Cerebral Aneurysm Sac Growth as the Etiology of Recurrence After Successful Coil Embolization

David M. Hasan, MD; Alexander I. Nadareyshvili, PhD; Anna L. Hoppe, BS; Kelly B. Mahaney, MD; David K. Kung, MD; Madhavan L. Raghavan, PhD

Background and Purpose—Coil compaction is thought to be the main mechanism for recurrence in cerebral aneurysms with previously successful coil embolization. We hypothesize that sac growth may be equally or more important. The objective was to study the relative roles of coil compaction and sac growth as explanations for aneurysm recurrence requiring retreatment in a study population using quantitative 3D image processing methods.

Methods—From July 2009 to December 2010, 175 aneurysms were coiled at the University of Iowa hospitals and clinics. Eight aneurysms had major recurrence requiring retreatment (4.4–12.1 months between procedures; mean: 7.2 months). The 3D structures of the vessel and coil mass were reconstructed using rotational angiography data scanned before and after both initial coil embolization and retreatment. Changes in the sac and coil mass over time were visualized using model registration techniques and quantified using volume calculations.

Results—All 8 of the coiled aneurysms with major recurrence had significant aneurysm sac growth (15% to 102% increase in volume), independent of change in coil volume. Five aneurysms with major recurrence had sufficient data for assessment of coil compaction. The coil mass volume decreased in 1 aneurysm (12% compaction by volume), did not change significantly in 1 aneurysm (increased by 1%), and significantly increased in 3 aneurysms (8%, 21%, and 25%) between the first treatment and before the second treatment.

Conclusions—In this study population, aneurysm sac growth, not coil compaction, was the primary mechanism associated with recurrence after initial coil embolization. (Stroke. 2012;43:866-868.)

Key Words: cerebral aneurysm • recurrence • image analysis • sac growth • coil compaction

Recurrence remains a considerable challenge after coil embolization of aneurysms. Recurrence rates of ≤34%, with major recurrence rates of ≤21%, have been reported.1-3 However, the mechanisms underlying recurrence are poorly understood. Although coil compaction remains the presumptive mechanism, evidence to support that premise is mostly observational and qualitative.4-6 On the other hand, sac growth is considered only peripherally as a mechanism for recurrence.7-9 We submit otherwise. Previous studies of aneurysm recurrence have been confined to qualitative observations from 2D angiographic data, which may not allow for accurate discrimination of aneurysm sac growth from coil compaction, because the coil mass may appear smaller in relation to an aneurysm sac that has grown. However, rigorous quantitative studies on the evolution of the aneurysm sac and/or coil mass are lacking. The objective of this study was to use rigorous 3D image processing methods to assess the association of coil compaction and sac growth with recurrence in a study population of intracranial aneurysm patients treated with endovascular coils.

Methods

Between July 2009 and December 2010, 175 intracranial aneurysm patients were treated with coil embolization at the University of Iowa hospitals and clinics. Eight patients presented with major recurrence at follow-up and were treated with additional coiling (4.4–12.1 months between procedures; mean: 7.2 months). The study was conducted using 3D rotational angiography data collected retrospectively from this cohort of 8 patients who had recurrence. Previous institutional review board approval (No. 201007774) was obtained. Fine-cut cross-sectional images of a 3D acquisition run (using syngoInPace 3D, Siemens) were obtained from study subjects at 4 time points (prefirst treatment, postfirst treatment, pressecond treatment, and postsecond treatment). The 3D models of aneurysm sac and branch vessels were reconstructed from the prefirst treatment 3D rotational angiography data by using a vessel segmentation algorithm within image processing utility, 3D Slicer. For the 3D reconstruction of the coil mass structure from the following 3 time points, the bone scan data were used because its clarity was significantly better than the subtracted angiographic data for the coil region. The branch vessels and residual regions within the sac were reconstructed from the subtracted angiographic data for the respective time points. The centerlines of reconstructed 3D models of the nondiseased vessels within each data set were used as landmarks for alignment of structures from all 4 of the time points within a given subject (ie,
some sensitivity does exist. Although results from the primary investigator’s calculations are presented above, those of the secondary investigator are similar for sac growth ($V_{SG}=213\pm192\;\text{mm}^3; \%V_{SG}=51\pm37\%; P=0.016; n=8$) and coil compaction ($V_{CG}=0.2\pm122\;\text{mm}^3; \%V_{CG}=8\pm16\%$; registration). Centerlines were computed using a module available within 3D Slicer that was developed based on a technique reported by Ford et al.\(^{10}\) The prefirst treatment aneurysm sac was then isolated from its contiguous vessels using a cutting plane subjectively chosen by adjudication with a clinical investigator. Because all of the models have been registered in 3D space, this same cutting plane was used to isolate the sac for the latter 3 time points as well. The volumes for the following structures were then computed: (1) aneurysm sac volume at initial presentation ($V_{SI}$) from prefirst treatment scan; (2) aneurysm sac volume at follow-up ($V_{SF}$) by summing the coil mass volume with its residual volume in the postsed treatment scan; (3) initial coil mass volume ($V_{CI}$) from the postfirst treatment scan; and (4) follow-up coil mass volume ($V_{CF}$) from the presed treatment scan. From these, the sac volume growth ($V_{SG}=V_{SF}-V_{SI}$), percentage of sac growth ($\%V_{SG}=V_{SG}/V_{SI}$), coil mass volume growth ($V_{CG}=V_{CF}-V_{CI}$), and percentage of coil mass volume growth ($\%V_{CG}=V_{CG}/V_{CI}$) were calculated. Sac growth is indicated by $V_{SG}>0$ and coil mass compaction is indicated by $V_{CG}<0$. Paired $t$ tests comparing $V_{SI}$ with $V_{SF}$ and $V_{CI}$ with $V_{CF}$ were conducted to test our hypotheses (statistical significance at $P<0.05$). To assess how sensitive the volume calculations are to user subjectivity, a second investigator performed all of the image analyses and volume calculations blinded from the first investigator. The resulting volumes, $V_{SI}$, $V_{SF}$, $V_{CI}$, and $V_{CF}$, were compared to quantify the consistency in the measurements.

### Results

Demographic and procedural information on study subjects are provided in the Table. The baseline and subtraction angiographic 3D rotational angiography data needed for sac growth calculations were available in all 8 of the study subjects. However, image data needed for coil growth calculations were only available in 5 of these 8 study subjects. Figure 1 illustrates visually the morphological change in aneurysm sac and the coil mass in the follow-up period for study subjects, respectively. Sac growth was noted in 8 (of 8) study subjects, whereas coil compaction was noted in just 1 study subject (of 5). Indeed, in 3 (of 5) subjects, the coil mass was found to grow, not compact. Quantitative analysis of volumes is consistent with this visual observation. Figure 2 shows subject-specific initial and follow-up volumes, as well as the change in these volumes. Paired Student $t$ tests showed that the aneurysm sac volume at follow-up was larger than at initial presentation with statistical significance (mean±SD of paired differences, $V_{SG}=224\pm196\;\text{mm}^3$; $\%V_{SG}=49\pm31\%; P=0.014$; $n=8$), whereas coil mass volume was not ($V_{CG}=-2\pm152\;\text{mm}^3$; $\%V_{CG}=7\pm14\%; P=0.98$; $n=5$). User sensitivity studies suggest a strong agreement between the users for all of the volumes, although

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Age, y</th>
<th>Sex</th>
<th>Aneurysm Location*</th>
<th>Aneurysm Size, mm</th>
<th>Ruptured Status</th>
<th>Follow-Up Interval, mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>F</td>
<td>L MCA</td>
<td>16×11</td>
<td>Unruptured</td>
<td>5.8</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>F</td>
<td>Acom</td>
<td>9×8</td>
<td>Ruptured</td>
<td>12.1</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>M</td>
<td>R MCA terminus</td>
<td>7×10</td>
<td>Ruptured</td>
<td>4.4</td>
</tr>
<tr>
<td>4</td>
<td>59</td>
<td>M</td>
<td>Acom</td>
<td>5×10</td>
<td>Ruptured</td>
<td>5.7</td>
</tr>
<tr>
<td>5</td>
<td>49</td>
<td>F</td>
<td>Basilar tip</td>
<td>6×6</td>
<td>Unruptured</td>
<td>5.9</td>
</tr>
<tr>
<td>6</td>
<td>61</td>
<td>F</td>
<td>R pcom</td>
<td>16×11</td>
<td>Ruptured</td>
<td>11.5</td>
</tr>
<tr>
<td>7</td>
<td>47</td>
<td>M</td>
<td>Basilar tip</td>
<td>22×15</td>
<td>Ruptured</td>
<td>5.4</td>
</tr>
<tr>
<td>8</td>
<td>47</td>
<td>F</td>
<td>L cavernous</td>
<td>7×8</td>
<td>Unruptured</td>
<td>6.6</td>
</tr>
</tbody>
</table>

* L indicates left; R, right; M, male; F, female; MCA, middle cerebral artery; Acom, anterior communicating artery; pcom, posterior communicating artery.
The findings are consistent with our hypothesis that aneurysm sac growth remains the main cause of aneurysm recurrence over longer periods of time after treatment. In addition, differing mechanisms of recurrence may be present in ruptured aneurysms versus unruptured aneurysms. This study is not powered to assess such differences. Investigator subjectivity in calculations is not entirely negligible and neither is the scope for error from image artifacts, but they are unlikely to impact the overall findings of this study.

Conclusions
The findings are consistent with our hypothesis that aneurysm sac growth is an important mechanism for recurrence after initial complete or near-complete obliteration of the sac using coil embolization. There was little evidence to support coil compaction as a consistent mechanism in this population. If validated by future studies, this finding suggests that perhaps a growing aneurysm is better managed with surgical clipping.

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Disclosures
None.

References
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