Stent-assisted embolization of 100 middle cerebral artery aneurysms

Clinical article

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Object. The introduction of intracranial stents to aneurysm treatment allows endovascular repair of nearly all aneurysms, but the safety and durability of stent-assisted embolization of middle cerebral artery (MCA) aneurysms is unclear.

Methods. Ninety-one patients with 100 complex MCA aneurysms not amenable to simple coiling were treated with stent-assisted embolization as a first option. Technical and clinical results, initial follow-up imaging, and long-term annual MR angiography (MRA) were reviewed.

Results. Intracranial stents were successfully deployed in all 100 aneurysms. There was 1 case of significant neurological morbidity (1%) and 1 case of death (1%) related to treatment. Initial posttreatment angiography revealed complete occlusion of 48 aneurysms (48%), a residual neck in 21 (21%), and residual aneurysm filling in 31 (31%). Follow-up imaging performed in 85 (90.4%) of a possible 94 aneurysms showed complete occlusion of 77 aneurysms (90.6%), residual neck in 3 (3.5%), and residual filling in 5 (5.9%). Four aneurysms (4.7%) required retreatment. Long-term MRA follow-up revealed stability or progressive thrombosis in 47 (97.9%) of 48 aneurysms. In 11 patients Y-configuration stenting caused only 1 minor complication and provided durable occlusion in all cases.

Conclusions. Stent-assisted techniques increase the number of aneurysms that may be treated endovascularly and represent an acceptable alternative to craniotomy. Stents provided adequate vessel reconstruction, low complication rates, and good long-term occlusion.

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Key Words • aneurysm • endovascular • middle cerebral artery • stent • Y-configuration stent • vascular disorders • interventional neurosurgery

Abbreviations used in this paper: MCA = middle cerebral artery; MRA = MR angiography.
Stent embolization of MCA aneurysms

the safety, techniques, outcomes, and future role of endovascular aneurysm treatment at this anatomical site.

**Methods**

**Patient Population**

Ninety-one patients harboring 100 MCA aneurysms underwent stent-assisted aneurysm embolization performed by the senior author (D.K.L.) between October 2002 and June 2012. While all patients were given the options of open surgical or endovascular treatment, endovascular repair was recommended as the first option to patients presenting to the senior author. Informed written consent approved by the medical center's institutional review board was obtained for each patient in whom stenting was considered. If the aneurysm could not be safely managed with coil embolization alone, stent reconstruction was performed. Indications for stent placement included 1) aneurysm neck greater than 4 mm, 2) dome-to-neck ratio less than 2, 3) coil instability or parent vessel compromise during coiling, and 4) fusiform aneurysm morphology. Upcoming surgical procedures, particularly after aneurysm rupture, hematoma mass effect requiring surgical evacuation, and anatomical barriers to access were contraindications to stent-assisted aneurysm treatment.

Patient information, aneurysm details, and clinical course data were maintained in a database for future retrospective review. Patients ranged in age from 25 to 88 years (mean = 60.6 ± 12.9 years) at the time of treatment; patient and aneurysm characteristics are listed in Table 1. At our institution, embolization is performed in approximately 75% of unruptured and 65% of ruptured MCA aneurysms, of which stents are used in about 30% and less than 10% of cases, respectively.

**TABLE 1: Characteristics of 100 MCA aneurysms in 91 patients**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. of Aneurysms (n = 100)</th>
</tr>
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<tbody>
<tr>
<td>female (n = 73)</td>
<td>80</td>
</tr>
<tr>
<td>male (n = 18)</td>
<td>20</td>
</tr>
<tr>
<td>single MCA aneurysm</td>
<td>82</td>
</tr>
<tr>
<td>bilateral MCA aneurysms</td>
<td>12</td>
</tr>
<tr>
<td>multiple unilat MCA aneurysms</td>
<td>6</td>
</tr>
<tr>
<td>small aneurysm (&lt;10 mm)</td>
<td>37</td>
</tr>
<tr>
<td>wide neck (≥4 mm)</td>
<td>48</td>
</tr>
<tr>
<td>large aneurysm (≥10 mm)</td>
<td>12</td>
</tr>
<tr>
<td>giant aneurysm (≥25 mm)</td>
<td>3</td>
</tr>
<tr>
<td>previously clipped aneurysms</td>
<td>1</td>
</tr>
<tr>
<td>previously coiled aneurysms</td>
<td>4</td>
</tr>
<tr>
<td>previous rupture</td>
<td>11</td>
</tr>
<tr>
<td>acute*</td>
<td>5</td>
</tr>
<tr>
<td>subacute†</td>
<td>3</td>
</tr>
<tr>
<td>remote</td>
<td>3</td>
</tr>
</tbody>
</table>

* Acutely ruptured aneurysms were stented on first treatment.
† Subacutely ruptured aneurysms were coiled and subsequently stented during a short-term follow-up procedure.

**Stenting Procedures**

In addition to antiplatelet therapy, heparin was given to maintain an activated clotting time of greater than 250 seconds once the procedure began. In patients with ruptured aneurysms, heparin was given after the first coil was inserted. Heparin was not reversed following treatment unless postoperative CT revealed new bleeding.

Neuroform stents (Boston Scientific) were used in most patients; the open-cell design was preferred for the tight curves of the MCA complex. The closed-cell Enterprise stent (Cordis Neurovascular, Inc.) was frequently used in straighter segments or when a 0.027-inch-inner-diameter microcatheter could not navigate the distal branches. The Enterprise stent could also be partially deployed across the aneurysm during coiling. After coiling, a decision was made whether to fully deploy or remove the stent.17 Wingspan stents (Boston Scientific) were used in 2 patients. One had M 1 segment stenosis proximal to the aneurysm; the other had a dissecting aneurysm. Table 2 details the stents used in this series.

**Perioperative Antiplatelet Management**

When possible, patients took aspirin (325 mg) and clopidogrel (75 mg) daily for 5 days prior to expected stenting. Those unable to complete this regimen received a 600-mg load of clopidogrel prior to the procedure and began daily aspirin therapy. Point-of-care aspirin and P2Y12 assays (VerifyNow, Accumetrics) were routinely used beginning in 2005. In cases in which antiplatelet therapy was not therapeutic—that is, an aspirin reaction unit > 550 or P2Y12 reaction unit < 250 or < 30% inhibition—an intrarterial loading dose of 0.25 mg/kg abciximab (0.25 mg/kg) was given prior to stent placement, followed by a 12-hour infusion (0.125 µg/kg/min or 10 µg/min). Abciximab was also given if thrombus developed inside the stent or when patients had a new neurological deficit after treatment and a CT scan showing no intracerebral hemorrhage. Clopidogrel was reloaded after the procedure if P2Y12 inhibition was inadequate. All patients continued aspirin and clopidogrel therapy daily for 3 months. Patients with multiple stents remained on antiplatelet therapy until their 6-month angiography follow-up. An ischemic event or significant in-stent stenosis on follow-up imaging led to additional antiplatelet therapy on a case-by-case basis.

Eight patients in the series presented with acute subarachnoid hemorrhage presumably from rupture of the MCA aneurysm. Three of these aneurysms were coiled in the acute phase followed by a delayed stenting procedure for final aneurysm repair. These three patients were loaded with aspirin and clopidogrel in the usual fashion. Five patients with low-grade hemorrhages and without ventriculostomy were stented during the initial acute treatment. Unless a patient was already therapeutic on antiplatelet medication prior to their hemorrhage and procedure, no preoperative antiplatelet therapy was administered. A loading dose of abciximab was given as soon as the ruptured aneurysm was both coiled and stented. Following the procedure aspirin and clopidogrel were loaded and continued in similar fashion to unruptured aneurysm cases.
The overlapping or stent-in-stent technique was used to reinforce an existing stent or further cover the aneurysm neck. We used Y-configuration stenting as an option for bifurcations where both parent vessels could not be protected by a single stent (Fig. 1). In 2 patients, a single stent was placed over 2 distinct MCA aneurysms (Fig. 2).

**Postoperative Course**

Following treatment, nonenhanced CT scanning was performed in all cases to confirm stent and coil position and to confirm the absence of hemorrhage. Patients were admitted to the ICU overnight. Patients with unruptured aneurysms were discharged on postoperative Day 1 if possible. Patients with ruptured aneurysms or complications remained in the hospital as needed.

**Technical Results**

Stents were successfully placed in all patients; however, one Y-configuration stent deployment was abandoned due to movement of the first stent during attempted deployment of the second. The patient returned for successful staged Y-configuration stenting later. There were no intraoperative ruptures. Thrombus formation was detected inside the stent of 1 patient prior to the end of his aneurysm treatment. Abciximab was given, and the patient remained asymptomatic. Two treatments caused small vessel occlusion and transient symptoms, which were treated with abciximab and blood pressure augmentation.

In 4 cases, coils prolapsed despite stenting. In 3 of these cases a second overlapping stent was successfully deployed to plaster the coil to the vessel wall. In the fourth case, the coil stretched; it was successfully snared and subsequently released into the external carotid artery.

**Clinical Results**

Nine patients had new neurological symptoms following stent-assisted aneurysm treatment; all patients were given abciximab. Five of these patients had transient symptoms, including intermittent aphasia, contralateral weakness, and contralateral sensory symptoms, which resolved prior to discharge. Two of these patients had minor residual deficits at discharge including contralateral fingertip numbness and a subtle pronator drift on examination, but neither had long-term disability.

**Results**

Angiography was scheduled 6 months after treatment. In cases of significant or increased residual filling, a decision was made whether to retreat the aneurysm. Angiography was scheduled 6 months after repeat treatment in a similar fashion. If the aneurysm showed satisfactory occlusion, the patient was followed up with yearly clinic appointments and MRI and MRA. Both MRI and MRA with and without contrast with 3D time of flight were used to evaluate evidence of ischemia, in-stent stenosis, residual treated aneurysm, and de novo aneurysms.6,28

![Fig. 2. Left: Anteroposterior digital subtraction angiogram showing an M1 segment aneurysm treated with overlapping stents and coil embolization. Right: Magnetic resonance angiogram demonstrating new filling at the site of the aneurysm 3 years after treatment. This unusual case of either recurrence or adjacent de novo aneurysm formation was treated with coil embolization delivered through the struts of the existing stents.](image)

![Fig. 1. DynaCT (Siemens) oblique axial reconstructed scan showing Y-configuration stenting of an MCA aneurysm using Neuroform stents; the anterior communicating artery aneurysm is covered by a single Neuroform stent.](image)
gressive antiplatelet therapy, 1 patient developed contralateral hemiparesis and aphasia; symptoms improved, but the patient has permanent contralateral weakness. In 2 of the patients with persistent postoperative symptoms, MRI revealed corresponding restricted diffusion.

The ninth patient represented the single procedure-related death. This patient, who had HIV, hepatitis C virus, and required hemodialysis for kidney disease, had coil compaction 4 years after initial coil embolization. She was considered a poor candidate for surgical repair, and coiling without stenting did not seem adequate given the residual dome and neck widths of 8 mm and 6 mm, respectively. The residual aneurysm was coiled after overlapping Enterprise stents were placed. The patient experienced a new contralateral hemiparesis following treatment. The patient aspirated during an MRI 5 days after treatment and died after never regaining mental status. Table 3 provides a summary of neurological complications. Complications of subarachnoid hemorrhage and cancer caused 2 other patients to die before follow-up angiography could be undertaken.

The 98 patients living beyond 1 month after stent-assisted aneurysm treatment were followed up clinically for a mean 1.91 ± 1.84 years (range 1 month to 6.75 years). During the extended follow-up period, there were 4 transient events potentially related to aneurysm treatment, the latest of which occurred 27 months after treatment (Table 3).

During the follow-up period, 2 patients suffered intracranial hemorrhages. A de novo posterior communicating artery aneurysm ruptured in a patient 6 years after her MCA aneurysm was treated; she had not been compliant with her yearly imaging for 3 years prior to the event. A 75-year-old hypertensive, diabetic woman experienced an ipsilateral basal ganglia hemorrhage more than 1 year after her 6-mm MCA aneurysm repair; the relationship of these events is uncertain. To our knowledge, there have been no other adverse cerebrovascular events or deaths involving the patients in this series.

Three complications of femoral artery access caused morbidity but no permanent disability. Two patients developed significant retroperitoneal hematomas. The other patient required surgical thrombectomy for femoral artery thrombosis at the site of catheterization. One patient had significant epistaxis while on dual antiplatelet therapy. There were no complications from 5 retreatment procedures or 98 follow-up diagnostic angiograms.

**TABLE 3: Neurological complications**

<table>
<thead>
<tr>
<th>Complication</th>
<th>Total (%)</th>
</tr>
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<tbody>
<tr>
<td>transient deficits</td>
<td>6 (6)</td>
</tr>
<tr>
<td>minor permanent morbidity</td>
<td>2 (2)</td>
</tr>
<tr>
<td>permanent morbidity</td>
<td>1 (1)</td>
</tr>
<tr>
<td>death</td>
<td>1 (1)</td>
</tr>
<tr>
<td>late events</td>
<td></td>
</tr>
<tr>
<td>transient ischemic events</td>
<td>4 (4.1)</td>
</tr>
<tr>
<td>ipsilateral intracerebral hemorrhage</td>
<td>1 (1.0)</td>
</tr>
<tr>
<td>permanent morbidity/mortality</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

**Radiographic Results**

Initial follow-up imaging, usually after 6 months, was performed in 85 (90.4%) of 94 possible aneurysms (Table 4). Three patients died and 3 were treated too recently for appropriate follow-up. While only 42 of the initial 100 procedures resulted in complete occlusion, 77 (90.6%) of 85 aneurysms were completely occluded at follow-up. Four aneurysms worsened angiographically, and 4 (4.7%) required retreatment after first follow-up.

In 85 aneurysms with imaging follow-up, 8 stents (9.4%) had angiographically demonstrable in-stent stenosis. Five were visualized on 6-month follow-up angiography; 3 additional in-stent stenoses were demonstrated on MRA. One M1 segment was completely occluded with distal reconstitution of blood flow. Only 1 other stenosis was greater than 50%, and none was symptomatic.

The mean duration of imaging follow-up for these 85 aneurysms was 2.14 ± 1.88 years (range 4 months to 6.75 years). Subsequent follow-up imaging greater than 1 year after treatment has been performed in 48 (56.5%) of 85 at this juncture. Eight aneurysms showed residual filling less than 3 mm on MRA but have remained stable and not needed treatment. One small aneurysm treated with overlapping stents and coils was completely occluded on initial and 6-month angiography, but MRA 3 years after treatment showed new residual filling adjacent to the aneurysm. This was considered a recurrence but may actually represent an unusual de novo aneurysm formed adjacent to a previously treated aneurysm within the stented segment (Fig. 2).

**Overlapping and Y-Configuration Stents**

Overlapping stents were placed in 7 patients; 3 of these patients had neurological complications including the aforementioned case in which death occurred. Except for the late regrowth described above, these aneurysms remained completely occluded.

Eleven patients underwent aneurysm coiling with a Y-configuration stent. Transient contralateral upper-extremity weakness complicated 1 case, but the permanent operative morbidity and mortality rates were 0% for this subgroup. All aneurysms treated with a Y-shaped stent configuration had total occlusion on follow-up angiography; none required retreatment during the follow-up period.

**Discussion**

Stent-assisted aneurysm treatment has broadened the range of aneurysms accessible to the neurointerventionalist. The early aneurysm-stenting literature provides a relative paucity of MCA treatment, as distal aneurysms including MCA and pericallosal locations have historically been clipped more frequently than they have been treated endovascularly. However, the complex anatomy of the MCA may be particularly amenable to stent reconstruction. Our series of 100 aneurysms demonstrated 90.6% occlusion on first follow-up imaging; major morbidity and mortality rates were 1.0% each.

Vendrell et al.26 successfully deployed 50 stents, attempting to treat 52 MCA aneurysms in 49 patients.
Ten total perioperative thromboembolic events resulted in permanent neurological deficits in 2 patients despite treatment with abciximab, yielding a morbidity rate of 3.8% and a mortality rate of 0% in their series. Yang et al. treated 16 MCA aneurysms with stents without permanent procedure-related neurological sequelae. Fields et al. described the successful treatment of 22 aneurysms with 2 neurological complications.

Brinjikji et al. presented the composite endovascular results for MCA aneurysms in the prestenting era. Meta-analysis of 12 MCA aneurysm coiling series revealed an overall morbidity and mortality rate of 5.5% in 1030 aneurysm treatments. Only 4 stents were included in these data. For more appropriate comparison with our results, the combined morbidity and mortality rate for unruptured aneurysms was 5.1%.

Horowitz et al. cited 6 surgical series of MCA aneurysm treatments published in the last 30 years, demonstrating a combined morbidity and mortality rate of 10%, and a range of 3%–16%. However, direct comparison of endovascular and open surgical repair is not straightforward. Surgical series did not have the luxury of excluding unfavorable aneurysms prior to the advent of endovascular therapy, and endovascular series success rates may be overestimated secondary to selection bias. Every aneurysm carries different risks based on its architecture, anatomy of the MCA and treatment of aneurysms, many of which were previously untreatable with endovascular techniques. Stent-assisted embolization provides an alternative to craniotomy for these aneurysms, with an acceptable complication rate and high angiographic cure rate.

Our series demonstrated a trend of progressive thrombosis after aneurysm treatment and durability after stable follow-up imaging. Six-month angiography revealed an increase in complete occlusion from 48% to 90.6%, while only 5 aneurysms required retreatment. One of these retreatments was needed because MRA showed new filling at 3 years, but in 47 (97.9%) of 48 patients, annual MRA revealed aneurysm stability or progressive thrombosis. There were no posttreatment ruptures during the follow-up period. The observed long-term stability of the treatment speaks to the anatomical and physiological strength of the stent and coil construct.

Limitations to the present study include but are not limited to selection bias, lack of an adequate control group, and nonblinded review of angiograms. Referral patterns may have led to a preselected aneurysm population more favorable to endovascular treatment. Because open surgical management is frequently chosen for MCA aneurysms, the population of MCA aneurysms referred to the senior author (D.K.L.) may be particularly amenable to stent-assisted embolization. A control group with matching characteristics is not feasible, and historical control group comparison is limited by differences in patient selection and study protocol.

The use of Y-shaped stenting may increase thromboembolic risks due to intraluminal struts and altered stent strut apposition, but the method can provide excellent aneurysm repair, even in the absence of intrasaccular therapy. The success in our experience with Y-configuration stenting in all locations is similar to that of Spiotta et al., showing increased complications but satisfactory angiographic outcomes with the technique. In this series, the low morbidity rate with Y-configuration stenting at the MCA bifurcation may be a function of small sample size. Otherwise, the success could be related to specific anatomical features of the MCA bifurcation including the large caliber of the M1 and M2 segments or the location distal to the circle of Willis.

### Conclusions

Intracranial stents allow reconstruction of the complex anatomy of the MCA and treatment of aneurysms, many of which were previously untreatable with endovascular techniques. Stent-assisted embolization provides an alternative to craniotomy for these aneurysms, with an acceptable complication rate and high angiographic cure rate.

### Disclosure

Demetrius Lopes discloses that he has financial and research relationships with Penumbra, Covidien, and Stryker. Drs. Johnson and Heiferman report no financial disclosures.

Author contributions to the study and manuscript preparation include the following. Conception and design: Lopes, Johnson. Acquisition of data: all authors. Analysis and interpretation of data: Lopes, Johnson. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Statistical analysis: Johnson. Administrative/technical/material support: Lopes. Study supervision: Lopes.

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