVT. However, recent literature has revealed that the significance of time to outcome may differ on an individual basis, and rapid and slow growers may be identified by infarct volume and collateral status, as shown in the anterior circulation.

Some studies have shown that time criteria may be modified by baseline infarct volumes. The multicenter ETIS registry showed that time dependent deteriorations in clinical outcomes was less significant in those with PC-ASPECTS ≥8, compared with the decay in probability of good outcomes as time passed in medium to large stroke (PC-ASPECTS <8). A predictive model of good outcomes generated from the ASIAN KR
registry also agrees with this finding. In the generated predictive model for good outcomes (BAO patients within 24 hours from onset-to-EVT), the three most important variables identified were baseline infarct volume (<10 mL), onset-to-puncture time (<8 hours), and embolic occlusions (compared with ICAS occlusions). If the patient suffered an embolic VBAO and the presenting infarct volume was small, the total score of the predictive model was sufficiently enough that good outcomes could be expected irrespective of time.

Similarly, several studies have shown that time criteria may be modified by collateral status. A pooled analysis of the multicenter BATMAN and BASICS registries showed that in patients with poor collaterals (unfavorable BATMAN collateral score), time-to-treatment of ≤6 hours was associated with improved outcomes, while this association was not shown in patients with good collaterals, concluding that revascularization can be associated with favorable outcomes in BAO patients with good collaterals and less extensive occlusion, even >6 hours after onset. This result was also replicated in another single center retrospective study that showed pronounced impact of collateral status on functional outcome and mortality, particularly in the subgroup of patients who experienced recanalization beyond 6 hours.

### Core–penumbra mismatch for PC–EVT

Criteria of core and penumbra
An imminent challenge is to better understand the core–penumbra mismatch or clinical–core mismatch in the posterior circulation. The clinical–core mismatch concept is based on preliminary data that showed a mismatch between NIHSS score ≥8 and DWI volume ≤25 mL to strongly predict infarct...
growth in patients with middle cerebral artery M1 occlusion.\textsuperscript{83,84} Similarly, it is important to generate an optimal mismatch criterion in the posterior circulation. First, the upper limit of the tolerable infarct volume must be identified. In VBAO, an overall infarct volume of 10 mL,\textsuperscript{85} or a volume of 10 mL localized to the brainstem, is considered a predictor of poor outcomes.\textsuperscript{83,84} If MRI is not feasible, PC-ASPECTS should be considered. A PC-ASPECTS score of ≥6, predictive of favorable outcomes,\textsuperscript{80} or a score of PC-ASPECTS ≥5,\textsuperscript{85} which was identified as the lower limit for benefit of EVT, may be used as a core criterion. In the latter study, EVT was associated with favorable outcomes and lower mortality than medical therapy in both PC-ASPECTS 5–7 and 8–10 subgroups. Furthermore, the association of onset-to-puncture time and favorable outcome was not significant after adjustment for PC-ASPECTS, suggesting that the core criterion is more significant than time parameters.\textsuperscript{85}

Second, penumbral criteria for predicting infarct growth should be established. It may be generated clinically by utilizing NIHSS criteria of ≥10, which showed promising results in BASICS.\textsuperscript{12} Alternatively, alteration of mental status may be used as a criterion. In a retrospective study evaluating VBAO patients with acceptable infarct volumes (PC-ASPECTS ≥6), a decrease in the NIHSS consciousness subset scores of ≥1 was more strongly predictive of infarct growth than an NIHSS score of >10.\textsuperscript{86} Reduction in mental status may be indicative of global perfusion failure of the vertebrobasilar territory, resulting in infarct growth.

Mismatch studies with perfusion maps

Only recently studies utilizing perfusion imaging in VBAO have been published. In these studies, perfusion parameters were considered proxies for the infarct core and predictors of outcome, rather than to identify the core and penumbral mismatch. In 2019, the value of PC-ASPECTS manually measured in CT perfusion parameters was reported.\textsuperscript{87} The cerebral blood volume (CBV) PC-ASPECTS was predictive of poor outcomes, with an area under the receiver operating characteristic curve (AUROC) of 0.83 (95% CI, 0.72 to 0.93), which was significantly higher than that of CTASI (AUROC, 0.64; 95% CI, 0.50 to 0.79). In the logistic regression analysis, CBV PC-ASPECTS ≤8 was independently associated with poor outcomes (aOR, 9.3; 95% CI, 2.2 to 41). Inter-rater agreement was substantial for the CBV PC-ASPECTS (intraclass correlation coefficient, 0.82; 95% CI, 0.71 to 0.90). Other CT perfusion parameters in BAO were also reported to be of prognostic significance.\textsuperscript{88} In this study, perfusion deficit was defined as “the presence of a focal decrease of cerebral blood flow (CBF) or CBV, or focal increase of mean transit time or time to drain compared with the contralateral side on at least two adjacent slices.” Quantitative thresholds were not used in this study. In this analysis, early ischemic changes were measured using PC-ASPECTS on non-contrast CT, CTASI, and parametric whole-brain CT perfusion images. Perfusion deficit volumes on all CT perfusion maps (OR range, 0.77 to 0.98; 95% CI, 0.63 to 1.00) were independent outcome predictors in multivariable analysis adjusted for age and NIHSS. CBF deficit volume yielded the best performance for the classification of good clinical outcomes (AUROC, 0.92; 95% CI, 0.84 to 0.99). The predictive ability of the critical area perfusion score (CAPS, 0 to 6 points) on perfusion maps in BAO patients undergoing thrombectomy was also reported.\textsuperscript{89} CAPS points were assigned based on the presence of Tmax >10 seconds, which involved adjacent axial image slices and had a minimum diameter of 6 mm on at least one slice within the following brain regions: cerebellum (1 point per hemisphere), pons (2 points), and midbrain and/or thalamus (2 points), for a total of 6 possible points. In this analysis, CAPS ≤3 was a robust independent predictor of favorable outcomes after adjustment for reperfusion, age, and NIHSS score (OR, 39.25; 95% CI, 1.34 to >999). Despite these significant results, successive studies focusing on cutoff values for the core and penumbra criteria are needed in the future. Using such criteria, fast/ultra-fast growers and slow growers,\textsuperscript{79} which may potentially compose 19% and 14% of BAO strokes, respectively,\textsuperscript{80} can be identified to provide individualized treatment.

Technical issues of EVT in posterior circulation stroke

Contact aspiration vs. stent retrieval

Comparison of contact aspiration and stent retrieval in AC-EVT has shown similar results in revascularization rate and clinical efficacy.\textsuperscript{91} While no clinical trials exist regarding this issue in PC-EVT, first-line contact aspiration may be more feasible. First, due to the blunt angle of the basilar bifurcation, microwire penetration inside the small thalamoperforating arteries may result in perforation or dissection of the arteries.\textsuperscript{92,93} Passing through the thrombus with a microwire and microcatheter is not required in contact aspiration methods, but it is necessary to deploy a stent retriever. Blind navigation of the microwire beyond the occlusive segment may increase the risk of perforation or dissection.\textsuperscript{92} Second, a large thrombus burden in both PCAs may result in a to-and-fro movement of the thrombus into the contralateral PCA without efficient thrombus removal if stent retrievers are deployed in only one PCA. Dual stent retrievers deployed to both PCAs have been utilized as a rescue...
Contact aspiration may be superior to stent retrievers in this regard, as different forces are used. Furthermore, delivery of larger-bore catheters to the basilar artery is easier than to the anterior circulation because of the relatively straight vascular course; hence, the procedure time is reduced. Cohort data support such concerns. In the Multi-center Randomized Clinical Trial of Endovascular Treatment for Acute Ischemic Stroke in The Netherlands (MR CLEAN) registry data including 205 patients with posterior circulation stroke, contact aspiration was associated with better functional outcomes than stent retrieval (adjusted common OR for a 1-point improvement on the mRS, 1.94; 95% CI, 1.03 to 3.65), with higher rates of successful reperfusion and shorter procedure time when used as a first-line strategy. Furthermore, in the ETIS prospective multicenter registry regarding BAO patients, contact aspiration was a strong predictor of the first pass effect. In a meta-analysis including eight observational studies, compared with the stent retriever group, the direct aspiration group was associated with a higher thrombolysis in cerebral infarction 2b/3 reperfusion rate (OR, 1.85; 95% CI, 1.06 to 3.23). There was a tendency for higher rates of complication with stent retrievers, although statistical significance was not reached. However, the findings may be attributed to selection bias inherent for observational studies. As a first-line treatment, direct aspiration with a large-bore aspiration catheter was likely used for patients with favorable vascular anatomy, while stent retriever thrombectomy might be provided to those in whom contact aspiration was not applicable.

A recent retrospective analysis including two prospectively maintained stroke registries showed higher odds of complete recanalization using combined stent retrievers plus direct aspiration than stent retrieval or direct aspiration alone or switching techniques. Flow arrest with balloon guide catheters to reduce distal embolization is not feasible in most cases of PC-EVT due to dual VA supplies. Combined techniques may reduce antegrade blood flow due to the larger caliber and negative pressure, thus creating an environment similar to flow arrest.

Overcoming underlying atherosclerosis
ICAS LVO in the posterior circulation poses a greater therapeutic challenge given its higher proportion (40%) than that in the middle cerebral artery (23%) or internal carotid artery occlusions (6%) among patients treated with EVT. Different EVT results have been reported for ICAS-related VBAO. Some studies reported that the PC-EVT outcome was worse in patients with ICAS LVO than in those with embolic occlusions. However, others reported similar outcomes. Longer procedure times and complicated procedures may in part be accountable for the poor outcomes. ICAS LVO may also be associated with involvement of the pontine perforators, as occlusion location tends to be lower than in embolic occlusions.

Practically, it may be important to identify ICAS LVOs before the procedure. If ICAS LVO can be identified before procedure, stent retrieval may be preferred over aspiration as the first-line treatment, as in some cases, in situ thrombus removal may be difficult due to lack of contact between catheter tip and thrombus during contact aspiration. Furthermore, the operator may prepare for rescue therapy, which is needed in a large number of cases.

Overcoming tandem occlusions
Vertebrobasilar occlusion may have been caused by tandem occlusion. There may be a severe stenosis or occlusion at the proximal VA, limiting distal flow. When compared with embolic occlusions without tandem lesion, tandem BAO was more frequently associated with longer procedural time, and poorer clinical outcome, despite a high rate of successful recanalization, with a marginally lower rate of good outcomes (53% vs. 29%, P=0.05), which was not significant in multivariable analysis. This result was reproduced in another cohort data, in which tandem occlusions were associated with lower rates of successful reperfusion and good clinical outcomes, and higher rates of mortality. However, in one study, EVT of tandem occlusions was reported to be safe and feasible. The majority of the tandem occlusion patients were treated by the dirty-roadway (via the stenotic or occluded vertebral artery) and treated by retrograde technique (thrombectomy performed first). In some cases, it is not possible to select and cross the vertebral stump using the femoral approach, and the contralateral VA is too thin for the clean-road pathway. In these cases, vascular access may be gained through exchange-length microwire access through the vertebrobasilar junction from the contralateral VA to the ipsilateral VA. The lesion is retrogradely crossed, and then the microwire can be snared out of the arm through the ipsilateral trans-brachial approach. The microwire can then be used as a rail for angioplasty/stenting and further advancement of the brachial guide catheter.

Adjuvant treatment with balloon angioplasty with or without stent insertion can be performed on the tandem VA lesion. However, the decision to perform angioplasty of the tandem VA lesion may be controversial if the clean-road pathway is selected for intracranial thrombectomy, or due to concerns of hemorrhage. In a case series of 55 tandem VBAO patients, angioplasty of the tandem VA lesion was performed in 29% of the patients, and there were no procedure-related
complications. Two patients developed short-term reocclusion of the basilar artery after MT, and both had been treated with contralateral VA access without angioplasty of the tandem VA lesion.\textsuperscript{10} If angioplasty is planned, it may be assisted by a distal embolic protection device,\textsuperscript{108} and both balloon-mounted and self-expanding stents may be used.\textsuperscript{106,108,111}

Conclusions

While two RCTs investigating the utility of PC-EVT have shown negative results, the results of following studies seem to be optimistic. These studies indicate that the therapeutic efficacy of PC-EVT may be maximized by reducing futile recanalization through the identification of prognostic factors and optimizing EVT procedures. Neurological severity, infarct volume, collateral circulation, and the time from onset-to-EVT were identified as prognostic variables. Research unveiling the interplay of these variables and the application of advanced imaging, such as perfusion maps, will generate the core-penumbra criteria for PC-EVT. Such advances will lead to the success of RCTs and improve patient outcomes through individualized patient selection.

Disclosure

The authors have no financial conflicts of interest.

References

1. Writing Group for the BASILAR Group, Zi W, Qiu Z, Wu D, Li F, Liu H, et al. Assessment of endovascular treatment for acute basilar artery occlusion via a nationwide prospective registry. \textit{JAMA Neurology} 2020;77:561-573.

2. Mokin M, Sonig A, Sivakanthan S, Ren Z, Elijovich L, Arthur A, et al. Clinical and procedural predictors of outcomes from the endovascular treatment of posterior circulation strokes. \textit{Stroke} 2016;47:782-788.

3. Bouslama M, Haussen DC, Aghaebrahim A, Grossberg JA, Walker G, Rangaraju S, et al. Predictors of good outcome after endovascular therapy for vertebrobasilar occlusion stroke. \textit{Stroke} 2017;48:3252-3257.

4. Gory B, Mazighi M, Blanc R, Labreuche J, Piotin M, Turjman F, et al. Mechanical thrombectomy in basilar artery occlusion: influence of reperfusion on clinical outcome and impact of the first-line strategy (ADAPT vs stent retriever). \textit{J Neurosurg} 2018;129:1482-1491.

5. Gory B, Mazighi M, Labreuche J, Blanc R, Piotin M, Turjman F, et al. Predictors for mortality after mechanical thrombectomy of acute basilar artery occlusion. \textit{Cerebrovasc Dis} 2018;45:61-67.

6. Novakovic-White R, Corona JM, White JA. Posterior circulation ischemia in the endovascular era. \textit{Neurology} 2021;97(20 Suppl 2):S158-S169.

7. Li C, Wu C, Wu L, Zhao W, Chen J, Ren M, et al. Basilar artery occlusion Chinese endovascular trial: protocol for a prospective randomized controlled study. \textit{Int J Stroke} 2021 Aug 28 [Epub]. https://doi.org/10.1177/17474930211040923.

8. Tao C, Li R, Zhu Y, Qun S, Xu P, Wang L, et al. Endovascular treatment for acute basilar artery occlusion: a multicenter randomized controlled trial (ATTENTION). \textit{Int J Stroke} 2022 Feb 22 [Epub]. https://doi.org/10.1177/174749302221077164.

9. BAOCHE Investigators. Basilar artery occlusion chinese endovascular trial. Oral presentation at European Stroke Organisation Conference; 2022 May 4–6; Lyon, FR.

10. ATTENTION investigators. Endovascular treatment for acute basilar artery occlusion. Oral presentation at European Stroke Organisation Conference; 2022 May 4–6; Lyon, FR.

11. Liu X, Dai Q, Ye R, Zi W, Liu Y, Wang H, et al. Endovascular treatment versus standard medical treatment for vertebrobasilar artery occlusion (BEST): an open-label, randomised controlled trial. \textit{Lancet Neurol} 2020;19:115-122.

12. Langezaal L, van der Hoeven E, Mont’Alverne F, de Carvalho J, Lima FO, Dippel D, et al. Endovascular therapy for stroke due to basilar-artery occlusion. \textit{N Engl J Med} 2021;384:1910-1920.

13. Wang F, Wang J, He Q, Wang L, Cao Y, Zhang H, et al. Mechanical thrombectomy for posterior circulation occlusion: a comparison of outcomes with the anterior circulation occlusion. \textit{Atheroscler Thromb} 2020;27:1325-1339.

14. Desai SM, Haussen DC, Aghaebrahim A, Al-Bayati AR, Santos R, Nogueira RG, et al. Thrombectomy 24 hours after stroke: beyond DAWN. \textit{J Neurointerv Surg} 2018;10:1039–1042.

15. Albers GW, Marks MP, Kemp S, Christensen S, Tsai JP, Ortega-Gutierrez S, et al. Thrombectomy for stroke at 6 to 16 hours with selection by perfusion imaging. \textit{N Engl J Med} 2018;378:708-718.

16. Yoshimura S, Sakai N, Yamagami U, Uchida K, Beppu M, Toyoda K, et al. Endovascular therapy for acute stroke with a large ischemic region. \textit{N Engl J Med} 2022;386:1303-1313.

17. Sarraj A, Hassan A, Savitz SI, Grotta JC, Cai C, Parsha KN, et al. Endovascular thrombectomy for mild strokes: how low should we go? \textit{Stroke} 2018;49:2398-2405.

18. Volny O, Zerna C, Tomek A, Bar M, Roczek M, Padr R, et al. Endovascular thrombectomy vs medical management in low NIHSS acute anterior circulation stroke. \textit{Neurology} 2020;95:e3364-e3372.

19. Saver JL, Chapot R, Agid R, Hassan A, Jadhav AP, Liebeskind
DS, et al. Thrombectomy for distal, medium vessel occlusions: a consensus statement on present knowledge and promising directions. *Stroke* 2020;51:2872–2884.

20. Kidwell CS, Alger JR, Saver JL. Beyond mismatch: evolving paradigms in imaging the ischemic penumbra with multimodal magnetic resonance imaging. *Stroke* 2003;34:2729–2735.

21. Nguyen TN, Strbian D. Endovascular therapy for stroke due to basilar artery occlusion: a BASIC challenge at BEST. *Stroke* 2021;52:3410–3413.

22. Hu SY, Yi HJ, Lee DH, Hong JT, Sung JH, Lee SW. Effectiveness and safety of mechanical thrombectomy with stent retrievers in basilar artery occlusion: comparison with anterior circulation occlusions. *J Korean Neurol Soc* 2017;60:635–643.

23. Weber R, Minnerup J, Nordmeyer H, Eyding J, Krogias C, Hadisurya J, et al. Thrombectomy in posterior circulation stroke: differences in procedures and outcome compared to anterior circulation stroke in the prospective multicentre RES-VASK registry. *Eur J Neurol* 2019;26:299–305.

24. Alonso de Leciñana M, Kawiorski MM, Ximénez-Carrillo Á, Cruz-Culebras A, García-Pastor A, Martínez-Sánchez P, et al. Mechanical thrombectomy for basilar artery thrombosis: a comparison of outcomes with anterior circulation occlusions. *J Neurointerv Surg* 2017;9:1173–1180.

25. Uno J, Kameda K, Otsuji R, Ren N, Nagaoka S, Maeda K, et al. Mechanical thrombectomy for basilar artery occlusion compared with anterior circulation stroke. *World Neurosurg* 2020;134:e469–e475.

26. Meinel TR, Kaesmacher J, Chaloulos-Iakovidis P, Panos L, Mordasini P, Mosimann PJ, et al. Mechanical thrombectomy for basilar artery occlusion: efficacy, outcomes, and futile recanalization with anterior circulation. *J Neurointerv Surg* 2019;11:1174–1180.

27. Lee JS, Lee SJ, Hong JM, Alverne F, Lima FO, Nogueira RG. Endovascular treatment of large vessel occlusion strokes due to intracranial atherosclerotic disease. *J Stroke* 2022;24:3–20.

28. Lee SH, Kim JS. Acute diagnosis and management of stroke presenting dizziness or vertigo. *Neuro Clin* 2015;33:687–698.

29. Kwon H, Lee D, Lee DH, Suh DC, Kwon SU, Kang DW, et al. Etiology-related outcome of endovascular therapy in posterior or circulation stroke compared to anterior circulation stroke. *J Stroke* 2022;24:245–255.

30. Schoneville WJ, Wijman CA, Michel P, Rueckert CM, Weimar C, Mattle HP, et al. Treatment and outcomes of acute basilar artery occlusion in the Basilar Artery International Coopera tion Study (BASICS): a prospective registry study. *Lancet Neurol* 2009;8:724–730.

31. Lee SJ, Hwang YH, Hong JM, Choi JW, Kang DH, Kim YW, et al. Predictors and prognoses of Willisian collateral failure during mechanical thrombectomy. *Sci Rep* 2020;10:20874.

32. Wu D, Guo F, Liu D, Hu R, Shen Z, Yang Y, et al. Characteristics and prognosis of acute basilar artery occlusion in minor to moderate stroke and severe stroke after endovascular treatment: a multicenter retrospective study. *Clin Neurol Neurosurg* 2021;202:106504.

33. Seners P, Roca P, Legrand L, Turc G, Cottier JP, Cho TH, et al. Better collaterals are independently associated with post-thrombolysis recanalization before thrombectomy. *Stroke* 2019;50:867–872.

34. Raymond S, Rost NS, Schaefer PW, Leslie-Mazwi T, Hirsch JA, Gonzalez RG, et al. Patient selection for mechanical thrombectomy in posterior circulation emergent large-vessel occlusion. *Interv Neuroradiol* 2018;24:309–316.

35. Koh S, Lee SE, Jung WS, Choi JW, Lee JS, Hong JM, et al. Predictors of early neurological deterioration in stroke due to vertebrobasilar occlusion. *Front Neurol* 2021;12:696042.

36. Yeo L, Holmberg A, Mpotsaris A, Söderman M, Holmin S, Kurtze Söderquist A, et al. Posterior circulation occlusions may be associated with distal emboli during thrombectomy: factors for distal embolization and a review of the literature. *Clin Neuroradiol* 2019;29:425–433.

37. Guenego A, Lucas L, Gory B, Richard S, Aubertin M, Weissenburger-Lile D, et al. Thrombectomy for comatose patients with basilar artery occlusion: a multicenter study. *Clin Neuroradiol* 2021;31:1131–1140.

38. Ritvonen J, Sairanen T, Silvennoinen H, Virtanen P, Salonen O, Lindsberg PJ, et al. Comatose with basilar artery occlusion: still odds of favorable outcome with recanalization therapy. *Front Neurol* 2021;12:665317.

39. Kong W, Yuan J, Huang J, Song J, Zhao C, Sang H, et al. Outcomes of endovascular therapy in acute basilar artery occlusion with severe symptoms. *JAMA Neurol* 2021;4:e2139550.

40. Yoon W, Kim SK, Heo TW, Baek BH, Lee YY, Kang HK. Predictors of good outcome after stent-retriever thrombectomy in acute basilar artery occlusion. *Stroke* 2015;46:2972–2975.

41. Singer OC, Berkefeld J, Noite CH, Bohner G, Haring HP, Trenkler J, et al. Mechanical recanalization in basilar artery occlusion: the ENDOSTROKE study. *Ann Neurol* 2015;77:415–424.

42. Choi JW, Han M, Park JH, Jung WS. Effect of manual aspiration thrombectomy using large-bore aspiration catheter for acute basilar artery occlusion: comparison with a stent retriever system. *BMC Neurol* 2020;20:434.

43. Baek JH, Kim BM, Heo JH, Kim DJ, Nam HS, Kim YD. Endo-
vascular and clinical outcomes of vertebrobasilar intracranial atherosclerosis-related large vessel occlusion. Front Neurol 2019;10:215.
44. Giorgianni A, Biraschi F, Piano M, Mardighian D, Gasparotti R, Frigerio M, et al. Endovascular treatment of acute basilar artery occlusion: Registro Endovascolare Lombardo Occlusione Basilar Artery (RELOBA) study group experience. J Stroke Cerebrovasc Dis 2018;27:2367-2374.
45. Kang DH, Jung C, Yoon W, Kim SK, Baek BH, Kim JT, et al. Endovascular thrombectomy for acute basilar artery occlusion: a multicenter retrospective observational study. J Am Heart Assoc 2018;7:e009419.
46. Li C, Zhao W, Wu C, Shang S, Chen J, Ren M, et al. Outcome of endovascular treatment for acute basilar artery occlusion in the modern era: a single institution experience. Neuroradiology 2018;60:651-659.
47. Luo G, Mo D, Tong X, Liebeskind DS, Song L, Ma N, et al. Factors Associated with 90-day outcomes of patients with acute posterior circulation stroke treated by mechanical thrombectomy. World Neurosurg 2018;109:e318-e328.
48. Lee JS, Demchuk AM. Choosing a hyperacute stroke imaging protocol for proper patient selection and time efficient endovascular treatment: lessons from recent trials. J Stroke 2015;17:221-228.
49. Puetz V, Sylaja PN, Coutts SB, Hill MD, Dzialowski I, Mueller P, et al. Extent of hypointenattenuation on CT angiography source images predicts functional outcome in patients with basilar artery occlusion. Stroke 2008;39:2485-2490.
50. Puetz V, Khomenko A, Hill MD, Dzialowski I, Michel P, Weimar C, et al. Extent of hypointenattenuation on CT angiography source images in basilar artery occlusion: prognostic value in the Basilar Artery International Cooperation Study. Stroke 2011;42:3454-3459.
51. Schaeffer PW, Yoo AJ, Bell D, Barak ER, Romero JM, Nogueira RG, et al. CT angiography-source image hypointenattenuation predicts clinical outcome in posterior circulation strokes treated with intra-arterial therapy. Stroke 2008;39:3107-3109.
52. Lee SJ, Hong JM, Choi JW, Park JH, Park B, Kang DH, et al. Predicting endovascular treatment outcomes in acute vertebrobasilar artery occlusion: a model to aid patient selection from the ASIAN KR registry. Radiology 2020;294:628-637.
53. 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.
54. Mourand I, Machi P, Nogue E, Arquizan C, Costalat V, Picot MC, et al. Diffusion-weighted imaging score of the brain stem: a predictor of outcome in acute basilar artery occlusion treated with the Solitaire FR device. AJNR Am J Neuroradiol 2014;35:1117-1123.
55. Yang H, Ma N, Liu L, Gao F, Mo D, Sun X, et al. Early diffusion-weighted imaging brain stem score for acute basilar artery occlusion treated with mechanical thrombectomy. J Stroke Cerebrovasc Dis 2018;27:2822-2828.
56. Guillaume M, Lapergue B, Gory B, Labreuche J, Consoli A, Mione G, et al. Rapid successful reperfusion of basilar artery occlusion strokes with pretreatment diffusion-weighted imaging posterior-circulation ASPECTS <8 is associated with good outcome. J Am Heart Assoc 2019;8:e010962.
57. Pallesen LP, Gerber J, Dzialowski I, van der Hoeven EJ, Michel P, Pfefferkorn T, et al. Diagnostic and prognostic impact of pc-ASPECTS applied to perfusion CT in the basilar artery international cooperation study. J Neuroimag 2015;25:384-389.
58. Son S, Kim YW, Oh MK, Kim SK, Park JI, Choi NC, et al. Initial factors affecting the clinical outcome after successful recanalization via MR-based mechanical thrombectomy in patients with acute ischemic stroke due to basilar artery occlusion. J Neurointerv Surg 2016;8:889-893.
59. Monnin P, Sfameni N, Gianoli A, Ding S. Optimal slice thickness for object detection with longitudinal partial volume effects in computed tomography. J Appl Clin Med Phys 2017;18:251-259.
60. Khatibi K, Nour M, Tateshima S, Jahan R, Duckwiler G, Saver J, et al. Posterior circulation thrombectomy-PC-ASPECT score applied to preintervention magnetic resonance imaging can accurately predict functional outcome. World Neurosurg 2019;129:e566-e571.
61. van der Hoeven EJ, McVerry F, Vos JA, Algra A, Puetz V, Kappelle LJ, et al. Collateral flow predicts outcome after basilar artery occlusion: the posterior circulation collateral score. Int J Stroke 2016;11:768-775.
62. Alemseged F, Shah DG, Diomedri M, Sallustio F, Bivard A, Sharma G, et al. The basilar artery on computed tomography angiography prognostic score for basilar artery occlusion. Stroke 2017;48:631-637.
63. Kwak HS, Park JS. Mechanical thrombectomy in basilar artery occlusion: clinical outcomes related to posterior circulation collateral score. Stroke 2020;51:2045-2050.
64. Alemseged F, Van der Hoeven E, Di Giuliano F, Shah D, Sallustio F, Arba F, et al. Response to late-window endovascular revascularization is associated with collateral status in basilar artery occlusion. Stroke 2019;50:1415-1422.
65. van Houwelingen RC, Luijckx GJ, Mazuri A, Bokkers RP, Eshghi OS, Uyttenboogaard M. Safety and outcome of intra-arterial treatment for basilar artery occlusion. JAMA Neurol 2016;73:1225-1230.
66. Yang H, Ma N, Liu L, Gao F, Mo D, Miao Z. The basilar artery on computed tomography angiography score for acute basilar artery occlusion treated with mechanical thrombectomy. *J Stroke Cerebrovasc Dis* 2018;27:1570-1574.

67. Kim YW, Hong JM, Park DG, Choi JW, Kang DH, Kim YS, et al. Effect of intracranial atherosclerotic disease on endovascular treatment for patients with acute vertebrobasilar occlusion. *AJNR Am J Neuroradiol* 2016;37:2072-2078.

68. Lee JS, Lee SJ, Yoo JS, Hong JH, Kim CH, Kim YW, et al. Prognosis of acute intracranial atherosclerosis-related occlusion after endovascular treatment. *J Stroke* 2018;20:394-403.

69. Romero JR, Pikula A, Nguyen TN, Nien YL, Norbash A, Babikian VL. Cerebral collateral circulation in carotid artery disease. *Curr Cardiol Rev* 2009;5:279-288.

70. Cross DT 3rd, Moran CJ, Akins PT, Angtuaco EE, Derdeyn CP, Diringer MN. Collateral circulation and outcome after basilar artery thrombolysis. *AJNR Am J Neuroradiol* 1998;19:1557-1563.

71. Maus V, Kalkan A, Kabbasch C, Abdullayev N, Stetefeld H, Barnikol UB, et al. Mechanical thrombectomy in basilar artery occlusion: presence of bilateral posterior communicating arteries is a predictor of favorable clinical outcome. *Clin Neuroradiol* 2019;29:153-160.

72. Hong JM, Choi JY, Lee JH, Yong SW, Bang OY, Joo IS, et al. Impact of posterior communicating artery on basilar artery steno-occlusive disease. *J Neurol Neurosurg Psychiatry* 2009;80:1390-1393.

73. Lee SJ, Hong JM, Choi JW, Kang DH, Kim YW, Kim YS, et al. CTA-based truncal-type occlusion is best matched with postprocedural fixed focal stenosis in vertebrobasilar occlusions. *Front Neurol* 2019;9:1195.

74. Ahn SH, Kim BJ, Kim YJ, Kang DW, Kwon SU, Kim JS. Patterns and outcomes of the top of the basilar artery syndrome: the role of the posterior communicating artery. *Cerebrovasc Dis* 2018;46:108-117.

75. Kim BM, Bae JH, Heo JH, Nam HS, Kim YD, Yoo J, et al. Collateral status affects the onset-to-reperfusion time window for good outcome. *J Neurol Neurosurg Psychiatry* 2018;89:903-909.

76. Campbell BCV, Majoie C, Albers GW, Menon BK, Yassi N, Sharma G, et al. Penumbra imaging and functional outcome in patients with anterior circulation ischaemic stroke treated with endovascular thrombectomy versus medical therapy: a meta-analysis of individual patient-level data. *Lancet Neurol* 2019;18:46-55.

77. Jahan R, Saver JL, Schwamm LH, Fonarow GC, Liang L, Matsouaka RA, et al. Association between time to treatment with endovascular reperfusion therapy and outcomes in patients with acute ischemic stroke treated in clinical practice. *JAMA* 2019;322:252-263.

78. Joundi RA, Sun JL, Xian Y, Alhanti B, Nogueira RG, Bhatt DL, et al. Association between endovascular therapy time to treatment and outcomes in patients with basilar artery occlusion. *Circulation* 2022;145:896-905.

79. Albers GW. Late window paradox. *Stroke* 2018;49:768-771.

80. Ravindren J, Aguilar Pérez M, Hellstern V, Bhogal P, Bäzner H, Henkes H. Predictors of outcome after endovascular thrombectomy in acute basilar artery occlusion and the 6hr time window to recanalization. *Front Neurol* 2019;10:923.

81. Dávalos A, Blanco M, Pedraza S, Leira R, Castellanos M, Pumar JM, et al. The clinical-DWI mismatch: a new diagnostic approach to the brain tissue at risk of infarction. *Neurology* 2004;62:2187-2192.

82. Nogueira RG, Kemmling A, Souza LM, Payabvash S, Hirsch JA, Yoo AJ, et al. Clinical diffusion mismatch better discriminates infarct growth than mean transit time-diffusion weighted imaging mismatch in patients with middle cerebral artery–M1 occlusion and limited infarct core. *J Neurointerv Surg* 2017;9:127-130.

83. Tajima Y, Hayasaka M, Ebihara K, Yokoyama D, Suda I. Predictors of very poor outcome after mechanical thrombectomy for acute basilar artery occlusion. *Neur Med Chir (Toyo)* 2020;60:507-513.

84. Jadhav AP, Desai SM, Panczykowski DM, Rangaraju S, Campbell D, Ritvonen JK, et al. Predicting outcomes after acute reperfusion therapy for basilar artery occlusion. *Eur J Neurol* 2020;27:2176-2184.

85. Sang H, Li F, Yuan J, Liu S, Luo W, Wen C, et al. Values of baseline posterior circulation acute stroke prognosis early computed tomography score for treatment decision of acute basilar artery occlusion. *Stroke* 2021;52:811-820.

86. Koh S, Park JH, Park B, Choi MH, Lee SE, Lee JS, et al. Prediction of infarct growth and neurological deterioration in patients with vertebrobasilar artery occlusions. *J Clin Med* 2020;9:3759.

87. Alemseged F, Shah DG, Bivard A, Kleinig TJ, Yassi N, Diomedi M, et al. Cerebral blood volume lesion extent predicts functional outcome in patients with vertebral and basilar artery occlusion. *Int J Stroke* 2019;14:540-547.

88. Fabritius MP, Tiedt S, Puhr-Westerheide D, Grosu S, Maurus S, Schwarze V, et al. Computed tomography perfusion deficit volumes predict functional outcome in patients with basilar artery occlusion. *Stroke* 2021;52:2016-2023.

89. Cereda CW, Bianco G, Mlynash M, Yuen N, Qureshi AH, Hinduja A, et al. Perfusion imaging predicts favorable outcomes after basilar artery thrombectomy. *Ann Neurol* 2022;91:23-
32. Desai SM, Tonetti DA, Jovin TG, Jadhav AP. Fast and slow progres-
sors of infarct growth in basilar artery occlusion strokes. J Neu-
rointerv Surg 2022;14:nеви. neurintsurg-2021-017394.

90. Laperegue B, Blanc R, Gory B, Labreuche J, Duhamel A, Mar-
nat G, et al. Effect of endovascular contact aspiration vs stent retriever on revascularization in patients with acute ischemic stroke and large vessel occlusion: the ASTER random-
domized clinical trial. JAMA 2017;318:443-452.

92. Carneiro AA, Rodrigues JT, Pereira JP, Alves JV, Xavier JA. Me-
chanical thrombectomy in patients with acute basilar occlu-
sion using stent retrievers. Interv Neuroradiol 2015;21:710-
714.

93. Eom YI, Hwang YH, Hong JM, Choi JW, Lim YC, Kang DH, et al. Forced arterial suction thrombectomy with the penumbra reperfusion catheter in acute basilar artery occlusion: a ret-
rospective comparison study in 2 Korean university hospitals. AJNR Am J Neuroradiol 2014;35:2354-2359.

94. Patro SN, Iancu D. Dual-stent retrieval for mechanical thrombectomy of refractory clot in acute stroke as a rescue technique. CMAJ 2017;189:E634-E637.

95. Bernsen M, Bruggeman A, Brouwer J, Emmer BJ, Majoie C,

96. Aubertin M, Weisenburger-Lie D, Brouwer J, Emmer BJ, Majoie C, Coutinho JM, et al. Aspiration versus stent retriever thrombectomy for posterior circulation stroke. Stroke 2022;53:
749-757.

97. Xenos D, Texakalidis P, Karras CL, Murthy NK, Kontzialis M, Rivet DJ, et al. First-line stent retriever versus direct aspiration for acute basilar artery occlusions: a systematic review and meta-analysis. World Neurosurg 2022;158:258-267.e1.

98. Piechowiak EI, Kaeasmacher J, Zibold F, Dobrocky T, Mosimann PJ, Jung S, et al. Endovascular treatment of tandem occlusions in vertebrobasilar stroke: technical aspects and out-
come compared with isolated basilar artery occlusion. J Neurointerv Surg 2020;12:25-29.

99. Lee JS, Hong JM, Kim JS. Diagnostic and therapeutic strat-
egies for acute intracranial atherosclerosis-related occlusions. J Stroke 2017;19:143-151.

100. Boeckh-Behrens T, Pree D, Lummel N, Friedrich B, Maegerlein C, Kreiser K, et al. Vertebral artery patency and thrombecto-
my in basilar artery occlusions. Stroke 2019;50:389-395.

101. Lee YY, Yoon W, Kim SK, Baek BH, Kim GS, Kim JT, et al. Acute basilar artery occlusion: differences in characteristics and outcomes after endovascular therapy between patients with and without underlying severe atherosclerotic stenosis. AJNR Am J Neuroradiol 2017;38:1600-1604.

102. Cross DT 3rd, Moran CJ, Akins PT, Angtuaco EE, Diringer MN. Relationship between clot location and outcome after basilar artery thrombolysis. AJNR Am J Neuroradiol 1997;18:1221-
1228.

103. Eckert B, Kucinski T, Pfeiffer G, Groden C, Zeumer H. Endo-
vascular therapy of acute vertebrobasilar occlusion: early treatment onset as the most important factor. Cerebrovasc Dis 2002;14:42-50.

104. Baik SH, Park HJ, Kim JH, Jang CK, Kim BM, Kim DJ. Mechanical thrombectomy in subtypes of basilar artery occlusion: relationship to recanalization rate and clinical outcome. Radiology 2019;291:730-737.

105. Elhorany M, Boulouis G, Hassen WB, Crazier S, Shotar E, Sourour NA, et al. Outcome and recanalization rate of tan-
dem basilar artery occlusion treated by mechanical thrombectomy. J Neurointerv Surg 2020;47:404-409.

106. Lee YY, Yoon W, Kim SK, Baek BH, Kim GS, Kim JT, et al. Acute basilar artery occlusion: differences in characteristics and outcomes after endovascular therapy between patients with and without underlying severe atherosclerotic stenosis. AJNR Am J Neuroradiol 2017;38:1600-1604.

107. Elhorany M, Boulouis G, Hassen WB, Crazier S, Shotar E, Sourour NA, et al. Outcome and recanalization rate of tan-
dem basilar artery occlusion treated by mechanical thrombectomy. J Neurointerv Surg 2020;47:404-409.

108. Piechowiak EI, Kaeasmacher J, Zibold F, Dobrocky T, Mosimann PJ, Jung S, et al. Endovascular treatment of tandem occlusions in vertebrobasilar stroke: technical aspects and out-
come compared with isolated basilar artery occlusion. J Neurointerv Surg 2020;12:25-29.

109. Ecker RD, Tsujiura CA, Baker CB, Cushing D. Endovascular re-
construction of vertebral artery occlusion prior to basilar thrombectomy in a series of six patients presenting with acute symptomatic basilar thrombosis. J Neurointerv Surg 2014;6:379-383.

110. Lee DH, Sung JH, Kim SU, Yi HJ, Hong JT, Lee SW. Effective use of balloon guide catheters in reducing incidence of me-
chanical thrombectomy related distal embolization. Acta Neurochir (Wien) 2017;159:1671-1677.

111. Chung SY, Lee DH, Choi JW, Choi BS, In HS, Kim SM, et al. Use of self-expanding stents for the treatment of vertebral artery ostial stenosis: a single center experience. Korean J Radiol 2010;11:156-163.