# Getting More Out of Follow-up Three-Dimensional Time-of-Flight Magnetic Resonance Angiography in Endovascularly Treated Intracranial Aneurysms

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## Abstract

**Background:** We retrospectively re-evaluated follow-up three-dimensional (3D) time-of-flight (TOF) magnetic resonance angiography (MRA) in patients with aneurysms treated with coiling at our Institute. **Aims:** To document the type and frequency of postcoiling residue patterns as seen on follow-up MRA and to document their evolution with time where a further follow-up MRA was available. To assess the implications of the location of the aneurysm on residue and recurrence. **Subjects and Methods:** 3D TOF MRA for 104 aneurysms were evaluated for residue size and residue pattern. Mainly, three residue patterns were identified. The aneurysms were allocated to different groups depending on the location. Multiple MRA studies were available in subgroup 1* and subgroup 2* where the residue growth or reduction and pattern change was noted and residue growth rates were calculated. **Results:** Collectively 54 (51.92%) aneurysms showed occlusion (pattern 1 and 1A), 31 (29.81%) showed neck residue (pattern 2A, 2B and 2C) and 19 (18.27%) showed recurrence (pattern 3A, 3B and 3C, residue size >3 mm) at the last follow-up MRA. Type 2A/3A patterns were more common. In terms of residue and recurrence, the distally located aneurysms (Group 3) appeared to do well. For those showing growing residue/recurrence, the average growth rate was calculated at 0.094 mm/month and 0.15 mm/month, respectively, for subgroup 1* and subgroup 2*, although the difference was not statistically significant. With longer follow-up the persisting and growing residues from both the subgroups, not warranting early re-treatment, showed a low growth rate at approximately 0.05 mm/month. **Conclusions:** TOF MRA helps in identifying different residue patterns in coiled aneurysms. Serial follow-up MRA appears useful in showing the pattern and size changes in the residual aneurysm. Although more work is required in this regard, calculation of aneurysm/residue growth rate may be useful in prognostication and in scheduling further follow-up or retreatment. The risk factor related to the location of the aneurysm warrants further study.

**Keywords:** *Aneurysm, endovascular treatment, magnetic resonance angiography, recurrence*

## Introduction

The endovascular coiling of ruptured intracranial aneurysms, currently, is the preferred mode of treatment with acceptably low re-bleeding rates.[1-6] Nevertheless, residues and recurrences are more frequent,[6-10] as shown by follow-up digital subtraction angiography (DSA) at standard intervals.[6-16] More recently, magnetic resonance angiography (MRA) has proven its utility in the evaluation of the residues. Several papers comparing the efficacy of MRA vis-a-vis DSA have amply shown excellent agreement between the two modalities in depicting the aneurysm residue in coiled aneurysms, especially where a stent is not used.[17-39] The residues/recurrences shown on MRA need a reassessment as regards further follow-up or retreatment. Keeping this Neurointerventionist's perspective in mind, in this retrospective study, we re-analyzed follow-up MRA studies that were available as original data for the residue pattern and its evolution. The study is not a comparison of DSA and MRA for aneurysm residue recognition. Instead, it already presupposes the efficacy of three-dimensional (3D) time-of-flight (TOF) MRA.

## Subjects and Methods

The retrospective study was approved by the Institute ethics committee and provided



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a consent waiver. Only those cases where original MRA data were available for reconstruction and evaluation were included in the study. The evaluation was done by the first three authors in consensus. Original MR angiography data in 161 (MRA) studies, in 97 patients (male: female 45:52 and 23 <40 years of age, 37 in 41–50 age group and 37 above 50 years of age) treated with endovascular coiling for 104 intracranial aneurysms in our institution during the study period from 2002 to 2018 was available for reconstruction and re-evaluation. 150 MRA studies on 3T scanner GE Signa HDXT and 11 on 1.5 T scanner GE Genesis Signa were available for analysis. Standard available protocol was used for MRA without any modifications. MRA protocol used on 3T equipment was: 3D TOF MRA in the axial plane with TR/TE: 18/2.4, two overlapping slabs (48 locs with 13 locs overlap), FOV – 22*16.5, phase FOV – 0.75, slice thickness 1.2 mm/0.6 mm overlap, matrix – 320*224, NEX – 1, flip angle – 15, bandwidth – 31.25 kHz, acquisition time – 2.35 min.

The data were loaded in the dedicated workstation (Advantage Windows GE, software version ADW 4.6). Maximum intensity projection (MIP) and multiplanar reconstruction (MPR) images were generated. The aneurysm residue was evaluated in appropriate profile, and the largest dimension of the residue was documented. The aneurysm details, including the angiographic (DSA) outcome at the time of coiling, were available from records. The follow-up period of the MRA study (s) till the therapeutic follow-up procedures, if any, were noted.

Of the 104 aneurysms, 94 were in the anterior circulation and 10 in posterior circulation; 94 ruptured and 10 unruptured; 65 with size <6 mm, 26 with size 6–10 mm, and 13 with size more than 10 mm). Of the ten unruptured aneurysms, six were >10 mm in size. Aneurysms treated by endovascular coiling with or without balloon assistance were only included in this study. Forty-eight aneurysms were treated with balloon assistance and 56 aneurysms were treated without balloon assistance. Aneurysms treated with stent assistance, primary treatment with flow diverter, or parent vessel occlusion were excluded from the study.

For analysis purpose the aneurysms were allocated to different groups. Group 1 ($n$ = 48) included anterior communicating artery aneurysms (ACOM $n$ = 45, A1 segment of ACA $n$ = 3). Group 2 ($n$ = 37) included larger artery sidewall aneurysms, i.e., posterior communicating artery aneurysm (PCOM $n$ = 9); internal carotid artery (ICA) paraophthalmic aneurysms ($n$ = 10); anterior choroidal artery region ICA aneurysms ($n$ = 5); ICA superior hypophyseal ($n$ = 3) and other supraclinoid ICA aneurysms ($n$ = 6) excluding the ICA bifurcation aneurysms; basilar artery sidewall aneurysms ($n$ = 2); and M1 segment of middle cerebral artery sidewall aneurysms ($n$ = 2). Group 3 ($n$ = 10) included distally located aneurysms, i.e., distal anterior cerebral artery aneurysms (DACA $n$ = 8), distal anterior inferior cerebellar artery aneurysm ($n$ = 1), and distal superior cerebellar artery aneurysm ($n$ = 1). In addition, there were bifurcation aneurysms, i.e., ICA bifurcation aneurysm ($n$ = 3) and basilar top aneurysm ($n$ = 1), vertebro-basilar fenestration related aneurysm ($n$ = 1), proximal PICA $n$ = 3, and proximal superior cerebellar artery aneurysm ($n$ = 1).

Looking at aneurysm-wise, 187 MRA studies were available for 104 aneurysms (a single study in 51, 2 studies in 35, 3 studies in 8, 4 studies in 8 and 5 studies in 2). The last follow-up MRA at 12 months or more was available in 66, at 24 months or more in 43 and at 36 months or more was available in 28. In addition, contrast MRA was available in 2 aneurysms treated. 18 DSA studies were performed in the follow-up, of these eight were for the endovascular therapeutic procedure (retreatment).

## Residue pattern scheme for magnetic resonance angiography evaluation

Different residue patterns that were seen were documented as per the scheme mentioned below. While evaluating the MRA studies, we soon realized that a gross look at the MIP or MPR may not be enough to identify a small residue. As shown in a previous study[17] evaluation of base images along with MIP and MPR in appropriate profile is important. Taking into cognizance the residue patterns mentioned in literature, we formulated a residue pattern scheme. The scheme, while subcategorizing the residue patterns, still conforms to the widely used angiographic Raymond and Roy (Raymond-Roy) aneurysm residue/recurrence scale. To add objectivity to recurrence identification, any residue more than 3 mm was regarded as recurrence.

Angiographic outcome at the time of initial coiling was recorded as per Raymond-Roy class scheme. For residue outcome at MRA, the following scheme was followed. Total occlusion = 1, slight irregularity at base <1 mm = 1A, residue at the base <3 mm = 2A, a dog ear residue <3 mm = 2B, a residue at the center of the coil mass <3 mm = 2C, and residues 3 mm or more were labeled as 3A, 3B and 3C, respectively. In addition, interstitial filling of the coil mass, if any, was noted separately. Residue size was measured as per the largest diameter of residue. Any residue larger than 3 mm was regarded as recurrence. The residue patterns are depicted in Figure 1. For final outcome calculations, patterns 1 and 1A were regarded as occlusion, pattern 2A, 2B, and 2C as residue and pattern 3A, 3B, and 3C as recurrence.

Where 2 or more MRA studies were available in the follow-up, the evolution of the residue in terms of pattern change or size change was documented. The growth rate was calculated in patients with multiple follow-up MRA studies as the difference in residue size in the first and last MRA study divided by the gap in months. It was then averaged

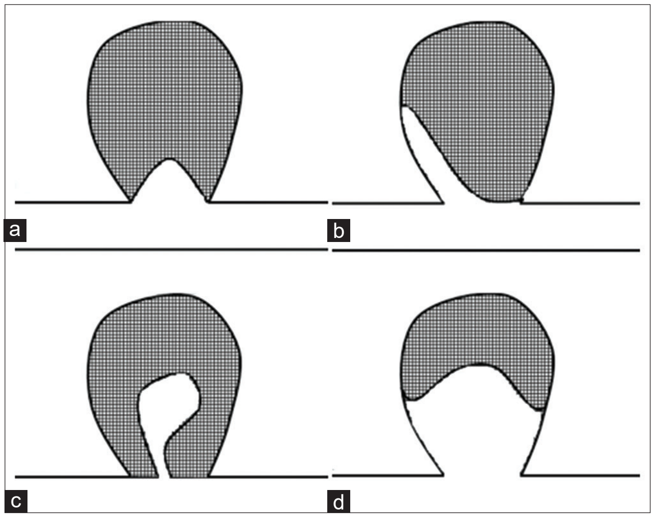


**Figure 1: Sketch diagram showing Type A residue at the base of the aneurysm (a), Type B dog ear residue (b), Type C residue within the coil mass (c) and aneurysm recurrence with coil compaction (d)**

for the group. All 1A pattern residues were regarded as 0.5 mm in size for this purpose.

MRA was unsatisfactory in one patient, presumably due to artifacts from dental implant. Follow-up DSA carried out in this patient at 9 months showed no residue. Bulbous shape of the anterior communicating artery posed difficulty in residue size measurement in 2 patients. A small coil loop prolapse at the time of coiling was present in 2 patients. However, this did not appear to affect the MRA visualization. In addition, early postcoiling MRI/MRA (mostly in the first 2 weeks) was available in 20 aneurysms. It was mainly performed for periprocedural management. However, the MRA quality was suboptimal in some, and hematoma degraded the interpretation in six of these. In any case, these studies were not included in the analysis. In addition, seven co-existing untreated aneurysms were evaluated for growth.

## Results

Raymond-Roy class at coiling and the first follow-up MRA outcome is detailed in Table 1.

The 2A and 3A patterns of residue/recurrence were the most common. The higher recurrence numbers in MRA may be due to the definition of recurrence (>3 mm) and to some extent due to a larger average time gap since coiling. 53/104 aneurysms were studied with more than one follow-up MRA. Seen as per the last follow-up MRA, Type I/IA pattern was seen in 54, Type 2 ABC pattern in 31 and type 3 ABC pattern in 19.

In four aneurysms in Group 2, neck residue looked like interstitial filling on DSA at the end of coiling, 3 of these progressing to occlusion on follow-up MRA and one progressed to 3B pattern, later changing and growing to 3A pattern. Three aneurysms in Group 1 showed residue interpreted as interstitial filling on DSA at the neck at the time of coiling, two of these progressing to 2C pattern and one progressing to 3A pattern. The interstitial pattern of residue on MRA, however, was not seen in any of the aneurysms.

For Group 1 and Group 2, average residue size was 2.05 mm (standard deviation [SD] 0.53) and 1.9 mm (SD 0.4), respectively, and average recurrence size was 5.3 mm (SD 2.38) and 6.9 mm (SD 4.2), respectively.

Distal aneurysms largely comprised DACA aneurysms (Group 3) showed good follow-up MRA outcome. Group 1 mainly comprised ACOM aneurysms appeared to do better than Group 2 (large vessel sidewall aneurysms) in terms of stable occlusion and recurrences; however, it was not statistically significant [Table 2].

### Multiple follow-up magnetic resonance angiography analysis

In 20 aneurysms in Group 1 and 25 aneurysms in Group 2, multiple follow-up MRA studies were available (the last MRA being >12 months after the coiling procedure). These subgroups are referred to as subgroup 1* and subgroup 2*, respectively, hereafter. Tables 3 and 4 show the evolution of residue in these.

Of the 20 aneurysms from subgroup 1* (at average follow-up 34 months) and 25 aneurysms in subgroup 2* (at average follow-up 46 months) studied with multiple follow-up MRA studies, 40% and 32% showed/attained occlusion, respectively. Residues were seen in 40% in both the subgroups. Recurrence (residue >3 mm) was seen in 20% and 28% in subgroup 1* and subgroup 2*, respectively.

Thus, 20% in both the subgroups progressed from occlusion to residue or recurrence. Only 10% in subgroup 1* and 4% in subgroup 2* progressed from residue to occlusion. None of the aneurysms with recurrence (i.e., residue size >3 mm) progressed to occlusion.

Residue/recurrence pattern change was noted in these two subgroups [Table 4]. Pattern 1, 1A, and 2A may progress to 2A or 3A. Pattern 3B eventually progressed to 3A. Thus, the majority of the recurrences (residue >3 mm) showed or converted to pattern 3A. Pattern 2C and 3C appeared relatively stable. The residue patterns (in residues and recurrences) at the last MRA follow-up in subgroup 1* and subgroup 2* were Pattern A in 40% and 52%, respectively, and pattern C in 20% and 16%, respectively.

Of the 9 Pattern C residue/recurrences, 7 showed increase in size, but none progressing to recurrence size of >4 mm. Of the three 3C residues, only one changed to 3A. Outside these subgroups one 3C residue, although large (5 mm), in a vertebrobasilar fenestration aneurysm is stable for 144 months.

**Table 1: First follow-up magnetic resonance angiography outcome in all aneurysms studied**

| Raymond -Roy class at coiling (*n*=104) | MRA outcome at first Follow-up MRA (*n*=104) | *n* (%) Pattern- wise numbers | First MRA time gap since coiling in months-range, average and (SD) in months |
|---|---|---|---|
| Class 1=56 (53.85%) | 1 and 1A | 57 (54.81) (1=36, 1A=21) | 2-118, 13.7, (18.7) |
| Class 2=43 (41.35%) | 2A, 2B, 2C (neck residue) | 29 (27.62) (2A=19, 2B=4, 2C=6) | 2–101, 17.4, (21.1) |
| Class 3=5 (4.8%) | 3A, 3B, 3C (recurrence) | 18 (17.30) (3A=8, 3B=3, 3C=7) | 3-134, 24.5, (36.9) |

*n*=104. Recurrence defined as >3 mm residue. MRA – Magnetic resonance angiography; SD – Standard deviation

**Table 2: Various groups compared for residue outcome with last follow-up magnetic resonance angiography at 12 months or more**

| Aneurysm group Last follow-up MRA range, average, (SD) in months | Aneurysm particulars | RR class | No. 1/1A (%) | No. 2 A/B/C (%) | No. 3 A/B/C (%) | *P* (One tail two sample *t*-test) |
|---|---|---|---|---|---|---|
| Group 1 (*n*=27) 12-127, 38.8, (27) | Aneurysm size <6 mm in 15, 6-10 mm in 9 and >10 mm in 3) (26 ruptured aneurysms, balloon assistance used in 8) | R1=11<br>R2=15<br>R3=1 | 10<br>6/4<br>(37.03%) | 13<br>9/1/3<br>(48.15%) | 4<br>3/0/1<br>(14.81%) | Group 1 and 2 compared<br>For residue size=0.074<br>For residue class=0.098 |
| Group 2 (*n*=27) 12-156, 47.2, (43.6) | Aneurysm size <6 mm in 17, 6-10 mm in 5 and >10 mm in 5) (19 ruptured aneurysms, balloon assistance used in 16) | R1=13<br>R2=13<br>R3=1 | 7<br>5/2<br>(25.92%) | 12<br>8/1/3<br>(44.44%) | 8<br>7/0/1<br>(29.63%) | |
| Group 3 (*n*=6) 12-118, 37, (40.7) | Aneurysm size <6 mm in 5 and 6-10 mm in 1 (all ruptured, balloon assistance was not used) | R1=3<br>R2=3<br>R3=0 | 6<br>4/2 (100%) | 0 | 0 | Group 1 and 2 compared with Group 3 = <0.01 (for residue size and class) |
| All groups (groups 1, 2, 3 and other) (*n*=64) 12-156, 42.9, (37.8) | Aneurysm size <6 mm in 40, 6-10 mm in 16 and >10 mm in 8) (55 ruptured aneurysms, balloon assistance used in 27) | R1=29<br>R2=32<br>R3=3 | 25<br>17/8<br>(39.06%) | 26<br>17/3/6<br>(40.62%) | 13<br>10/0/3<br>(20.31%) | |

MRA – Magnetic resonance angiography; SD – Standard deviation; RR – Raymond-Roy

**Table 3: The stability/evolution of residue. (recurrence defined as residue 3 mm or more)**

| Occlusion/residue progression | Subgroup 1* (ACOM region aneurysms) (total *n*=20) (range, average, (SD) in FU months=12-127, 34, (25) | Subgroup 2* (large vessel sidewall aneurysms) (total *n*=25) (range, average, (SD) in FU months=12-156, 46, (42) | Subgroup 1* and 2* together (total *n*=45) (range, average, (SD) in FU months= 12-156, 40.97, (36) |
|---|---|---|---|
| Stable occlusion (pattern 1/1A to 1/1A) (%) | 6 (30) | 7 (28) | 13 (28.89) |
| Occlusion progressing to residue (pattern 1/1A to 2 ABC) (%) | 4 (20) | 4 (16) | 8 (17.78) |
| Occlusion progressing to recurrence (pattern 1/1A to 3 ABC) (%) | 0 | 1 (4) | 1 (2.22) |
| Residue reducing to occlusion (pattern 2 ABC to 1/1A) (%) | 2 (10) | 1 (4) | 3 (6.7) |
| Residue to residue with minor size change (pattern 2 ABC to 2 ABC) | 4 (20) | 5 (20) | 9 (20) |
| Residue progressing to recurrence (pattern 2ABC to 3 ABC) (%) | 2 (10) | 0 | 2 (4.44 ) |
| Recurrence reducing to occlusion (pattern 3 ABC to 1/1A) (%) | 0 | 0 | 0 |
| Recurrence reducing to residue (pattern 3 ABC to 2 ABC) (%) | 0 | 1 (4) | 1 (2.22) |
| Recurrence persisting (pattern 3 ABC to 3 ABC) (%) | 2 (10) | 6 (24) | 8 (17.78) |
| Total occlusion (%) | 8 (40) | 8 (32) | 16 (35.56) |
| Total residue (%) | 8 (40) | 10 (40) | 18 (40) |
| Total recurrence (%) | 4 (20) | 7 (28) | 11 (24.44) |

Subgroup 1* and subgroup 2* are compared for significance in table 5. SD – Standard deviation; ACOM – Anterior communicating artery; FU – Follow-Up

Growth in the aneurysm residue was seen in 11/20 (55%) in subgroup 1* and in 15/25 (60%) in subgroup 2*.

Size changes of residue/recurrence between the first and last MRA were calculated for growth rates [Table 5]. When calculated for only those with increase in size it was 0.094 mm/month (average follow-up 32 months) and 0.15 mm/month (average follow-up 49 months) for subgroup 1* and subgroup 2*, respectively (however, it was

**Table 4: Residue pattern change as noted in subgroup 1* and subgroup 2* aneurysms**

| MRA pattern change from/to | Subgroup 1* (7/20) (residue pattern change In months/total MRA follow-up months) | Subgroup 2* (10/25) (residue pattern change in months/total MRA follow-up months) |
|---|---|---|
| 1 to 1A | | 1A (19/25), 1A (8/13) |
| 1 to 2ABC | 2A (30/37), 2C (17/24) | 2A (18/37), 1A (18/25) |
| 1A to 2ABC | 2A (50/52), 2A (33/45) | 2A (17/23), 2A (42/48) |
| 1A to 3 ABC | | 3A (24/38) |
| 2A to 3ABC | 3A (12/23), 3A (24/32) | |
| 3B to 3A | | 3A (96/156), 3A (24/113), 3A (24/31) |
| 3C to 3A | 3A (48/55) | |
| **MRA pattern improvement from/to** | **Subgroup 1* (2/20) (improving residue pattern change In months/total MRA follow-up months)** | **Subgroup 2* (2/25) (improving residue pattern change in months/total MRA follow-up months)** |
| 2A to 1/1A | 1A (119/127) | 1 (24/43) |
| 2B to 1A | 1A (7/12) | |
| 3A to 2A | | 2A (82/84) |

Subgroup 1* and subgroup 2* are compared for significance in table 5. MRA – Magnetic resonance angiography; SD – Standard deviation

**Table 5: Aneurysm residue/recurrence growth rate calculations**

| Particulars | Residues/recurrences subgroup 1* (*n* and size) growth rate mm/month, range (average last FU MRA months) | Residues/recurrences subgroup 2* (*n* and size) growth rate mm/month, range (average last FU MRA months) | *P*-One tail (two sample *t*-test) Comparing subgroup 1* and subgroup 2* | Residues/recurrences combined subgroups 1* and group 2* (*n*) growth rate mm/month, range (average last FU MRA months) | Mixed location small aneurysms, 3 MCA and 2 ICA (*n*) growth rate mm/month (average last FU MRA months) |
|---|---|---|---|---|---|
| Those with multiple MRA and last follow up MRA at >12 months and increasing residue size | (*n*=11/20) 0.094, 0.0083-0.125 (32) (5/20 showed decrease in size and 4/20 showed no change in size) | (*n*=15/25) 0.15, 0.002-1.43 (49) (5/25 showed decrease in size and 5/25 showed no change in size) | 0.298 | (*n*=26/45) 0.12, 0.002-1.43 (43) (10/45 showed decrease in size and 9/45 showed no change in size) | - |
| Those with last follow-up MRA 24 months or more and gap in MRA 12 months or more with residue size increasing | (*n*=7/12) 0.046, 0.0083-0.075 (40) (size <6 mm in 3, 6-10 mm in 4) (2/12 showed decrease in size and 3/12 showed no change in size) | (*n*=11/18) 0.059, 0.002-0.125 (65) (size <6 mm in 6, 6-10 mm in 3 and >10 mm in 2) (5/18 showed decrease in size and 2/18 showed no change in size) | 0.30 | (*n*=18/30) 0.054, 0.002-0.125 (55) (size <6 mm in 9, 6-10 mm in 7 and >10 mm in 2) (7/30 showed decrease in size and 5/30 showed no change in size) | - |
| Pattern "C" residues with multiple MRA and last follow-up MRA at >12 months and increasing residue size | (*n*=3/4) 0.077, 0.0083-0.125 (25) (1/4 decreasing in size) | (*n*=2/4) 0.0093, 0.0021-0.0167 (99) (2/4 decreasing in size) | | (*n*=5/8) 0.05, 0.0021-0.125 (55) (3/8 decreasing in size) | |
| Untreated and unruptured associated aneurysms with increasing size | - | - | - | | (*n*=5/7) 0.02 (66) |

When compared there was no statistically significant difference in subgroup 1* and subgroup 2*. FU – Follow-up; MRA – Magnetic resonance angiography; ICA – Internal carotid artery

not statistically significant, $P = 0.298$). The Type "C" residues in these subgroups showed a lesser growth rate of 0.05 mm/month. Residues increasing in size from subgroup 1* and subgroup 2* with last follow-up MRA at 24 months or more and MRA studies with a gap of 12 months or more were evaluated for average growth rate and significant difference in the variance. Last follow-up MRA at 24 month or more ensures the elimination of aneurysms with early large recurrence with faster growth and those undergoing early retreatment. Thus, the steady growth rate of 0.046 in subgroup 1* compares well with 0.059 in subgroup 2* with a *P* value of 0.3, again suggesting no significant difference between the two subgroups.

Residue increasing in the interim period and then decreasing was seen in one aneurysm (subgroup 2*) with a total follow-up of 43 months and residue decreasing in the interim period and then increasing was seen in one subgroup 1* aneurysm with a total follow-up of 55 months.

Of the seven co-existing untreated aneurysms, 3 MCA bifurcation aneurysms and 2 ICA aneurysms showed an average growth rate of 0.02 mm/month, whereas two small <3 mm aneurysms (1 DACA and 1 ICA Superior hypophyseal) showed no change in size over 12 and 25 months, respectively.

### Recurrences and retreatments

None of the aneurysms bled in the follow-up. There were 19 recurrences (>3 mm residue with 3 A, B, C patterns). Overall, 7/48 from Group 1, 9/37 from Group 2 and 3 from the rest of the 19 aneurysms showed recurrences. Early recurrence (within the first year) was seen in six from Group 1 (1 larger than 6 mm) and 5 from Group 2 (2 larger than 6 mm) and 2 from the rest of the aneurysms. Eighteen DSA studies, including eight retreatment procedures, were undertaken in the follow-up. Residue measurements matched with MRA in all except in one case where the residue was not seen on DSA presumably due to the so-called "helmet effect."

Four aneurysm recurrences (all Group 2 aneurysms) were dealt with flow diverter procedure and one with stent-assisted coiling in the follow-up (within 13 months of initial coiling in 3/5) and two more of Group 2 aneurysms are awaiting flow diverter treatment. Two aneurysms from Group 1 (ACOM) required stent-assisted coiling after 55 months follow-up for a moderate (3.7 mm) recurrence in one and for a major (8 mm) recurrence at 23 months follow-up in another. One ICA bifurcation aneurysm showed early recurrence and had to undergo re-procedure with balloon-assisted coiling within 6 months. Other aneurysms with recurrence <4 mm are on follow-up.

## Discussion

### Magnetic resonance angiography in follow-up of coiled aneurysms

Wallace *et al*. have nicely reviewed the topic of MRA follow-up in endovascularly treated aneurysms.[17] Most of the earlier studies comparing DSA and MRA reported a sensitivity and specificity of 90% and 100%, respectively, for the detection of residual aneurysms on MRA.[17-28] The importance of interpretation of MRA from source images as well as MPRs and MIPs[17,31] and comparison with angiographic profile views that are available from the coiling procedure is important and has been duly emphasized.[17,31,32]

### Residue/recurrence in aneurysms treated with endovascular coiling

Residue, remnant, recurrence, regrowth, recanalization are the various terms used to describe the follow-up imaging findings. However, many studies have combined the remnants and recurrences as residual flow.[31] A growth of residue and/or compaction of the coils are listed as the causes of the residual flow.[40] DSA owing to its better spatial resolution, is eminently suitable to demonstrate the deformed coil mass in cases with coil compaction.[41] In our study using MRA alone, we were not able to distinguish between coil compaction and re-growth.

### Patterns of residual flow

Angiographic follow-up studies report aneurysm occlusion class as per the Raymond–Roy classification.[6,40,42] Most follow-up MRA studies conform to this scheme. There exists some ambiguity as regards the definition of recurrence or the class III occlusion of aneurysm in Raymond-Roy classification. Any persistent flow in the sac is considered as residual aneurysm, and so the intra-coil-mass filling is labeled as class III obliteration. There is no definite size criterion to label a residue as recurrence. In addition, aneurysm remnant along the wall in the form of a "dog ear" was not separately classified. In practice, in the majority with recurrence, the coil mass is either deformed due to compaction or pushed away from the neck due to re-growth. Hence, we preferred residue size as a criterion to identify recurrence, and aneurysm residues of 3 mm or larger size were labeled as recurrence. Although it can be argued that a 2 mm residue is as good as recurrence in a 3 mm aneurysm, the definition mentioned above makes the evaluation easier and more objective. MRA (especially the source images and MPR images) can easily identify intra-aneurysmal filling in the center of the coil mass or filling at the base as well as a dog ear remnant along the sidewall of the coiled aneurysm. Mascitelli *et al*. have used "modified Raymond – Roy classification" for angiographic follow-up.[40] They highlighted the significance of "dog ear" type residue for aneurysm recurrence. The intra-coil mass residue may be masked at DSA due to the so-called "helmet effect" as shown by Shankar *et al*.[32] As has been shown previously,[17] MRA inherently depicts different residue patterns such as the residue at the base, the dog ear residue, and the intra-coil mass aneurysmal residue and at times, the so-called interstitial filling. Since MRA has practically replaced DSA in screening for residue and re-growth evaluation in treated aneurysms as current standard practice, we thought it important to separately identify and label the residue patterns. We incorporated these patterns into the residue evaluation scheme while still conforming to the Raymond-Roy classification. Figures 2-6 show different residue patterns. Thus the intra-coil mass filling was labeled as type 2C or type 3C depending on the size of the residue. The pattern identification helps comparison and the assessment of the increase in size and change of pattern at the follow-up study. The identification of cases that need re-treatment can then be based on size, pattern and "treatment feasibility" assessment as seen on MRA. The type B residue pattern (dog ear) progressed with

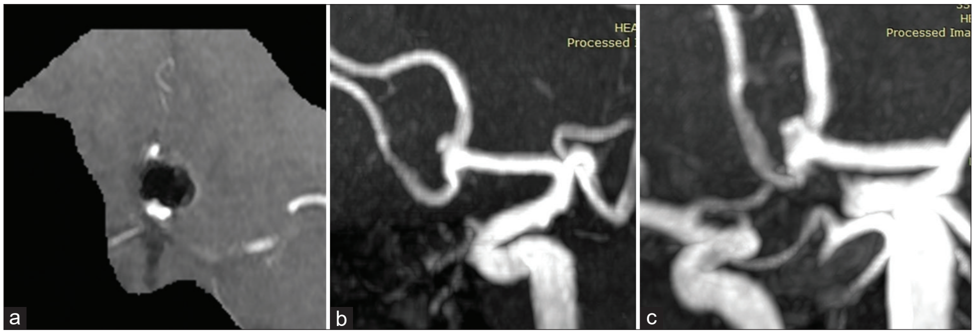


**Figure 2: An 8 mm ACOM (subgroup 1*) aneurysm shows small irregularity at the base (Type IA) in 12 months follow-up (a), progressed to a 1.9 mm Type 2A residue at 24 months (b) and shows further slow growth to 2.9 mm at 45 months (c)**

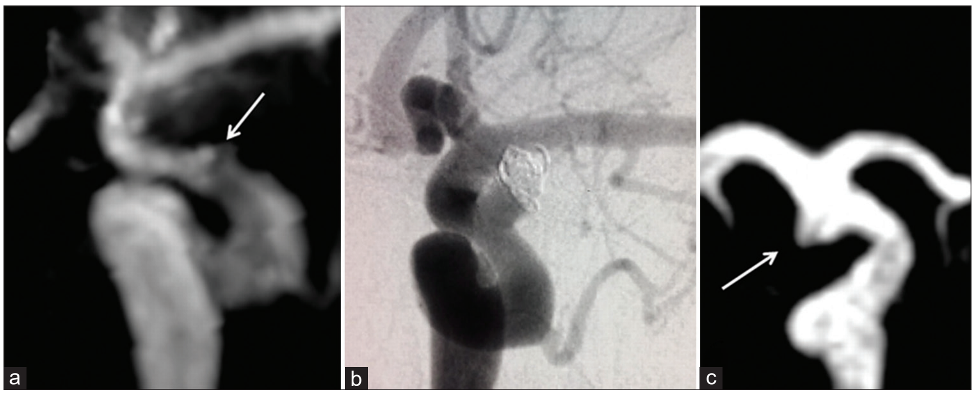


**Figure 3: A 5 mm internal carotid artery aneurysm (subgroup 2*) treated with balloon assisted coiling shows mild irregularity (Type 1A residue) at the base (a) at immediate postcoiling magnetic resonance angiography, showed residue at 14 months magnetic resonance angiography and a well-defined recurrence at 21 months follow-up digital subtraction angiography (b). Another patient with a 5.5 mm proximal MCA side wall aneurysm (subgroup 2*) shows a broad neck recurrence 3.3 mm (Type 2A) at 134 months magnetic resonance angiography (c)**

time to aneurysm recurrence at the base of the aneurysm converting to a type A pattern presumably owing to both, coil compaction and re-growth [Figure 4]. The type C residue (in the center of the coil mass) appeared more stable in our study with a lower growth rate, presumably due to surrounding coil mass [Figure 5].

Group 1 largely comprised of ACOM artery aneurysms, showed some cases with a bulbous ACOM artery in the follow-up MRA. Similarly, residual interstitial filling pattern, although not identified in any of our cases, has been described, especially with contrast-enhanced MRA.[17] Assessment of residue size in these cases poses a difficulty, and the implications are undefined. Follow-up studies are required to look for the evolution of the residue in these cases.

## Risk factors for recurrence

The risk factors for aneurysm recurrence have been previously studied, which include aneurysm size >10 mm, wide neck, initial incomplete occlusion, treatment in acute phase and length of follow-up period.[6-15,43] We tried to see the influence of location on aneurysm recurrence by comparing different location groups. Groups 2, 1, and 3 essentially represent, respectively, proximal, middle, and distal locations in the cerebral vascular tree. Although our data are insufficient to show the independent influence of the location of aneurysm on residue and recurrence, it did show some trends. Thus smaller and more distally located aneurysms (Group 3) did well and none of the DACA aneurysms in our series showed residue or recurrence [Figure 6]. On the other hand, proximally located aneurysms (large vessel sidewall aneurysms Group 2) like those arising from supraclinoid ICA [Figure 3] or from basilar artery showed higher recurrence and required further treatment. When compared, Group 1 aneurysms (ACOM region) appeared to show a better outcome than Group 2 (large vessel sidewall) aneurysms in terms of residue and recurrence, although it did not show statistical significance in this small sample size.

## Residue growth rates

Small neck remnants do tend to grow over a period of time, although slowly in the majority of the cases [Figure 2]. Aneurysm residue growth probably does not follow a linear pattern. Nevertheless, we calculated growth rates for aneurysm residues in subgroup 1* and subgroup 2*. In these subgroups, about 45% and 40% showed either decrease in size or were unchanged. For those showing residue growth, the overall average growth rate was calculated at 0.094 mm/month and 0.15 mm/month, respectively, for subgroup 1* and subgroup 2*. Type C pattern residues in these subgroups appeared more stable with a slower growth rate at 0.05 mm/month. A vast majority of residues in the range of 2-4 mm appear to stay stable for long periods. So with longer follow-up, as the aneurysms with larger recurrence requiring retreatment got excluded, the slow-growing aneurysm residues from both subgroups showed a similar rate at approximately 0.05 mm/month. Interestingly, the growth rate in untreated co-existing aneurysms was also low at 0.02 mm/month [Table 5].

### Retreatment decision based on magnetic resonance angiography findings

Schaafsma *et al*.[44] compared DSA and MRA for decision-making as regards additional treatment for aneurysm residue/recurrences. Our study being retrospective, this aspect could not be assessed. However, it appears that the pattern of residue/recurrence may be useful in deciding endovascular therapeutic options. Thus, a large 3A recurrence in a proximal vessel (Group 2) may be suitable for stent-assisted coiling or a flow diverter procedure. On the other hand, type 3C recurrence may be amenable to balloon-assisted coiling. On the other hand, there is no established size measure of the residue/recurrence, which is recommended for re-treatment. In general, residues smaller than 3 mm are further followed up. We added some objectivity to identifying recurrence by using a size criterion (i.e., 3 mm or more).


**Figure 4: A 10 mm ICA-PCOM aneurysm (subgroup 2*) showed a small dog ear (2 mm) at first MRA (a), and showed 3.5 mm recurrence Type 3B at 90 months MRA (b and c) which progressed to a major recurrence at the base pushing the coil mass away on digital subtraction angiography at 113 months (d). The case shows a Type 2B residue progressing to a major Type 3A recurrence. Flow diverter treatment is planned in this case**

### Recommendations regarding follow-up magnetic resonance angiography

Wallace *et al*.[17] recommend MRA at immediate postcoiling and then at 3–6 months, 12–15 months, and 24–36 months. Once the aneurysms with early recurrence are eliminated with re-treatment decisions, the rest of the aneurysms, as seen in our study, can be followed up with the schedule suggested by Wallace *et al*.[17]

### Limitations of the study

1. The study is retrospective, and the material is limited
2. Residues are often irregular in shape, as seen on MRA. Measurement of sizes does pose a difficulty, especially as the residues are small in many. Furthermore, the distinction between type 2A and type 2C is, at times, difficult. The size and pattern evaluation was done by consensus and not by independent observers
3. Apart from the small number, in our data, the follow-up MRAs were not at prespecified time intervals affecting the calculation of growth rates
4. Although we compared for statistical significance, the two subgroups with different location of aneurysm for the growth rates, the other risk factors previously identified were not considered in the calculation as the sample size was too small.

## Conclusion

The study emphasizes the need for longer follow-up imaging in coiled aneurysms to detect and monitor the residues/recurrences. 3D TOF MRA, especially on 3 T magnet, is sensitive, provides the necessary information and

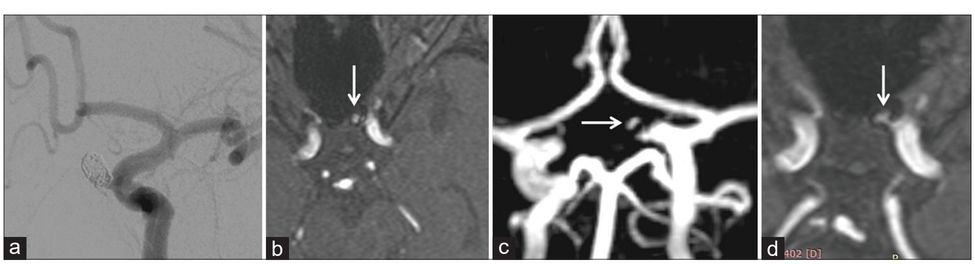


**Figure 5: A 5.5 mm internal carotid artery - paraophthalmic aneurysm (subgroup 2*) at coiling (a), shows a small residue in the coil mass (Type 2C) at 3 months as shown in MPR and MIP images (b and c), with a small increase in size at 23 months MPR image (d). It showed similar pattern at further follow-up MRA at 41 months and 54 months (2 mm)**

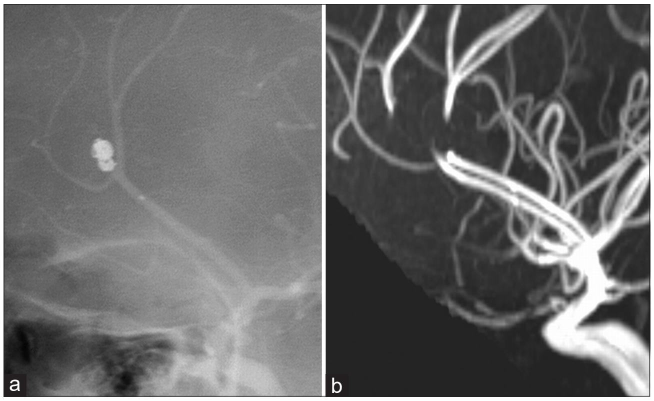


**Figure 6: A 5.5 mm DACA aneurysm (Group 3) at coiling (a) showed stable occlusion on MRA at 75 months (b). Note the signal loss in the parent vessel due to coil mass. The result was stable at a further follow-up MRA at 118 months**

appears largely sufficient for sequential follow-up for coiled aneurysms. The MRA residue pattern that we saw and used for evaluation allows comparison of follow-up studies for an increase in residue/recurrence size. MRA residue patterns may be helpful in taking therapeutic decisions. Although more work is required in this regard, calculation of aneurysm growth rate may be useful in prognostication and scheduling further follow-up or retreatment. Residues in aneurysms at different locations apparently behave differently. A trend in the risk factor related to the location of the aneurysm was highlighted in this study.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

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