Background and Purpose—Stent-assisted coiling has expanded the treatment of intracranial aneurysms, but the rates of procedure-related neurological complications and the incidence of angiographic aneurysm recurrence of this novel treatment are not yet well known. We present our experience with stent-assisted coiling with special emphasis on procedure-related neurological complications and incidence of angiographic recurrence.

Methods—Clinical and angiographic outcomes of 1137 consecutive patients (1325 aneurysms) coiled with and without stent-assisted coating technique from January 2002 to January 2009 were retrospectively analyzed.

Results—There were 1109 aneurysms (83.5%) treated without and 216 (16.5%) treated with stents (15 of 216; 6.9% balloon-expandable versus 201 of 216; 93.1% self-expandable stents). Stents were delivered after coiling in 55.1% (119 of 216) and before coiling in 44.9% (97 of 216) of the cases. Permanent neurological procedure-related complications occurred in 7.4% (16 of 216) of the procedures with stents versus 3.8% (42 of 1109) in the procedures without stents (logistic regression \(P=0.644;\) OR: 1.289; 95% CI: 0.439 to 3.779). Procedure-induced mortality occurred in 4.6% (10 of 216) of the procedures with stents versus 1.2% (13 of 1109) in the procedures without stents (logistic regression \(P=0.006;\) OR: 0.116; 95% CI: 0.025 to 0.531). A total of 52.7% (114 of 216) of aneurysms treated with stents have been followed so far versus 69.8% (774 of 1109) of aneurysms treated without stents, disclosing angiographic recurrence in 14.9% (17 of 114) versus 33.5% (259 of 774), respectively (Fisher exact test \(P<0.0001;\) OR: 0.3485; 95% CI: 0.2038 to 0.5960).

Conclusions—Stents were associated with a significant decrease of angiographic recurrences, but they were associated with more lethal complications compared with coiling without stents. (Stroke. 2010;41:110-115.)

Key Words: cerebral aneurysm ▪ embolization ▪ therapeutic

Recanalization remains a limitation of aneurysm coiling.\(^1\) The potential for successful treatment of intracranial aneurysms with stents is gradually recognized. At the beginning, stent-assisted coiling of intracranial aneurysms was proposed to treat fusiform or very wide neck aneurysms in which other surgical or endovascular treatment strategies were not deemed feasible.\(^2\)-\(^5\) With more experience, stenting has been used to treat smaller berry aneurysms. To date, only limited series of stented aneurysms have been published without a control group of aneurysms treated without the use of adjunctive stents.\(^3\)-\(^6\),\(^12\) Our objective was to compare the clinical and angiographic results of stent-assisted compared with aneurysm coiling with and without the use of adjunctive stent placement.

Materials and Methods

Patient Selection

Clinical and angiographic outcomes of 1137 consecutive patients (1325 aneurysms) coiled from January 2002 to January 2009 were retrospectively analyzed. Coiling was initiated at our institution in 1992, whereas stent-assisted was started in 2002. All patients were referred to us from other institutions for endovascular treatment.

Definition End Point

Aneurysms were saccular and dichotomized in sidewall versus bifurcation aneurysms depending on their respective locations.

Surgical Procedures

Coiling was performed under general anesthesia and full anticoagulation with heparin. Anticoagulation was aimed at keeping the activated clotting time at 2 to 3 times above the normal value (approximately 100 seconds) during catheterization and coil placement. In addition, in all patients with no history of subarachnoid hemorrhage within the previous 4 weeks, 250 mg aspirin was given intravenously. Heparin was discontinued after embolization in the majority of patients. Whenever stenting was anticipated, patients were given dual antiplatelet therapy preoperatively, which was continued for 6 months (75 to 150 mg clopidogrel, 250 mg aspirin daily). They were no strict exclusion criteria, but a massive subarachnoid hemorrhage requiring drainage was thought to be a contraindication to stenting.
Follow-Up Protocol

Angiographic images obtained immediately after endovascular treatment were compared with those obtained at each follow-up examination. The standard angiographic follow-up protocol consisted of a first angiographic follow-up performed 1 to 6 months after endovascular treatment and a second angiographic follow-up being performed 1 year after the first follow-up. A third angiographic follow-up was performed 2 years after the second follow-up. In case of angiographic recurrence and/or associated aneurysms left untreated, the follow-up was continued on a yearly basis.

Data Collection and Statistical Analysis

Patient’s age and gender, aneurysm location, and type of aneurysm (sidewall versus bifurcation), size, rupture status at presentation, degree of occlusion, use of balloon remodeling technique, use of stents, and neurological complications were noted. Aneurysm status (ruptured versus unruptured at presentation), aneurysm type, gender, and complication rates for subgroups of patients according to stent placement were evaluated for statistical significance using a Fisher exact test. Patient ages, sac and neck size of aneurysms treated with and without stents, and packing densities (the ratio between the volume of the inserted coils and the volume of the aneurysm) within the 2 subgroups were compared using the Mann-Whitney U test. A stepwise multivariate logistic regression analysis was performed to control for potential confounders in aneurysm characteristics and in the occurrence of complications. A single reader evaluated all angiograms. Aneurysm occlusion was classified as described by Roy. At follow-up, an aneurysm was considered recurrent if a previously totally occluded aneurysm had a partial recurrence of the neck and/or the sac. An aneurysm was considered remnant regrowth if a subtotally occluded aneurysm was found to have an increasing neck remnant or residual aneurysm. Aneurysm dimensions were determined on 3-dimensional images derived from rotational angiography. The same reader reviewed follow-up angiograms, and aneurysm recurrence was dichotomized as absent or present. Univariate analysis was performed to evaluate the effect of stenting on recurrence. Recurrence rates for subgroups according to aneurysm sizes (with 10 mm chosen as a threshold) and types (sidewall versus bifurcation aneurysms) and aneurysm status at presentation (ruptured versus unruptured) were evaluated for statistical significance with the Fisher exact test. Finally, a stepwise logistic regression analysis was performed to determine the factors associated with angiographic recurrence. A probability value of <0.05 was considered statistically significant. Statistical tests were performed with SAS Release 8.2 (SAS Institute Inc, Cary, NC).

Results

Aneurysms Treated

Aneurysms treated with stents included aneurysms in the internal carotid artery (56.9% [123 of 216]), middle cerebral artery (16.2% [35 of 216]), vertebral or basilar artery (14.8% [32 of 216]), anterior communicating artery (10.2% [22 of 216]), posterior cerebral artery (1.4% [3 of 216]), and pericallosal artery (0.5% [one of 216]; Figure). Stents were delivered after coiling in 55.1% (119 of 216), including a subgroup of 8.3% (18 of 216) of bailed-out stenting to prevent parent vessel closure from coil protrusion into the parent artery with the idea of promoting flow diversion. Stents were delivered before coiling in 44.9% (97 of 216) in cases of wide neck aneurysms to permit or facilitate coiling by neck scaffolding. In the latter group, 9 aneurysms were treated using the stent-jack technique. It consisted of positioning the coil delivery microcatheter first into the aneurysm sac and then navigating a self-expandable stent into the parent vessel without delivering the stent before the first coil was deposited in the sac. The first coil was placed into the sac (no matter if a coil loop was slightly protruding into the arterial lumen) with coil deployment aiming at forming the most homogenous framing of the aneurysm sac. As a next step, before coil detachment, the stent was carefully deployed across the neck. Once the stent was delivered, the first coil was detached. If necessary, additional coils were introduced into the aneurysm to obtain circulatory exclusion of the lesion. Five aneurysms were treated with the jailed catheter technique. Fifteen aneurysms (6.9% [15 of 216]) were treated with balloon-expandable stents (a subgroup of early treated patients) and 201 (93.1% [201 of 216]) with self-expandable stents. Seven aneurysms in 7 patients were recently treated with self-expandable flow-diverting-type stents (pipeline and silk stents) and coils. Seven aneurysms in 7 patients were treated using 2 stents with the “Y” stenting technique (3 middle cerebral artery, 2 basilar tip, and one anterior communicating artery aneurysms). Of the 584 ruptured aneurysms, 35 (6%) were treated with stent-assisted coiling. All but one of these 35 patients was World Federation
of Neurological Surgeons Grade 1; the remaining patient was in World Federation of Neurological Surgeons Grade 3. In the no-stent group, 659 of 1109 (59.4%) aneurysms were coiled with the balloon remodelling technique with a mean packing density of 28% versus 29% for the 450 aneurysms treated without balloon remodelling (Mann-Whitney U test, \( P = 0.0457 \)). In the stent group, 127 of 216 (58.8%) aneurysms were coiled with the balloon remodelling technique with a mean packing density of 27% versus 24% for the 89 aneurysms treated without balloon remodelling (Mann-Whitney U test, \( P = 0.1366 \)).

### Immediate Angiographic Results

In the no-stent group, 63.5% (704 of 1109) of the aneurysms were totally occluded, 18.2% (202 of 1109) had a neck remnant, and 18.3% (203 of 1109) had a sac remnant. In the stent group, 46.3% (100 of 216) of the aneurysms were totally occluded, 19.0% (41 of 216) had a neck remnant, and 34.7% (75 of 216) had a sac remnant.

### Treatment-Related Complications

Within the stent group, permanent neurological complications occurred in 7.4% (16 of 216) of the procedures versus 3.8% (42 of 1109) in procedures without stents (\( P = 0.027 \); Table 1). In procedures with stents, mortality occurred in 6.0% (13 of 216) versus 1.2% (13 of 1109) in procedures without stents (\( P = 0.002 \)). In the multivariate analysis, mortality was significantly higher in the group of aneurysms treated with stents (\( P = 0.006 \)), whereas the overall rate of permanent neurological complications was not found to be significantly higher (\( P = 0.644 \)). In the multivariate analysis, ruptured aneurysms and stent placement were found to increase the risk of procedure-related complications (Table 2). The Leo stent had a 14.8% rate of thrombotic complications (11.1% of mortality; Table 3). In the procedures without stents, 6 patients experienced delayed ischemic complications (1 to 45 days after the procedure), 5 in patients treated with surface-modified coils (Matrix; Boston Scientific, Natick, Mass) and one patient treated with bare platinum coils. In the group of patients treated with stents, 2 had delayed ischemic complications in keeping with in-stent thrombus formation; one at Day 8 (Neuroform) resulted in a mild but permanent neurological deficit and the other at Day 45 (Enterprise) after stent implantation had a large ischemic stroke that led to the patient’s death.

### (Re)bleeding

Of the 549 ruptured aneurysms treated without stents, 13 (2.4%) rebled after coiling. One of the 35 (2.8%) ruptured aneurysms treated with a stent rebled after coiling. Of the 560 aneurysms without hemorrhagic presentation treated without a stent, one (0.2%) bled after coiling. One of the 181 (0.5%) unruptured aneurysms treated with a stent bled after coiling.

### Followed Aneurysms

Mean packing densities of stented and nonstented aneurysms were 26% and 29%, respectively. There was a significantly lower packing density in the group of stented aneurysms with balloon remodeling technique and a mean packing density of 28% versus 29% for the 450 aneurysms treated without balloon remodelling (Mann-Whitney U test, \( P = 0.027 \); Table 1).

### Table 1. Baseline Demographics

<table>
<thead>
<tr>
<th></th>
<th>Aneurysms (n=1325)</th>
<th>Logistic Regression (Wald ( \chi^2 ))</th>
<th>Fisher Exact Test ( P )</th>
<th>Mann-Whitney U Test ( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stented</td>
<td>Not Stented</td>
<td>( P )</td>
<td>OR 95% CI</td>
</tr>
<tr>
<td>Age, mean ( \pm ) SD (n)</td>
<td>51.1 ( \pm ) 12.0 (216)</td>
<td>49.7 ( \pm ) 12.8 (1109)</td>
<td>0.776</td>
<td>0.998</td>
</tr>
<tr>
<td>Gender, female/male</td>
<td>163/53</td>
<td>746/363</td>
<td>0.861</td>
<td>0.966</td>
</tr>
<tr>
<td>Complications</td>
<td>16/216</td>
<td>42/1109</td>
<td>0.644</td>
<td>1.289</td>
</tr>
<tr>
<td>Procedure-related death</td>
<td>10/216</td>
<td>13/1109</td>
<td>0.006*</td>
<td>0.116</td>
</tr>
<tr>
<td>Bifurcation/sidewall</td>
<td>79/137</td>
<td>771/338</td>
<td>(&lt;0.001*)</td>
<td>4.123</td>
</tr>
<tr>
<td>Aneurysm size, mm</td>
<td>9.3 ( \pm ) 5.7</td>
<td>7.1 ( \pm ) 4.0</td>
<td>(&lt;0.001*)</td>
<td>1.091</td>
</tr>
<tr>
<td>Neck size, mm</td>
<td>5.6 ( \pm ) 3.1</td>
<td>3.7 ( \pm ) 1.7</td>
<td>(&lt;0.001*)</td>
<td>0.621</td>
</tr>
<tr>
<td>Packing density, %</td>
<td>26.2 ( \pm ) 14.7</td>
<td>28.2 ( \pm ) 12.6</td>
<td>0.491</td>
<td>1.005</td>
</tr>
<tr>
<td>Aneurysm status, unruptured/ruptured</td>
<td>181/35</td>
<td>560/549</td>
<td>(&lt;0.001*)</td>
<td>3.435</td>
</tr>
</tbody>
</table>

*Significant values.

### Table 2. Logistic Regression Analysis for Complications

<table>
<thead>
<tr>
<th>Effect</th>
<th>Logistic Regression (Wald ( \chi^2 ))</th>
<th>Fisher Exact Test ( P )</th>
<th>Mann-Whitney U Test ( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>0.505</td>
<td>1.231</td>
<td>0.668–2.270</td>
</tr>
<tr>
<td>Age</td>
<td>0.599</td>
<td>0.994</td>
<td>0.973–1.016</td>
</tr>
<tr>
<td>Ruptured aneurysm</td>
<td>0.027*</td>
<td>0.508</td>
<td>0.279–0.925</td>
</tr>
<tr>
<td>Aneurysm size</td>
<td>0.662</td>
<td>0.984</td>
<td>0.916–1.058</td>
</tr>
<tr>
<td>Neck size</td>
<td>0.222</td>
<td>0.918</td>
<td>0.799–1.053</td>
</tr>
<tr>
<td>Sidewall aneurysm</td>
<td>0.831</td>
<td>0.937</td>
<td>0.513–1.709</td>
</tr>
<tr>
<td>Balloon remodeling</td>
<td>0.693</td>
<td>0.892</td>
<td>0.506–1.572</td>
</tr>
<tr>
<td>Use of stent</td>
<td>0.035*</td>
<td>0.464</td>
<td>0.227–0.949</td>
</tr>
</tbody>
</table>

*Significant values.
Aneurysms treated with self-expandable stents

<table>
<thead>
<tr>
<th>No. (%)</th>
<th>Complications (Procedures)</th>
<th>Mortality (Procedures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15/216 (6.9%)</td>
<td>4/15 (26.7%)</td>
<td>2/15 (13.3%)</td>
</tr>
</tbody>
</table>

One stent

- 171 (81.9%) 4/171 (2.3%) 0 (0.0%)
- 45 (21.1%) 1/45 (2.2%) 0 (0.0%)

Aneurysms treated with self-expandable stents

<table>
<thead>
<tr>
<th>No. (%)</th>
<th>Complications (Procedures)</th>
<th>Mortality (Procedures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>201 (93.1%)</td>
<td>12/201 (6.0%)</td>
<td>8/201 (4.0%)</td>
</tr>
</tbody>
</table>

One stent

- 137 (70.8%) 4/137 (2.9%) 0 (0.0%)
- 64 (29.2%) 0 (0.0%) 0 (0.0%)

2 stents

- 20 (9.7%) 0 (0.0%) 0 (0.0%)
- 30 (14.3%) 0 (0.0%) 0 (0.0%)

3 stents

- 3 (1.5%) 0 (0.0%) 0 (0.0%)

4 stents

- 1 (0.5%) 0 (0.0%) 0 (0.0%)

Delayed Aneurysm Occlusion

In the nonstented aneurysm group, 54.5% (158 of 290) of the aneurysms that were not completely occluded showed angiographic improvement at follow-up. Thirty-six (24.2%) of 149 aneurysms with persisting neck opacification after coiling were totally occluded at follow-up. Eighty-two (58.1%) of the aneurysms with persisting sac opacification were totally occluded at follow-up, whereas 40 (28.4%) harbored persistent neck opacification. In the stented aneurysm group, 72.6% (45 of 62) of the aneurysms that were not totally occluded showed angiographic improvement at follow-up. Fourteen (100%) of 14 aneurysms with persisting neck opacification after coiling were totally occluded at follow-up. Twenty-one (67.7%) of 31 aneurysms with persisting sac opacification were totally occluded at follow-up, whereas 10 (32.3%) harbored persistent neck opacification.

Recurrence Rates

There were significantly fewer recurrences in the stented aneurysm group (Fisher exact test, \( P < 0.0001 \)). In the group of small aneurysms (\(<10\) mm), the recurrence rate of nonstented aneurysms was 183 (28.8%) of 636. For stented aneurysms, the recurrence rate was 2 (2.9%) of 68 (Fisher exact test, \( P < 0.0001 \)). In the group of large aneurysms (\(\geq 10\) mm), the recurrence rate of not stented aneurysms was 76 (55.1%) of 138. For stented aneurysms, the recurrence rate was 15 of 46 (32.6%; Fisher exact test, \( P = 0.0105 \)). Stenting was beneficial in terms of angiographic stability for both sidewall (Fisher exact test, \( P = 0.0065 \)) and bifurcation aneurysms (Fisher exact test, \( P = 0.0109 \)) and for both ruptured (Fisher exact test, \( P = 0.0339 \)) and unruptured aneurysms (Fisher exact test, \( P = 0.0073 \)). Multivariate logistic regression analysis confirmed the positive effect of stenting regarding recurrence rates. A larger aneurysm sac and neck size, the younger the patient, a ruptured aneurysm, and longer follow-up were associated with an increased recurrence rate. The use of a balloon-remodeling technique did not interfere with recurrence rate. Initial total aneurysm occlusion was not associated with a lower risk of angiographic recurrence. Higher packing density had a positive effect against recurrence (Table 4).

Discussion

Stents were delivered after coiling in the majority of cases with the goal of diverting the flow and diminishing intra-aneurysmal flow and also by creating a mesh at the level of the neck to be colonized and covered by endothelial cells.

The potential for successful treatment of intracranial aneurysms by flow diversion is gradually being recognized in the clinical setting; however, the majority of stents currently available (the pipeline and the silk stents excepted) are not specifically designed for this so-called flow diversion. In our
series, only 4 aneurysms were treated with flow-diverter stents and coils.

Balloon-expandable stents were used early in this series of patients when self-expandable stents, with improved tractability, were not yet available. Sidewall aneurysms were overrepresented in the group of stented aneurysms. This is due to anatomic consideration, stents being designed originally to treat sidewall aneurysms. Stented aneurysms had a lower rate of immediate total circulatory exclusion but showed increased delayed occlusion between immediate control and the first follow-up angiogram. The fact that immediate total aneurysm occlusion was less frequent in the stented group can be explained by the fact that tight coiling is more difficult to obtain when the stent is implanted before coiling, giving less maneuverability to the coiling microcatheter and thus resulting in looser aneurysm packing. Previous published series have also reported a similar finding with a relatively low rate of immediate complete aneurysm occlusion with delayed sac thrombosis at follow-up.11,12 Moreover, the use of dual antiplatelet therapy during the procedure in addition to heparin did not favor immediate per-procedural sac thrombosis.

There were more procedure-related complications in the stented patients. The conjunction of the use of antiplatelet drugs and guidewire exchange maneuvers explained our overincidence of hemorrhagic complications and more specifically vessel perforations. The necessity of dual antiplatelet therapy in stent-assisted coil embolization is known to increase the risk of hemorrhagic complications.16 Thromboembolic complications were also more frequent in the stented patients. This finding was similar to previously reported series.17 Antiplatelet activity assessment before stent delivery has later diminished the occurrence of such complications in our practice by identifying the patients who do not respond to antiplatelet drugs.18 Within the stented patients, there were also more complications associated with the use of balloon-expandable stents, which are more traumatic for the arterial wall during navigation and delivery compared with the self-expandable stents.19 Permanent neurological deficits occurred in 7.4% of stented patients in our series, which is a higher rate compared with previously published series.3,4,7–10 However, our study included both balloon-expandable and self-expandable stents, the former type being responsible for increased morbidity. Our study also showed that complications occurring with stenting were more deleterious (with statistically increased mortality) than coiling without the use of stents.

Bleeding or rebleeding rates were similar in both groups of patients showing no influence of stenting. This might be due to the small number of ruptured aneurysms included in the study.

Larger aneurysms are known to recur more frequently.1 There were significantly less recurrences in the stented aneurysm group despite that this group included larger aneurysms with lower packing densities than the non-stented aneurysm group. This finding shows that the key factor to prevent aneurysm recurrence is, aside from the packing density of the sac, better arterial wall reconstruction at the level of the neck. However, the duration of follow-up was shorter for stented aneurysms due to the fact that the majority of the stents were implanted during the last 3 years, and the duration of follow-up is obviously a key factor known to influence angiographic recurrence rate.1 Nevertheless, the advantages of stenting in our series were most evident for small aneurysms; Fiorella et al reported a similar finding.6 although the effect of stenting was demonstrated also for larger aneurysms. There were statistically more recurrences in aneurysms that were initially totally occluded. This paradoxical finding is explained by the fact that many incomplete initial occlusions were later found to be completely occluded at follow-up, probably related to the discontinuation of heparin and antiplatelet drug, which allowed sac thrombosis. To avoid this bias, Raymond et al suggested taking into consideration the first 3 to 6 months follow-up angiogram as the actual initial result.1 Unfortunately, our series (with short follow-up in the subgroup of stented aneurysms) did not allow us to avoid this bias.

Table 4. Logistic Regression Analysis for Factors Affecting Angiographic Recurrence

<table>
<thead>
<tr>
<th>Effect</th>
<th>Logistic Regression (Wald χ²)</th>
<th>Fisher Exact Test</th>
<th>Mann-Whitney U Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>OR</td>
<td>95% CI</td>
</tr>
<tr>
<td>Stent</td>
<td>&lt;0.001*</td>
<td>4.554</td>
<td>2.223–9.331</td>
</tr>
<tr>
<td>Aneurysm size</td>
<td>&lt;0.001*</td>
<td>0.871</td>
<td>0.819–0.927</td>
</tr>
<tr>
<td>Neck size</td>
<td>0.039*</td>
<td>0.880</td>
<td>0.779–0.994</td>
</tr>
<tr>
<td>Gender</td>
<td>0.887</td>
<td>1.026</td>
<td>0.722–1.458</td>
</tr>
<tr>
<td>Age</td>
<td>0.006*</td>
<td>1.019</td>
<td>1.006–1.033</td>
</tr>
<tr>
<td>Balloon remodeling</td>
<td>0.068</td>
<td>1.378</td>
<td>0.977–1.944</td>
</tr>
<tr>
<td>Duration of follow-up</td>
<td>&lt;0.001*</td>
<td>0.980</td>
<td>0.970–0.989</td>
</tr>
<tr>
<td>Ruptured aneurysm</td>
<td>0.002*</td>
<td>0.572</td>
<td>0.404–0.811</td>
</tr>
<tr>
<td>Initial total angiographic occlusion</td>
<td>0.041*</td>
<td>1.264</td>
<td>1.010–1.582</td>
</tr>
<tr>
<td>Sidewall aneurysm</td>
<td>0.501</td>
<td>0.884</td>
<td>0.616–1.267</td>
</tr>
<tr>
<td>Packing density</td>
<td>0.012*</td>
<td>1.017</td>
<td>1.004–1.031</td>
</tr>
</tbody>
</table>

*Significant values.
Summary
Stents conferred a statistically significant decrease in the rate of angiographic recurrence. Longer follow-up is mandatory to draw more definitive conclusions. Improvement in stent technology is still warranted to diminish complications.

Acknowledgments
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Disclosures
None.

References
Stent-Assisted Coiling of Intracranial Aneurysms: Clinical and Angiographic Results in 216 Consecutive Aneurysms
Michel Piotin, Raphaël Blanc, Laurent Spelle, Charbel Mounayer, Rhelen Piantino, Paul J. Schmidt and Jacques Moret

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