Endovascular Treatment of Intracranial Aneurysms With Flow Diveters
A Meta-Analysis

Waleed Brinjikji, MD; Mohammad H. Murad, MD, MPH; Giuseppe Lanzino, MD; Harry J. Cloft, MD, PhD; David F. Kallmes, MD

Background and Purpose—Flow diverters are important tools in the treatment of intracranial aneurysms. However, their impact on aneurysmal occlusion rates, morbidity, mortality, and complication rates is not fully examined.

Methods—We conducted a systematic review of the literature searching multiple databases for reports on the treatment of intracranial aneurysms with flow-diverter devices. Random effects meta-analysis was used to pool outcomes of aneurysmal occlusion rates at 6 months, and procedure-related morbidity, mortality, and complications across studies.

Results—A total of 29 studies were included in this analysis, including 1451 patients with 1654 aneurysms. Aneurysmal complete occlusion rate was 76% (95% confidence interval [CI], 70%–81%). Procedure-related morbidity and mortality were 5% (95% CI, 4%–7%) and 4% (95% CI, 3%–6%), respectively. The rate of postoperative subarachnoid hemorrhage was 3% (95% CI, 2%–4%). Intraparenchymal hemorrhage rate was 3% (95% CI, 2%–4%). Perforator infarction rate was 3% (95% CI, 1%–5%), with significantly lower odds of perforator infarction among patients with anterior circulation aneurysms compared with those with posterior circulation aneurysms (odds ratio, 0.15; 95% CI, 0.08–0.27; P<0.0001).

Ischemic stroke rate was 6% (95% CI, 4%–9%), with significantly lower odds of perforator infarction among patients with anterior circulation aneurysms compared with those with posterior circulation aneurysms (odds ratio, 0.15; 95% CI, 0.08–0.27; P<0.0001).

Conclusions—This meta-analysis suggests that treatment of intracranial aneurysms with flow-diverter devices is feasible and effective with high complete occlusion rates. However, the risk of procedure-related morbidity and mortality is not negligible. Patients with posterior circulation aneurysms are at higher risk of ischemic stroke, particularly perforator infarction. These findings should be considered when considering the best therapeutic option for intracranial aneurysms. (Stroke. 2013;44:442-447.)

Key Words: endovascular treatment ■ interventional neuroradiology ■ intracranial aneurysm ■ subarachnoid hemorrhage

Flow-diverter devices are new, important tools in the treatment of intracranial aneurysms.1 Several single- and multicenter studies have demonstrated acceptable rates of aneurysm occlusion, morbidity, and mortality for patients treated with flow diverters.2-20 These devices are being deployed in greater numbers of patients with more complex aneurysm morphologies and locations.9,12,18,22,25,29 With increasing experience, some of the limitations and unexpected complications of flow diverters have been recognized. These include intraparenchymal hemorrhage (IPH), postprocedural subarachnoid hemorrhage (SAH), as well as ischemic stroke.8

Improved understanding of safety and efficacy profiles associated with flow-diverter treatment of intracranial aneurysms would help guide practitioners in selection and follow-up of patients treated with these devices. We conducted a systematic review and meta-analysis of the literature regarding aneurysmal occlusion rates and procedure-related complication rates for intracranial aneurysms treated with flow diverters.

Methods

A comprehensive review of the literature was performed using the keywords “Intracranial aneurysm”, “divert”, “diversion”, “silk”, “pipeline,” and “pipeline embolization device” to search Pubmed, Ovid Medline, Ovid EMBASE, Scopus, and Web of Science database. Inclusion criteria were the following: English language, >5 patients, studies published between January 2005 and September 2012, and data on postoperative complications and aneurysmal occlusion rates. The exclusion criteria were the following: case reports, in vitro or cadaveric studies, review articles, guidelines, technical notes, and disaster series (series in which all patients were selected because of certain major complication).

The electronic search was supplemented by contacting experts in the field and reviewing the bibliographies of included studies for relevant publications. Abstracts, methods, results, figures, and tables

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of full text were searched for data on aneurysmal occlusion rates, procedure-related morbidity and mortality, and procedure-related complications.

Aneurysm occlusion was defined as complete occlusion at 6 months. We studied the effect of aneurysm size and aneurysmal occlusion rates, stratifying aneurysms as small (<10 mm), large (10 mm ≤ aneurysm size ≤ 25 mm), or giant (>25 mm).

Procedure-related complications were stratified as total, early (within ≤ 30 days), and late (≥ 30 days). Complications studied included total, early, and late ICH; total, early, and late ischemic stroke; total perforator infarction; and total, early, and late SAH. We examined the association between aneurysm size (small versus large/giant) and aneurysm location (anterior versus posterior) and the total rates of each of the studied complications.

### Statistical Analysis

We estimated from each study the cumulative incidence (event rate) and 95% confidence interval (CI) for each outcome. Event rates were pooled across studies using random effects meta-analysis.31 Subgroup interactions (ANCOVA) were conducted using an interaction test as described by Altman.32 Heterogeneity across studies was evaluated using the F statistic.33

### Results

#### Study Selection

A total of 505 articles were retrieved, of which 29 met our inclusion criteria (Table 1). Eighteen studies were retrospective case series, and 11 were prospective single-arm studies. Twenty-six studies reported aneurysmal occlusion rates; 29 reported procedure-related morbidity, mortality, and complication rates; and 26 reported both. We included 1451 patients and 1654 treated aneurysms. The mean (±SD) number of patients and treated aneurysms per study were 50.0±59.4 and 57.0±69.9, respectively.

#### Study Outcomes

Complete occlusion rate was 76% (95% CI, 70%–81%) at 6 months. Complete occlusion rate was 80% (95% CI, 69%–88%) for small aneurysms, 74% (95% CI, 63%–83%) for large aneurysms, and 76% (95% CI, 53%–90.0%) for giant aneurysms (P=0.83).

Procedure-related permanent morbidity rate was 5% (95% CI, 4%–7%), and procedure-related mortality rate was 4% (95% CI, 3%–6%). ICH rate was 3% (95% CI, 2%–4%), with 3% (95% CI, 2%–4%) experiencing early ICH and 2% (95% CI, 1%–3%) experiencing late ICH. Aneurysm size and location were not significantly associated with ICH rate (OR, 0.43; 95% CI, 0.11–1.65; P=0.24 and OR, −1.73; 95% CI, 0.62–4.68, respectively; P=0.35).

SAH rate was 4% (95% CI, 3%–5%), with 3% (95% CI, 2%–5%) experiencing early SAH and 2% (95% CI, 1%–3%) experiencing late SAH. Patients with small aneurysms had a significantly lower rate of postoperative SAH (OR, 0.10; 95% CI, 0.02–0.42; P<0.0001). Aneurysm location was not associated with SAH rate (OR, 1.89; 95% CI, 0.43–8.21; P=0.55).

Total ischemic stroke rate was 6% (95% CI, 4%–9%), with 5% (95% CI, 3%–8%) experiencing early ischemic stroke and 3% (95% CI, 2%–4%) experiencing late ischemic stroke. Patients treated for smaller aneurysms had lower rates of ischemic stroke than their large/giant counterparts (OR, 0.26; 95% CI, 0.07–0.91; P=0.03). Patients treated for anterior circulation aneurysms also had significantly lower ischemic stroke rates than those treated for posterior circulation aneurysms (OR, 0.15; 95% CI, −0.08 to 0.27; P<0.0001). Perforator infarction rate was 3% (95% CI, 1%–5%). Patients with anterior circulation aneurysms had significantly lower perforator infarction rates than their posterior circulation counterparts (OR, 0.01; 95% CI, 0.00–0.08; P<0.0001). Aneurysm size was not associated with perforator infarction risk (OR, 0.33; 95% CI, 0.09–1.25; P=0.13).

Analyses of aneurysm occlusion, total ischemic stroke, and perforator infarction were associated with substantial heterogeneity (F ≥50%), suggesting unexplained differences in study populations and procedures. The remaining analyses had minimal heterogeneity.

Table 2 summarizes outcomes independent of aneurysm size and location. Table 3 summarizes clinical outcomes by aneurysm size and location.

#### Discussion

Our meta-analysis demonstrated high occlusion rates for aneurysms treated with flow diverters, irrespective of aneurysm size. However, we also demonstrated that the complications associated with flow diverter treatment are not negligible, with morbidity and mortality rates of 5% and 4%, respectively. The safety of flow diversion in small aneurysms was superior to that of large aneurysms, with the latter associated with higher rates of both ischemic infarction and SAH. Higher morbidity in larger aneurysms may relate to the technical challenges as well as the inherent instability of these lesions. We did not find any specific aneurysm type associated with higher rates of IPH but did find an alarmingly high association between perforator infarction and posterior location of intracranial aneurysms. These findings suggest that practitioners must be judicious in selecting candidates for flow-diverter therapy, especially for large or posterior circulation aneurysms.

Published aneurysmal complete occlusion rates are often variable, ranging anywhere from 55% to 95%.4,21 In combining aneurysmal occlusion rates from 29 studies, our meta-analysis provides more representative data on aneurysmal occlusion rates than any single study. Furthermore, in studying such a large sample, we had more power to detect differences in aneurysmal occlusion rates by size. This lends greater validity to our finding that aneurysmal occlusion rates were high regardless of size. This finding is extremely important because the current dogma in endovascular intracranial aneurysm treatment is that smaller aneurysms have better occlusion rates than larger aneurysms.34 The finding that even giant aneurysms have such high occlusion rates provides important implications for those looking to stem the rates of aneurysm recurrence among this population.

Among larger studies, mortality rates have ranged from 0% to 7%,22 whereas morbidity has ranged from 0% to 12%.2,33 Our meta-analysis provides more representative data on morbidity, mortality, and complication rates associated with flow-diverter treatment. Another advantage of this meta-analysis is its increased power to detect differences in complication rates.
### Table 1. Studies Included in Meta-Analysis

<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
<th>Journal</th>
<th>Year</th>
<th>Study Design</th>
<th>No. of Patients</th>
<th>Aneurysms Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barros Faria et al</td>
<td>The role of the pipeline embolization device for the treatment of dissecting intracranial aneurysms</td>
<td>American Journal of Neuroradiology</td>
<td>2011</td>
<td>Retrospective</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Briganti et al</td>
<td>Italian multicenter experience with flow-diverter devices for intracranial unruptured aneurysm treatment with periprocedural complications—a retrospective data analysis</td>
<td>Neuroradiology</td>
<td>2012</td>
<td>Retrospective</td>
<td>273</td>
<td>295</td>
</tr>
<tr>
<td>Byrne et al</td>
<td>Early experience in the treatment of intracranial aneurysms by endovascular flow diversion: a multicentre prospective study</td>
<td>PLoS ONE</td>
<td>2010</td>
<td>Prospective single-arm interventional cohort</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Chan et al</td>
<td>Pipeline embolization device for wide necked internal carotid artery aneurysms in a hospital in Hong Kong: preliminary experience</td>
<td>Hong Kong Medical Journal</td>
<td>2011</td>
<td>Retrospective</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Colby et al</td>
<td>Immediate procedural outcomes in 35 consecutive pipeline embolization cases: a single-center single-user experience</td>
<td>Journal of Neurointerventional Surgery</td>
<td>2012</td>
<td>Retrospective</td>
<td>34</td>
<td>41</td>
</tr>
<tr>
<td>Cruz et al</td>
<td>Delayed ipsilateral parenchymal hemorrhage following flow diversion for the treatment of anterior circulation aneurysms</td>
<td>American Journal of Neuroradiology</td>
<td>2012</td>
<td>Retrospective</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>Deutschmann et al</td>
<td>Long-term follow-up after treatment of intracranial aneurysms with the pipeline embolization device: results from a single center</td>
<td>American Journal of Neuroradiology</td>
<td>2012</td>
<td>Prospective single-arm interventional cohort</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Fischer et al</td>
<td>Pipeline embolization device for neurovascular reconstruction; initial experience in the treatment of 101 intracranial aneurysms and dissections</td>
<td>Neuroradiology</td>
<td>2011</td>
<td>Retrospective</td>
<td>88</td>
<td>101</td>
</tr>
<tr>
<td>Kulcsar et al</td>
<td>High-profile flow-diverter (silk) implantation in the basilar artery: efficacy in the treatment of aneurysms and the role of perforators</td>
<td>Stroke</td>
<td>2010</td>
<td>Retrospective</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Lubicz et al</td>
<td>Flow-diverter stent for the endovascular treatment of intracranial aneurysms: a prospective study in 29 patients with 34 aneurysms</td>
<td>Stroke</td>
<td>2010</td>
<td>Prospective single-arm interventional cohort</td>
<td>29</td>
<td>34</td>
</tr>
<tr>
<td>Lylyk et al</td>
<td>Curative endovascular reconstruction of cerebral aneurysms with the pipeline embolization device: the buenos aires experience</td>
<td>Neurosurgery</td>
<td>2009</td>
<td>Prospective single-arm interventional cohort</td>
<td>53</td>
<td>63</td>
</tr>
<tr>
<td>Maimon et al</td>
<td>Treatment of intracranial aneurysms with the SILK flow diverter: 2 years experience with 28 patients at a single center</td>
<td>Acta Neurochir</td>
<td>2012</td>
<td>Retrospective</td>
<td>28</td>
<td>32</td>
</tr>
</tbody>
</table>

(continued)
by aneurysm size and location, thus allowing practitioners to risk stratify potential patients.

One of the unanticipated and most feared complications of flow diverters is aneurysm rupture after treatment with these devices. The overall incidence of this complication is unknown, although it is thought to be low and critically related to the complexity of the treated aneurysm. Our meta-analysis suggests that SAH from delayed aneurysm rupture occurs in ≈4% of patients treated with flow diverters, with significantly higher rates among patients with large and giant aneurysms. Aneurysm rupture at ≥1 month postoperative was a relatively rare occurrence (2% of cases). Nonetheless, concerns regarding delayed rupture are so serious that Balt Extrusion issued a medical device alert instructing practitioners not to use the Silk flow diverter without coils owing to the potential for patient death.15 Our study emphasizes that postoperative SAH is a real and significant complication of flow-diverter patients, especially for those with large or giant aneurysms. It is not known at this point whether the practice of using endovascular coils in association with flow diverters in the treatment of larger aneurysms has resulted in a decreased incidence of this devastating complication.

IPH not associated with aneurysm rupture is another dreaded and poorly understood complication of flow-diverter treatment. Previous studies have reported rates ranging from 0% to 10% for this complication.2,4,8,19 We demonstrated a
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Table 2. Outcomes for Endovascular Treatment of Intracranial Aneurysms With Flow Diverters

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Rate</th>
<th>95% CI</th>
<th>P (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete aneurysmal occlusion ≥6 months</td>
<td>76.0</td>
<td>70.0–81.0</td>
<td>69.0</td>
</tr>
<tr>
<td>Procedure-related morbidity</td>
<td>5.0</td>
<td>4.0–7.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Procedure-related mortality</td>
<td>4.0</td>
<td>3.0–6.0</td>
<td>35.0</td>
</tr>
<tr>
<td>SAH ≤30 days</td>
<td>3.0</td>
<td>2.0–5.0</td>
<td>0.0</td>
</tr>
<tr>
<td>SAH &gt;30 days</td>
<td>2.0</td>
<td>1.0–3.0</td>
<td>0.0</td>
</tr>
<tr>
<td>SAH total</td>
<td>4.0</td>
<td>3.0–5.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Intraparenchymal hemorrhage ≤30 days</td>
<td>3.0</td>
<td>2.0–4.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Intraparenchymal hemorrhage &gt;30 days</td>
<td>2.0</td>
<td>1.0–2.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Intraparenchymal hemorrhage total</td>
<td>3.0</td>
<td>2.0–4.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Ischemic stroke ≤30 days</td>
<td>5.0</td>
<td>3.0–8.0</td>
<td>48.0</td>
</tr>
<tr>
<td>Ischemic stroke &gt;30 days</td>
<td>3.0</td>
<td>2.0–4.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Ischemic stroke total</td>
<td>6.0</td>
<td>4.0–9.0</td>
<td>56.0</td>
</tr>
<tr>
<td>Perforator infarction</td>
<td>3.0</td>
<td>1.0–5.0</td>
<td>60.0</td>
</tr>
</tbody>
</table>

CI indicates confidence interval; and SAH, subarachnoid hemorrhage.

3% rate of IPH among flow-diverter patients. The mechanism for IPH is unknown. Hemorrhagic transformation of ischemic stroke, hemodynamic alteration from flow-diverter placement, and dual antiplatelet therapy are proposed mechanisms.8 In our study, neither aneurysm size nor location was associated with IPH rate. All studies included both preoperative and postoperative dual antiplatelet therapy; thus, we could not examine any independent role this might play in IPH formation. Further studies are needed to determine the ultimate cause of IPH.

Ischemic stroke and perforator infarction are well-described complications of flow-diverter treatment.15,30 We demonstrated an ischemic stroke rate of 6%, with higher rates in posterior circulation aneurysms and large/giant aneurysms. Ischemic stroke is thought to result from thrombus formation along the stent wall, leading to stent occlusion, parent artery occlusion, or distal thromboembolic events.15,30 The higher rates of ischemic stroke among patients with large/giant aneurysms may be related to the fact that, these aneurysms likely required more flow-diverter devices to achieve successful occlusion and may have subject to longer operation times. Intraoperatively, acute thrombus formation can be mitigated by prompt injection of Abciximab.27 However, in the long term, it is difficult to reduce the risk of thromboembolic events associated with flow-diverter treatment.

Perforator infarction in our meta-analysis was not uncommon and often led to devastating consequences. Perforator vessels in the posterior circulation are at particularly high risk for infarction relative to those in the anterior circulation. This is likely because of the delicate perfusion and lack of collaterals to brain stem structures. Many case series of posterior circulation aneurysms treated with flow diverters have demonstrated this fact.12,21,25 Thus, given the relatively high rate of this complication and the devastating consequences of brain stem infarction, treatment of posterior circulation aneurysms in which perforator vessels could be involved should be performed only when absolutely necessary. When possible, deconstructive technique (parent vessel occlusion with flow

Table 3. Outcomes by Aneurysm Size and Location

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Odds Ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischemic stroke</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aneurysm size (small/large vs giant)</td>
<td>0.26</td>
<td>0.07–0.91</td>
</tr>
<tr>
<td>Aneurysm location (anterior vs posterior)</td>
<td>0.15</td>
<td>0.08–0.27</td>
</tr>
<tr>
<td>SAH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aneurysm size (small/large vs giant)</td>
<td>0.10</td>
<td>0.02–0.42</td>
</tr>
<tr>
<td>Aneurysm location (anterior vs posterior)</td>
<td>1.89</td>
<td>0.43–8.21</td>
</tr>
<tr>
<td>Perforator infarction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aneurysm size (small/large vs giant)</td>
<td>0.33</td>
<td>0.09–1.25</td>
</tr>
<tr>
<td>Aneurysm location (anterior vs posterior)</td>
<td>0.01</td>
<td>0.00–0.08</td>
</tr>
<tr>
<td>Intraparenchymal hemorrhage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aneurysm size (small/large vs giant)</td>
<td>0.43</td>
<td>0.11–1.65</td>
</tr>
<tr>
<td>Aneurysm location (anterior vs posterior)</td>
<td>0.48</td>
<td>0.17–1.35</td>
</tr>
</tbody>
</table>

CI indicates confidence interval; and SAH, subarachnoid hemorrhage.

*Denotes statistically significant results. Odds ratio <1.0 favors the characteristic mentioned first.

reversal) should be the first consideration for treatment of large or giant basilar artery aneurysms.

This study has various limitations. Ecological bias (ie, comparisons are made across studies and not within studies), presence of publication bias, and statistical heterogeneity are limitations that affect all meta-analyses. Our study also has limitations because of the methodologic limitations of included studies. A majority of the included studies were retrospective case series. No prospective studies included were randomized or included control groups. Many of the included studies had a small sample size and incomplete follow-up data. Because a majority of previously published studies did not stratify outcomes based on important variables, such as patient demographics, duration of antiplatelet therapy, aneurysm rupture status, aneurysm subtype (secular versus fusiform), number of devices deployed, use of concomitant coiling, and previous aneurysm treatment status, we were unable to control for these findings in our analysis. Efficacy of flow-diverter treatment in treating compressive symptoms was rarely reported in the included studies; thus, we were unable to determine the efficacy of flow diverters in treatment of these symptoms. Our findings represent a very wide spectrum of aneurysms and clinical presentations, and thus our findings cannot be applied to determine the risks and complications associated with treating individual patients or different subgroups of aneurysms with flow diverters. Given the heterogeneity of the patients and aneurysms in our study, our data cannot be used to compare the efficacy of flow-diverter technology versus treatments, such as coiling and clipping. Therefore, the overall quality of evidence (strength of inference) presented in this systematic review is considered to be low.

Conclusions

Our study suggests that treatment of intracranial aneurysms with flow-diverter devices is feasible and effective with high complete occlusion rates. The rates of procedure-related morbidity and mortality are not negligible. Patients with posterior circulation aneurysms are at higher risk of ischemic stroke, particularly perforator infarction, and patients with larger aneurysms are at increased risk of ischemic stroke.
and SAH. These findings should be considered when determining the best therapeutic option for intracranial aneurysms.

**Disclosures**

Dr Cloft was the site PI at enrolling site for SAPPHIRE (Stenting and Angioplasty with Protection in Patients and High Risk for Endarterectomy) registry sponsored by Cordis Endovascular, and Dr Kallmes received a grant, ev3-funding for clinical trials and preclinical research and has pending grants from Penumbra, MicroVention, Micrus, and Cordis. The other authors have no conflicts to report.

**References**

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Flow Diverter を用いた脳動脈瘤の血管内治療
メタアナリシス

Endovascular Treatment of Intracranial Aneurysms With Flow Diverters
A Meta-Analysis

Waleed Brinjikji, MD2; Mohammad H. Murad, MD, MPH3; Giuseppe Lanzino, MD2,4; Harry J. Cloft, MD, PhD1,2; David F. Kallmes, MD1,2

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背景および目的: Flow diverter は脳動脈瘤の治療において重要な器具である。しかし、動脈瘤閉塞率、罹病率、死亡率、および合併症の発生率に対する影響については完全には解明されていない。

方法: 個々のデータベースで flow diverter を用いた脳動脈瘤の治療に関する論文を検索した文献を系統的に調べた。ランダム効果メタ解析を用いて、6カ月目の動脈瘤閉塞率の転帰、手技が原因の罹病率、死亡率、および合併症の発生率をすべての論文から収集した。

結果: 合計29篇の論文を解析に含めた（患者は1,654箇の動脈瘤を有する1,451例）。動脈瘤の完全閉塞率は76%であった（95%信頼区間 [CI] : 70 ~ 81%）。手技が原因の罹病率は5%（95% CI: 4 ~ 7%）、死亡率は4%（95% CI: 3 ~ 6%）であった。術後のくも膜下出血発生率は3%（95% CI: 2 ~ 5%）、脳実質内出血の発生率は3%（95% CI: 2 ~ 4%）であった。穿通枝梗塞の発生率は3%（95% CI: 1 ~ 5%）であった。前方循環動脈瘤患者の穿通枝梗塞のオッズは、後方循環動脈瘤患者（オッズ比 = 0.01; 95% CI: 0.00 ~ 0.08; p < 0.0001）と比較して有意に低かった。虚血性脳卒中の発生率は6%（95% CI: 4 ~ 9%）であった。前方循環動脈瘤患者の穿通枝梗塞のオッズは、後方循環動脈瘤患者と比較して有意に低かった（オッズ比 = 0.15; 95% CI: 0.08 ~ 0.27; p < 0.0001）。

結論: 今回のメタアナリシスの結果、flow diverter を用いた脳動脈瘤の治療は可能で、かつ効果的であり、高い完全閉塞率を示した。しかし、手技が原因の罹病率や死亡率のリスクは無視することはできない。前方循環動脈瘤患者では虚血性脳卒中のリスクが高く、特に、穿通枝梗塞のリスクが高い。脳動脈瘤の最良の治療オプションを検討する際にはこれらの知見を考慮する必要がある。

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