

Usefulness of Craniograms in Discriminating Coiled Intracranial Aneurysms Requiring Retreatment

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Abstract

While endovascular coil embolization has become one of the major therapeutic modalities for intracranial aneurysms, long-term imaging follow-up is required because of the higher rate of retreatment compared with surgical clipping. The purpose of this study was to show the usefulness of craniograms to discriminate coiled intracranial aneurysms that required retreatment. Under the study protocol approved by institutional review board, a retrospective review of the medical record was done regarding coil embolization for intracranial aneurysms performed between January 2014 and December 2018. Coil embolization performed as the initial treatment and followed up for more than 1 year without additional treatment, and those performed as retreatment after the initial coil embolization performed at our institution were recruited. Craniograms obtained just after the initial treatment were compared with those obtained just before the additional treatment in the retreated cases and compared with the latest ones in the non-recurrence cases. Correlation between the morphological changes in the coil mass on the craniograms and retreatments was evaluated. During the study period, 288 coil embolization procedures for intracranial aneurysms were performed. From these, 191 treatments that were followed up for more than 1 year without any additional treatments and 30 retreatments were included. Morphological change of the coil mass was observed in 4 of the 191 non-recurrence treatments and 26 of the 30 retreatments, which was significantly correlated with retreatments ($p < 0.001$). Craniogram was a useful modality in following up the coiled intracranial aneurysms to detect those required retreatments.

Keywords: craniogram, intracranial aneurysm, coil embolization, retreatment

Introduction

Coil embolization for intracranial saccular aneurysms has been widely accepted as a comparable alternative to surgical clipping since the ISAT trial,¹ and the number of the procedures has been increasing.^{2,3} Compared with the surgical clipping, however, a higher recanalization rate of the coil embolization has been reported.^{4–6} Furthermore, recanalization of coiled aneurysms would occur even after long-term follow-up,^{6–17} and retreatment

may be required even more than 5 years after the coil embolization.⁷ Therefore, long-term follow-up is necessary after the coil embolization for intracranial aneurysms.

Regarding the follow-up imaging modality of coiled aneurysms, magnetic resonance imaging (MRI)^{18–20} and digital subtraction angiography (DSA)²¹ are usually employed as an imaging modality to detect recanalization of the coiled aneurysms. These modalities, however, carry inherent shortcomings: high medical costs and long examination time for both modalities, and high invasiveness for DSA.²²

In this article, we describe the usefulness of a craniogram, which is less expensive, less invasive, and less time consuming compared with MRI and DSA, for discriminating retreatment of intracranial aneurysms after coil embolization.

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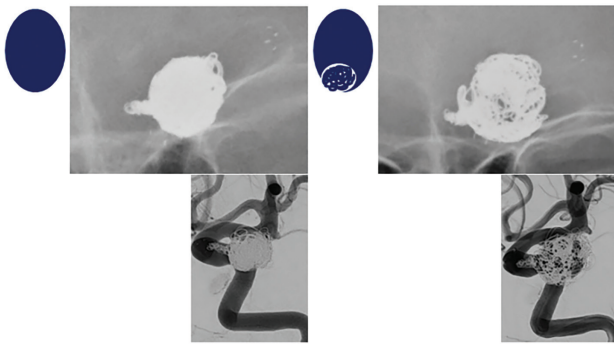
Methods

The protocol of this study was approved by our institutional review board (Approval no. M30-013-2). Opt-out consent was obtained from the patients included in this study. By retrospective review of the medical record at our institution between January 2014 and December 2018, patients who underwent coil embolization for either unruptured or ruptured intracranial saccular aneurysms were identified. In our institution, after the coil embolization, craniograms were consistently taken from 3 projections

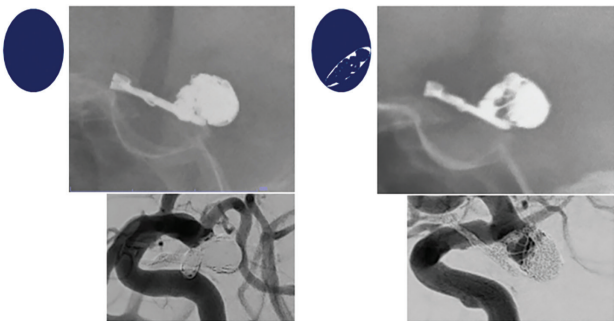
(anteroposterior, lateral, and Towne view) using digital X-ray machines on the postoperative day (POD) 1, 30, 90, 180, 270, 360, and annually thereafter. MRI was complementarily performed on the POD 180 and 360, and DSA was conducted on the POD 90 for ruptured cases and POD 180 for unruptured cases when a neck bridge stent was used. When recanalization was suspected, follow-up term was shortened to every 90 days.

Among the patients who underwent the coil embolization as the initial treatment, recurred cases and those whose follow-up term was less than or equal

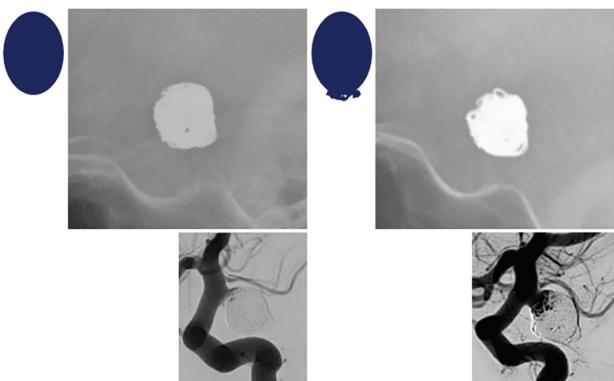
Sparseness



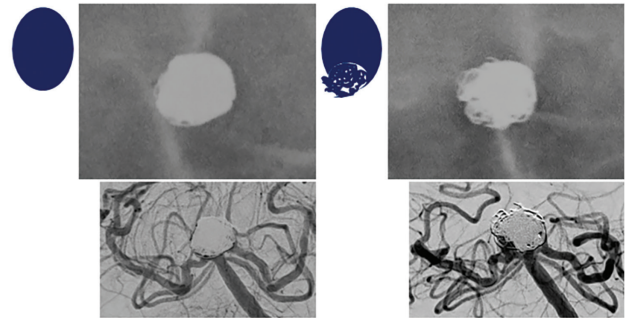
Cleft



Fray



Sparseness + Fray



Deformation

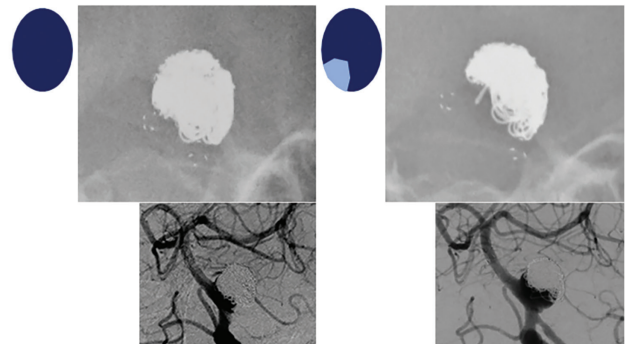


Fig. 1 Patterns of morphological changes in the coil mass. 1) Sparseness: a part of the coil mass gets sparse. 2) Cleft: a cleft crossing the coil mass is observed. 3) Fray: the margin of the coil mass gets frayed. 4) Sparseness and Fray: the combination of 1) and 3). 5) Deformation: the coil mass shows remarkable shrinkage or compaction.

to 1 year were excluded. In the remaining cases that required no additional treatment for more than 1 year, the craniograms on POD 1 and the latest ones were compared for morphological change of the coil mass. Among the patients who underwent the coil embolization as the retreatment, the following cases were excluded: craniograms just after the previous coil embolization and/or just before the retreatment were not available, the previous treatment was clipping, and the previous treatment was performed at another institution. For the remaining retreatment cases, craniograms obtained just after the previous coil embolization and those obtained just before the following treatment were compared. In our institution, retreatment for the coiled aneurysms was conducted for the following cases: 1) both morphological change in the coil mass on craniograms and increase in residual intra-aneurysmal flow on MRA were apparent during the follow-up period and 2) recanalization grew up to consensus grading scale (CGS) for aneurysm occlusion of Grade 3 or worse.²³⁾

Two experienced neurosurgeons (MN and JCT) who were blinded to patients' clinical information compared the craniograms for each patient and distinguished if the morphological change in the coil mass was observed. Patients were considered to have the morphological change in the coil mass when it was observed on at least 1 projection of their craniogram. The morphological change in the coil mass was categorized into the following patterns: 1) Sparseness: a part of the coil mass got sparse, 2) Cleft: a cleft crossing the coil mass was observed, 3) Fray: the margin of the coil mass got frayed, 4) Sparseness and Fray: the combination of 1) and 3), and 5) Deformation: showed remarkable shrinkage or compaction of the coil mass (Fig. 1). The relationship between retreatment and morphological changes in the coil mass was evaluated. Disagreements between the readers were resolved by consensus.

Statistical analysis was performed using SPSS software version 25.0 (IBM, Armonk, NY, USA), and *p*-value less than 0.05 was regarded as significant.

Results

During the study period, 288 coil embolization procedures were performed for 262 patients including 159 unruptured aneurysms. Of the 288 procedures, 247 were performed as the initial treatment for 224 patients and 41 were performed as retreatment for 38 patients. Twenty-four of the 224 cases recurred and underwent retreatment, and the remaining 223 procedures for 200 cases required no further treatment. Of the 223 procedures, 191 whose follow-up term was more than 1 year were included for further

analysis. From the 41 retreatments for 38 patients, 2 cases were excluded because of lack of the peri-operative craniograms, 4 were excluded because the previous treatment was clipping, and 5 were excluded because the previous coil embolization was performed at another institution.

The remaining 30 retreatments for 27 patients (27 aneurysms) included 12 ruptured aneurysms. The mean aneurysmal size at the initial treatment was 10.5 mm, and 9 of the 15 unruptured aneurysms were large (>12 mm). These aneurysms were mainly located at the internal carotid artery–posterior communicating artery (33.3%), paraclinoid (22.2%), or the posterior circulation (22.2%). At the initial treatment, the mean volume embolization ratio (VER) was 27.4%. The mean interval between retreatment and the initial coil embolization was 21.4 months (3 to 163 months).

Of the 30 retreatments, the morphological changes in the coil mass were observed in 26. In contrast, of the 191 coil embolization procedures that had required no retreatment for more than 1 year, the morphological changes in the coil mass were observed only in 4 (Fig. 2). As a result, morphological changes in the coil mass were significantly correlated with retreatments, with high sensitivity and specificity of 86.7% and 97.9%, respectively (*p* < 0.001, chi-square test). Interobserver agreement regarding presence or absence of morphological changes in the coil mass was excellent (kappa statistic = 0.81).

Craniograms of the 26 retreated cases accompanied with morphological changes in the coil mass resulted in 78 image comparisons (3 projections for each retreatment). Of the 78, Sparseness accounted for 17 (21.8%), Cleft 10 (12.8%), Fray 7 (9.0%), Sparseness and Fray 21 (26.9%), and Deformation 12 (15.4%). In the retreated cases, no specific pattern was found for morphological change in the coil mass.

There were 4 retreatments in which no morphological change in the coil mass was detected on the craniograms. In 3 of these 4 cases, regrowth was observed on DSA, while in the remaining 1 case, the morphological change was observed when the coil mass was observed from the projection in which coil embolization had been performed.

There were another 4 coiled aneurysms in which no retreatment was required in spite of the morphological change in the coil mass detected by follow-up craniograms. In all the cases, the morphological change was Fray where neck remnant of CGS Grade 1 was observed on the following angiogram.

Discussion

Since the ISAT trial,¹⁾ the coil embolization for intracranial aneurysms has been widely accepted

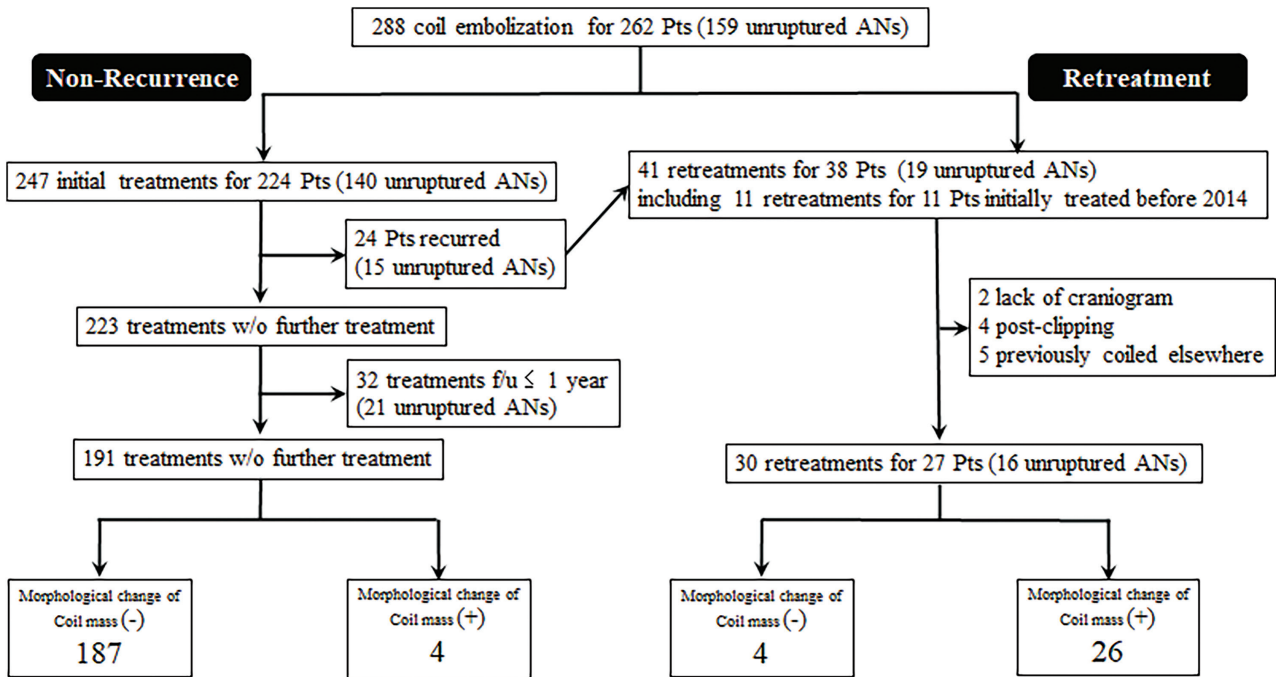


Fig. 2 Study flowchart. Pt: patient, f/u: follow-up, AN: aneurysm.

as an alternative to surgical clipping.^{2,3} Its less durability, however, has been recognized in several studies that has demonstrated a higher incidence of recanalization, retreatment, and rebleeding after the coil embolization compared with the surgical clipping.⁴⁻⁶ Recanalization and retreatment rate after the coil embolization have been reported as 2.5–41% and 0.7–26%, respectively,^{1,4-13,15-17,22,24-36} and the reported predisposing factors for recanalization after the coil embolization were as follows: larger size,^{6-13,15-17,24-26,28,29} wide neck,^{7,15} ruptured,^{7,9,10,16,25,28,30} posterior circulation,^{7,9,29} low VER and/or dome filling at the initial treatment,^{6,7,16,24-26,28,30-32} and intra-aneurysmal thrombus.^{7,12,25,26,30} Among the 27 retreated aneurysms in our series, 21 were ruptured or large (>12 mm), and 7 were at posterior circulation. These were likely the reason for recurrence although a relatively high VER of 27.4% was achieved at the initial treatment. Stent-assist for the coil embolization, especially using LVIS (MicroVention-Terumo, Tustin, CA, USA)³³ or Enterprise (Codman, Raynham, MA, USA)^{34,35} rather than NeuroForm (Stryker, Kalamazoo, MI, USA),³⁶ was instrumental to reduce recanalization^{11,12,25,26,28,37}; however, the recanalization rate was still up to 13.7%,³⁶ which was much higher than that of the surgical clipping.⁴⁻⁶

Retreatment may be required even in the long term.⁶⁻¹⁷ Koyanagi et al. reported that several patients who had undergone coil embolization for unruptured intracranial aneurysms required additional treatment more than 5 years after the initial treatment, with

the longest interval of 4674 days.⁷ Our study also included an aneurysm that was retreated 163 months after the initial coiling. Even the coiled aneurysms that were completely obliterated 6 months after the embolization can recur.^{9,10} Therefore, cessation of imaging follow-up after the coil embolization for intracranial aneurysms seems undesirable.

DSA remains a gold standard to follow up intracranial aneurysms treated with coil embolization. Because the coiled aneurysms can be observed from working projections with which the coil embolization was performed in the DSA, even a slight neck remnant can be detectable. However, this modality inheres several risks such as radiation exposure, thromboembolic complications, and contrast nephrotoxicity. MRI can eliminate these risks, and through the technical developments with 3D time-of-flight,¹⁸ contrast enhancement,¹⁹ or 3 Tesla,²⁰ it has become a comparable screening tool to DSA in depicting recanalization of coiled aneurysms.³⁸⁻⁴⁰ Compared with these modalities, a craniogram possesses several advantages in terms of medical cost, invasiveness, and examination time, all of which combine to make it a more favorable image modality for long-term follow-up.

In this study, craniograms were found useful in discriminating the necessity of retreatment after coiling of intracranial aneurysms with high sensitivity and specificity. Our results were consistent with those of the previous studies,⁴¹⁻⁴⁴ demonstrating that radiographic changes in coil mass, such as coil compaction,⁴¹⁻⁴³ loosening,^{41,42} or reorientation,^{41,42} were useful

surrogates for recanalization of coiled aneurysms. The coil compaction, which corresponded to Deformation in our study, is believed to be caused by the water hammer effect of pulsatile blood flow along with partial thrombus dissolution within the aneurysm.^{31,45)} Loosening of the coil mass, which corresponded to Sparseness in our study, may be also induced by the same mechanism. Increased intra-aneurysmal blood flow may sometimes lead to Cleft formation. It should be noted, however, that Sparseness does not always indicate recanalization of the aneurysm. When Sparseness was observed during follow-up, it may also reflect fluctuations between recanalization and rethrombosis of the aneurysm after coiling, and therefore result in the morphological change in the coil mass without net change of aneurysm occlusion.^{41,42)} Besides in the follow-up periods, Sparseness can be also observed just after the coil embolization. This is because, in some cases, coil loops may be distributed sparsely throughout the aneurysm rather than forming solid mass at the initial coil embolization. Even in such cases, however, follow-up craniograms seem to be still useful because they can detect morphological change in the scattered coil loops in most of the recurrent cases. In addition to these morphological changes in the coil mass, Fray, morphological changes at the margin of the coil mass, was also observed in the retreated cases. While Sparseness represents impingement of blood flow at the center of the coil mass, Fray suggests that in the margin of the coil mass. Given Fray and Sparseness and Fray accounted for more than 30% of our retreated cases, it seems to be also important to observe the margin of the coil mass in interpreting craniograms during follow-up of coiled aneurysms. In contrast to these qualitative assessment for morphological changes in the coil mass, Ahn et al. demonstrated quantitative assessment measuring the largest and the perpendicular diameter of the coil mass to indicate aneurysmal recurrence.⁴⁴⁾ Indeed this subjective method provided high reproducibility, it can just indicate outline of the coil mass and cannot reflect Sparseness as well as Fray, which accounted for more than half of the retreated cases. Therefore, our assessment might be more sensitive to detect coiled aneurysms that required retreatment.

There were several limitations in this study. The most important one was that there were 4 retreated cases without morphological changes in the coil mass in our series. This false negative can be reduced if craniograms are obtained from the projection used for coil embolization as Cottier et al. did.⁴¹⁾ Indeed, in one of these 4 cases, morphological change in the coil mass emerged when it was observed from the working projection during the follow-up DSA. In clinical settings, however, it seems unlikely that

craniograms can be always taken from the precisely same projections as those used for the coil embolization. In the rest of the 3 cases, no morphological change in the coil mass was observed on craniograms even from the working projection and regrowth⁴⁵⁻⁴⁷⁾ of the coiled aneurysms was later disclosed on DSA. Besides these, there might be cases in which coil compaction occurs just inside the outer shell of the coil mass. In such cases, craniograms would be helpless in detecting the hollow of the coil mass. Therefore, complementary use of MRI and/or DSA along with craniogram is desirable although not regularly. Another limitation was that there were 4 cases in which morphological changes in the coil mass were observed on craniograms while no additional treatment was required. In all the cases, morphological change was Fray reflecting slight neck remnant. Complementary use of MRI and/or DSA is again important to discriminate if further retreatment is considered in such cases. Nevertheless, we believe that the usefulness of craniograms as the primary modality for follow-up of coiled aneurysms was assured by the results described earlier in discriminating the necessity of retreatment, along with its less invasiveness and cost consciousness.

Recent studies demonstrated a very low incidence of rebleeding for ruptured aneurysms and bleeding for unruptured aneurysms after coil embolization^{48,49)} along with risk factors for the aneurysm rupture.⁴⁸⁾ Although the correlation between bleeding from coiled aneurysms and recanalization has not been well clarified, we believe that aggressive intervention for recanalized aneurysms is one of the reasons for this low rupture rate of coil aneurysms. Therefore, watchful imaging follow-up is still important and the craniogram will be a promising modality for coiled aneurysms.

Conclusion

A craniogram is a useful modality in following up the coiled intracranial aneurysms to detect those required retreatments especially when employed complementarily with MRI and DSA.

Conflicts of Interest Disclosure

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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