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Metallic Artifice Reduction Angiotomography Versus Digital Subtraction Angiography for the Evaluation of Occlusion of Intracranial Aneurysms after Endovascular Management

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Abstract

Objective: *To compare the accuracy of metallic artifice reduction Angiotomography (CTAMaR) and digital subtraction angiography (DSA) for the evaluation of occlusion of intracranial aneurysms after endovascular management with coils.*

Background: *Intracranial aneurysms affect about 2% of the general population. Endovascular embolization with coils is used to treat acute subarachnoid hemorrhage and unruptured aneurysms. Image follow-up is necessary and the DSA has been considered the "gold standard". Over time, time-of-flight MRA and other alternative techniques will replace DSA. In some cases, MRA is not an option, so (CTAMaR) is considered as a viable alternative for monitoring coil-embolized aneurysms.*

Methods: *Retrospective study in patients with intracranial aneurysms treated by coil embolization at the José Eleuterio González University Hospital (HU) in 2018 and 2019, who underwent CTAMaR and DSA for follow-up after embolization. The images were independently analyzed by two Neuroradiologists and two Endovascular Neurosurgeons. The observers agreed and K statistics were used to calculate the Cohen coefficient.*

Results: *66 patients were treated in 62 coil embolizations between 2018 and 2019. After the exclusions, 12 image pairs formed the study group. In 92% of the compared images, the results of the CTARAM and the DSA coincided. The sensitivity and specificity of the CTARAM were calculated, which were respectively 100% and 75%.*

Conclusion: *This study suggests that CTAMaR is a safe and valuable method for monitoring coil-embolized cerebral aneurysms. This technique is as accurate as DSA in the evaluation and detection of recanalization of coil-embolized aneurysms.*

Keywords: Angiography, Endovascular, Metallic Artifice, Digital Subtraction

Introduction

Intracranial aneurysms are a significant public health problem worldwide, affecting approximately 2% of the population [1]. Endovascular treatment, initiated in 1991 with the use of detachable Guglielmi coils (GDC) is currently widely accepted as a therapeutic option in patients with acute subarachnoid hemorrhage (SAH) or unruptured cerebral aneurysms [2-5].

However, aneurysms treated with GDC may recur. Results from the International Subarachnoid Aneurysm Trial (ISAT) showed a rebleeding rate of 0.2% per patient per year, with a follow-up ranging from 1 to 8 years and an average of 4 years [6]. Imaging follow-up is often necessary to assess the presence of residual or recurrent aneurysms after embolization. Traditionally, digital subtraction angiography (DSA) has been considered the "gold standard" for this follow-up, despite being invasive and carrying risks of complications, including exposure to ionizing radiation, nephrotoxicity of iodine-based contrast agents, cerebral thromboembolism, and iatrogenic arterial damage. Reported rates of neurological complications range from 0.34% to 1.3% [7].

Some studies suggest that magnetic resonance angiography (MRA) is superior to computed tomography angiography (CTA) due to the absence of metallic artifacts produced by the coil mass [7]. Therefore, alternative non-invasive imaging techniques such as time-of-flight MRA (TOF-MRA), contrast-enhanced MRA (CE-MRA), rotational flat-panel angiography with intravenous contrast injection (ivACT), and metallic artifact reduction software have been attempted to replace DSA for detecting residual aneurysms after embolization [8-10, 16-19, 22]. Some authors suggest that DSA 3 or 6 months after coil placement can be replaced by MRA [11]. In some countries and in some patients, MRA is not an option or not available; therefore, the technique of CTA with metallic artifact reduction (CTAMaR) is proposed as a viable alternative as efficient as DSA for the follow-up and evaluation of coil-embolized aneurysms.

The purpose of this retrospective study is to evaluate the accuracy of 64-slice CTAMaR compared to DSA in detecting recanalization or remnants of coil- embolized intracranial aneurysms.

In our country, the high costs of performing DSA for the follow-up of a coil- embolized cerebral aneurysm must be covered in most cases by the patient or their family. Similarly, MRA also has a high cost and is not available in some remote regions. On the other hand, DSA, being an invasive study, subjects the patient to a risk of complications, although low, which can be avoided through non- invasive imaging techniques. In some patients, such as those with claustrophobia or incompatible pacemakers, MRA is simply not an alternative [16].

Despite the proven effectiveness of endovascular therapy in managing cerebral aneurysms in various randomized controlled trials, a recurrence of the aneurysm up to 30% has been demonstrated, which does not always require retreatment but may be associated with a rebleeding risk of 0.2% per patient per year [6, 12, 13]. Therefore, it is understood that coil-embolized aneurysms must be strictly monitored, as there is a real risk of both recanalization and subarachnoid hemorrhage. CTAMaR is relatively inexpensive and can be performed quickly immediately after routine non-enhanced brain computed tomography (CT) in patients with suspected aneurysmal SAH or after treatment. CTAMaR has demonstrated potential in the non-invasive detection of intracranial aneurysms, as well as recanalization after embolization [16, 19]. For these reasons, DSA or MRA is performed in our environment for the control of embolized aneurysms; however, with the image optimization technique of CTA reducing artifacts produced by embolic material (coils, stents), the recanalization or residue of the embolized aneurysm can be reliably evaluated compared to DSA, at a lower cost and with a technique that is reproducible in other centers without MRA or DSA. This reduces the costs of these studies and makes the imaging follow-up of our patients more viable. Many hospitals may not have access to rotational DSA, but they have 64- slice CT machines, especially in developing countries [15].

Since the introduction of endovascular management of cerebral aneurysms with GDC in 1991, artifacts produced by these were noticed in tomography images, so follow-up protocols with brain resonance were quickly developed, where the imaging defect produced by the coil mass was attenuated. For this reason, and with the technology of the time, CTA was abandoned in the follow-up of embolized aneurysms. However, with the advancement of techniques for reducing metal artifacts (CTAMaR), a much better visualization of the embolized aneurysm, its neck, or even its recanalization was achieved. This technique can now be compared with both DSA and MRA, becoming an alternative for patients or places where the latter are not available for various reasons. Currently, optimized rotational CT images with angiography equipment have been developed as a new follow-up modality, which can be comparable to DSA or MRA [14, 17, 18, 19, 22]. However, in our environment, it is much less feasible and more expensive to take the patient to a hemodynamics room for rotational tomography than to perform CTAMaR or MRA.

Objectives

General Objective

The purpose of this retrospective study is to evaluate the accuracy of CTAMaR compared to conventional angiography (DSA) in detecting recanalization or remnants of intracranial aneurysms embolized at our hospital during 2018 and 2019.

Materials and Methods

Study Design

This study is an observational retrospective study involving patients with intracranial aneurysms treated through coil embolization at the Hospital Universitario José Eleuterio González (HU) during the years 2018 and 2019. These patients underwent both CTAMaR and DSA for the follow-up of the aneurysm post- embolization.

Image Analysis

CTAMaR and DSA images will be independently analyzed by two Neuroradiologists and two Endovascular Neurosurgeons. Findings will be classified into one of the three categories of the Raymond classification: complete occlusion, residual neck, or residual aneurysm. Concordance among observers and techniques will be assessed using Kappa statistics by calculating the Cohen coefficient. A coefficient value of 0.41-0.60 is interpreted as moderate agreement, 0.61o 0.80 as substantial agreement, and 0.81–1.00 as almost perfect agreement.

1. **Inclusion Criteria**

- Patients treated for cerebral aneurysms via endovascular coil embolization at HU during the years 2018 to 2019.
- Patients embolized with coils.
- Patients solely embolized at HU, not at another institution.
- Aneurysms larger than 2mm.

2. **Exclusion Criteria**

- Patients for whom access to their medical records is unavailable.
- Patients for whom both DSA and CTAMaR images are not available.
- Patients who received treatment at another institution.
- Patients with associated vascular abnormalities such as arteriovenous malformations, dural fistulas, or traumatic, fusiform, or mycotic aneurysms.
- Patients with follow-up images taken more than three years after the initial treatment.
- Patients with iodine contrast allergy.
- Poor-quality DSA or CTAMaR images.
- Patients with follow-up images conducted at another institution.

3. CTAMaR Multidetector Protocol

All skull CTA examinations were performed using a 64-slice CT scanner (LightSpeed VCT, General Electric) based on a standardized protocol. CTA was initiated using Smart Prep with "activation" of the common carotid artery after the intravenous contrast bolus was started. Non-ionic iodinated contrast material (OPTIRAY 300) was injected at a rate of 3.5-4.5 ml/s using a dual-head power injector (Medrad, Stellant). The volume of iodinated contrast material in each study was generally 50 to 80 ml. CTA data acquisition was performed according to the following protocol: 120-140 kV, 420 mAs, 0.625 mm slice thickness, and 0.625 mm reconstruction interval. The scan rotation time was 0.4 s. A caudocranial scanning direction was selected, and the coverage volume extended from the first cervical vertebra to the upper aspect of the frontal sinuses.

The number assigned to a pixel in a computed tomography (CT) image is called the "CT number." This CT number represents the linear attenuation coefficient at the pixel's position in the image. CTAMaR is achieved through window modification, also known as "gray-level mapping" or "histogram modification." This process involves adjusting the grayscale component of a CT image by modifying the CT numbers, thereby changing the appearance of the image to highlight specific structures. The brightness of the image is adjusted on the vertical axis (C) of the window (y-axis), while the contrast is adjusted across the transverse axis (A) of the window (x-axis). The window width (WW), on the x-axis, expressed as an "A," is the measure of the range of CT numbers contained in an image. A wide window width (e.g., 2000 Hounsfield Units, HU) will display a broader range of CT numbers. Therefore, the transition from dark to light structures will occur over a larger transition area compared to a narrow window width (e.g., <1000 HU).

The window level (WL), on the y-axis, also known as the window center and expressed as a "C," is the midpoint of the displayed range of CT numbers. When the window level is reduced, the CT image will appear brighter, and when increased, it will appear darker. Considering WW and WL, upper and lower gray levels can be calculated. Values above "x" will be displayed as white, and values below "y" will be displayed as black. The upper gray level (x) is calculated as: NV + (AV/2), and the lower gray level (y) is calculated as: NV - (AV/2). For example, the optimization of brain tissue visualization is achieved with the values A: 80 and C: 40. Although these values may vary slightly from one institution to another and from one observer to another, the proposed values for our CTAMaR protocol to assess residual aneurysms are A: 1140 and C: 2574

4. Protocol for Digital Subtraction Angiography (DSA) Cerebral Angiography

Intra-arterial DSA was performed within 60 days following the CT angiography (CTA) study. All DSAs were performed transfemoral using a 5Fr Jb2 diagnostic catheter introduced through an introducer. The procedure utilized a monoplane DSA unit (Allura Xper FD20 X-ray System Philips, Netherlands B.V.). Non-ionic contrast material (Optiray 240/100 ml; Mallinckrodt Medical Imaging Ireland, Damastown Mulhuddart) was employed in all cases. Manual injections were carried out for all angiography procedures in the angiography suite. Standard injection rates and volumes were as follows: 6 - 8 ml for the common carotid artery, 4–5 ml for the internal carotid artery, 3–4 ml for the vertebral artery, 6–8 ml for the subclavian artery, and 10 ml for the aortic arch. Selective angiograms of the carotid were obtained bilaterally in anteroposterior, lateral, and bilateral oblique (+45° and -45°) projections. Additional oblique projections were selectively obtained to clarify aneurysm anatomy at the discretion of the angiographer. DSA was conducted with a field of view of 30 cm x 38 cm and a matrix of 1024 × 1024. The spatial resolution was 0.32 mm × 0.32 mm.

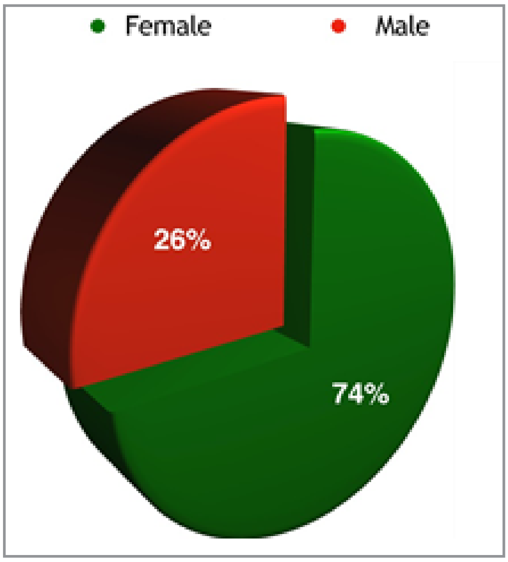
Results

Patient Demographics and Study Group

66 patients (49 females, 17 males) with an average age of 56.5 years (range: 4-86 years) and a total of 71 aneurysms underwent treatment through 62 coil embolizations between January 1, 2018, and December 31, 2019 (see Graph 1). Following exclusions (54 excluded patients), 12 pairs of images were included in the study group, representing 12 coil embolization procedures in an equal number of patients.

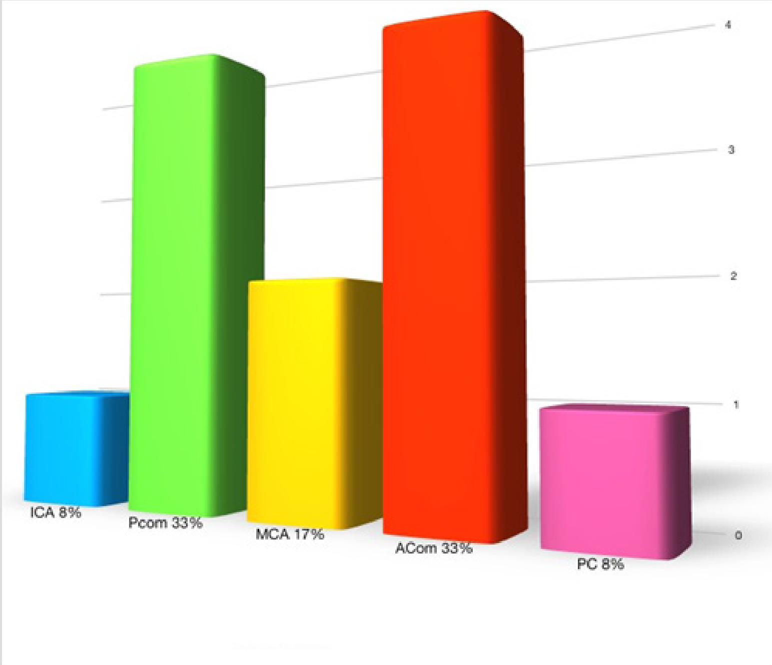
Graph 1. Distribution by Gender of embolized Aneu

Gender	No. of Patients
FEMALE	49
MALE	17



Study Group Characteristics

The study group comprised 10 females and 2 males, with an average age of 59.7 years (range 25-85). The aneurysms were located as follows: Internal Carotid Artery (ICA) 1, Posterior Communicating Segment of the Internal Carotid Artery (Pcom) 4, Middle Cerebral Artery (MCA) 2, Anterior Communicating Artery (AcoA) 4, and Posterior Circulation Aneurysms - Posterior Inferior Cerebellar Artery (PC) 1. Graph 2. The average time difference between paired follow-up investigations CTAMaR and DSA was 2.7 months (median of 3 months, range 0 to 3 months). The average time difference between embolization and the initial follow-up CTA (for recurrence detection, rather than other indications such as neurological deterioration or vasospasm) was 2.17 months (median of 3 months, range 0.5 to 6 months). Additionally, the average time difference between embolization DSA and the initial follow-up DSA was 3.83 months (median of 6 months, range 2 to 8 months). In 11 out of the 12 (92%) paired follow-up episodes, the results of CTAMaR and DSA coincided (see Graph 3). The agreement per patient regarding the diagnosis of aneurysm residue between Neuroradiologists and Endovascular Neurosurgeons, based on the Cohen's Kappa statistical test, was 0.82 (95% CI = 0.71–0.92), with a standard error r = 0.51 and significance < 0.05. Among these 11 patients with agreement, 7 (64%) showed no evidence of recurrence in either CTAMaR or DSA (see Graph 3).

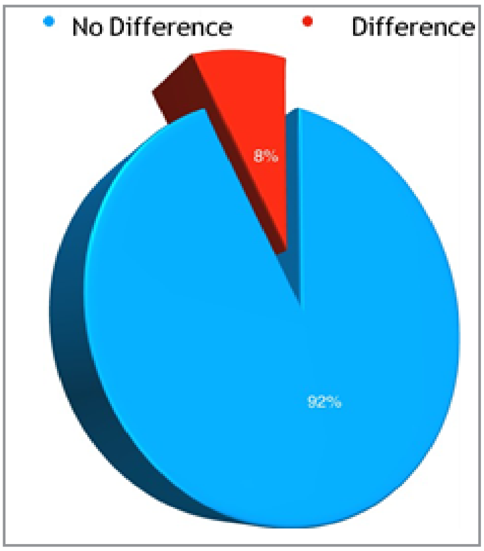


Graph 2. Location of Aneurysms

Graph 2. Localization of the 12 Studied Aneurysms: Internal Carotid Artery (ICA): 1, Posterior Communicating Segment of the Internal Carotid Artery (Pcom): 4, Middle Cerebral Artery (MCA): 2, Anterior Communicating Artery (AcoA): 4, Posterior Circulation Aneurysms - Posterior Inferior Cerebellar Artery (PC): 1

Graph 3. Difference Between CTAMaR and DSA

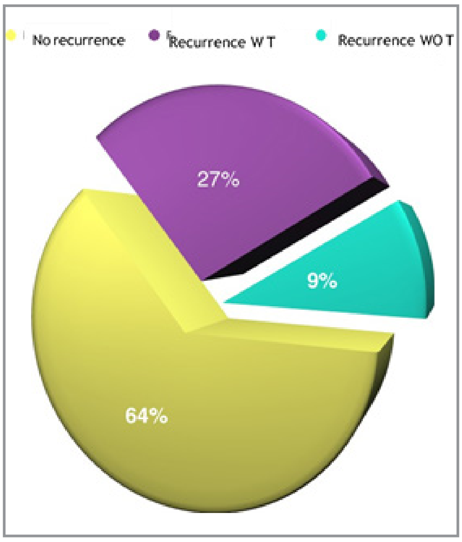
Difference	No. of Patients
NO	11
SI	1



In 3 out of 11 cases (27%), both CTAMaR and DSA revealed small areas of filling in the aneurysm neck, which did not necessitate additional treatment. In 1 out of 11 cases (9%), both modalities identified an aneurysm recurrence that required a repeat endovascular treatment. Graph 4 provides a visual representation of these findings.

Graph 4. Recurrences Requiring Additional Treatment

DSA and CTA recurrence. and treatment	No. of Patients
Non-recurrence	7
Recurrence without treatment	3
Recurrence with treatment	1



In one case (8%) out of the 12 episodes, a discrepancy was identified between the results of CTAMaR and DSA regarding the presence or absence of aneurysm recurrence (Table 1). In this case (Case No. 2), CTAMaR revealed a small recurrence that was not identified in the corresponding DSA. However, there was a time difference of 92 days between the two studies, with the DSA being performed first (Fig 2).

The sensitivity and specificity of CTAMaR were calculated as 100% and 75%, respectively. Similarly, the positive predictive value and negative predictive value of the test were calculated as 88.8% and 100%, respectively.

Table 1: Summary of Findings

Patients identified by number	Age	Gender	Location of the aneurysm	CATMaR Rechanneling/Resi due	DSA Rechanneling/Resi due	Retreatment
1	73	F	ICA	SIRR2	NO	No
2	57	F	PICA	NO	NO	No
3	42	M	ACoA	SIRR3	SIRR3	Si
4	49	F	PCom	NO	NO	No
5	48	F	MCA	NO	NO	No
6	49	F	PCom	NO	NO	No
7	25	F	ACoA	NO	NO	No
8	62	F	PCom	SIRR2	SIRR2	No
9	72	F	PCom	SIRR2	SIRR2	No
10	76	M	ACoA	SIRR2	SIRR2	No
11	79	F	MCA	NO	NO	No
12	85	F	ACoA	NO	NO	No

Table 1. Summarizes the findings of distribution by age, sex, location of aneurysms, recurrence with Raymond Roy Classification. (RR: 1 complete embolization, 2. Residual neck, 3. Residual aneurysm), difference between recurrence in CTAMaR and DSA, and the need of withdrawal. Internal Carotid Artery (ICA), Posterior Communicating Segment of Internal Carotid (Pcom), Middle Cerebral Artery (MCA), Anterior Communicating Artery (AcoA), Posterior circulation aneurysms - Posteroinferior Cerebellar Artery (PICA)

Case 1

Patient No. 3. Male, 42 years old. In 2009, he presented with subarachnoid hemorrhage. An acutely ruptured ACoA aneurysm measuring 13mm x 14mm was embolized with coils. For 9 years, he did not attend follow-up appointments. In 2018, he returned with severe headache, decreased vision, and behavioral changes. A CTA (Fig 1. A-D) was performed, followed by CTAMaR algorithm application (Fig 1. E-H) with three-dimensional (3D) reconstruction, revealing aneurysm recurrence with coil mass compaction at the bottom of a large thrombosed aneurysmal sac, transforming the initially large aneurysm into a giant one. The 3D reconstruction (Fig 1. I, J) shows the actual image of the aneurysmal sac, separating it from the thrombosed wall and the coil mass. DSA (Fig 1. K, L) identifies the recanalized aneurysm measuring 32mm x 27mm. In our series, this was the only recurrence that required retreatment, successfully performed in 2019.

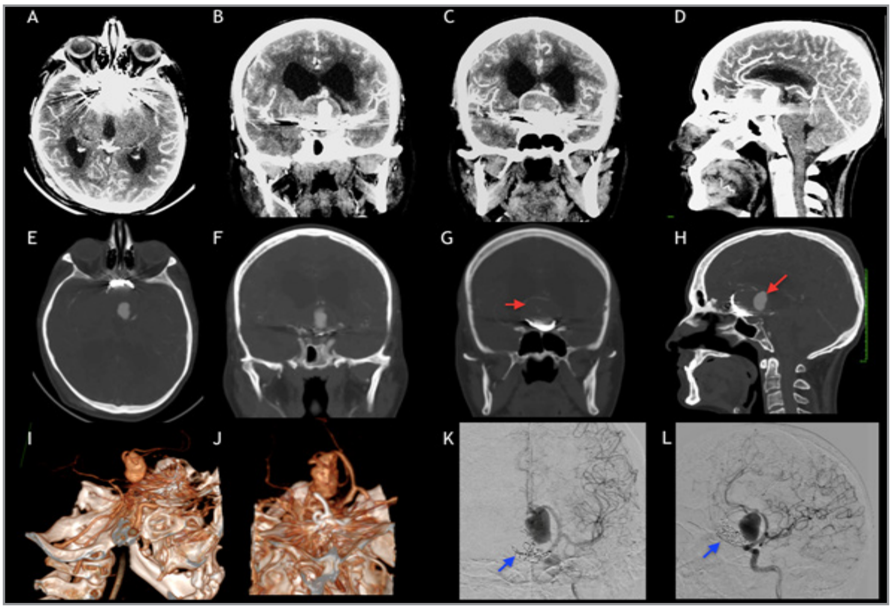


Figure 1: Recanalized Aneurysm, A-D: Shows traditional CTA with metallic artifact obscuring the true dimension of recanalization. B and C identify part of the partially thrombosed wall of the Anterior Communicating Artery aneurysm. E-H: CTAMaR completely reduces the metallic artifact, revealing detailed views of the active aneurysm wall (arrow in G) and the actual aneurysmal sac (arrow in H). I-J: 3D reconstruction of CTAMaR, depicting the recanalized aneurysm and its relationship with the cranial base and Anterior Cerebral Arteries. K-L: DSA reveals the residual aneurysm filling from the left Anterior Cerebral Artery and its relationship with compacted coils (arrow in K and L) at the bottom of the thrombosed wall of the giant aneurysm in frontal image K and left oblique L.

Case 2

Patient No. 1. Female, 73 years old. Subarachnoid hemorrhage. A ruptured right paraclinoid ICA aneurysm, type Ib, measuring 10.6mm x 7.0mm, was treated with coils (Fig 2. A, C). Control DSA at 3 months post-embolization shows no evidence of recanalization or aneurysmal residue (Fig 2. B, D). CTA at three months (Fig 2. E-G), using the CTAMaR algorithm (Fig 2. H-J), and with Maximum Intensive Projection (MIP) reconstruction, reveals contrast within the coil mass (Fig 2. K) and in the aneurysmal neck (Fig 2. L) as signs of attic recanalization. This case demonstrates disagreement among observers regarding recanalization, highlighting how CTAMaR can be more sensitive than DSA in some cases of recanalization that may not be evident in DSA. No additional treatment has been required.

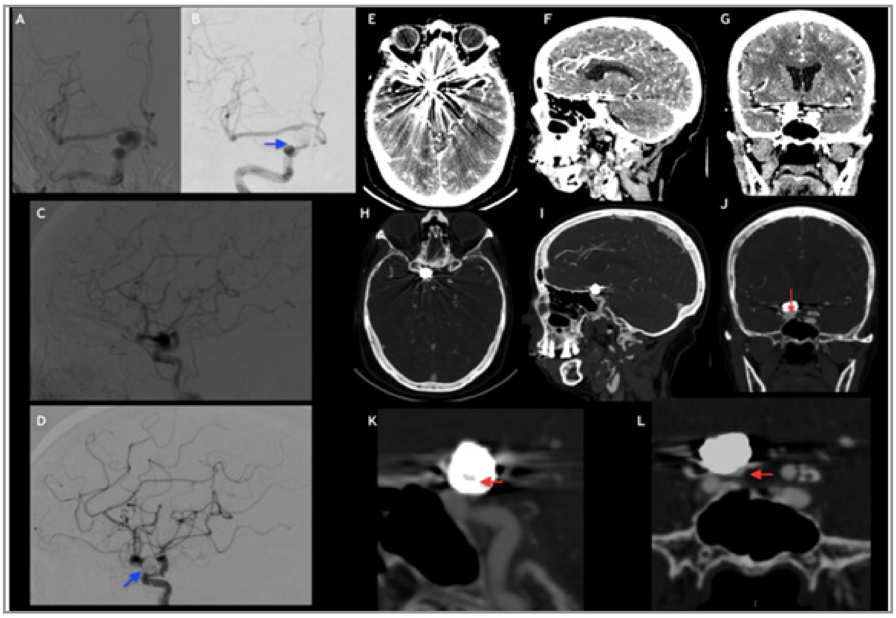


Figure 2: CTAMaR - DSA Discrepancy: A-D: DSA showing right paraclinoid aneurysm. Before embolization (A, C) and 3 months post-embolization (B, D). No evidence of residue/recanal ization (arrow in B and D). E G: CTA with traditional technique where metallic artifact prevents visualization of recanalization. H-J: CTAMaR showing 2.2mm recanalization in the aneurysmal neck in coronal section (arrow in J). K-L: MIP of CTAMaR exhibits contrast within the coil mass (arrow in K) and in the aneurysmal neck (arrow in L).

Discussion

Patients with a treated cerebral aneurysm require follow-up to assess the aneurysm occlusion level or possible recanalization. In the follow-up of aneurysms treated with coil embolization, MRA (Magnetic Resonance Angiography) is the preferred imaging modality due to its high diagnostic accuracy with limited coil artifacts. MRA has a clear advantage over DSA (Digital Subtraction Angiography) because it is a non-invasive procedure that does not necessarily require the administration of contrast medium. However, some patients may be unable to undergo an MRI examination due to unsafe implants (e.g., a pacemaker) or claustrophobia. MRA is also not feasible in patients with an aneurysm treated with a surgical clip, a flow diverter, or a Woven Endo Bridge (WEB) device, as susceptibility artifacts hinder diagnostic evaluation. In these situations, DSA is routinely performed in the follow-up of treated cerebral aneurysms [16.]

As far as we know, CT Angiography with Metal Artifact Reduction (CTARaM) has not yet been assessed in comparison to DSA for the follow-up of coiled aneurysms. In our study, CTARaM demonstrated high sensitivity and specificity in detecting residual or recanalized aneurysms, showing a significant correlation with DSA. Based on distinguishing any remnant and no remnant, the agreement of CTARaM with DSA was very similar in assessing the rate of aneurysm occlusion. One advantage compared to DSA is that CTARaM allows the evaluation of multiple coiled aneurysms in a single examination step, and it is not necessary to conduct the study in the catheterization laboratory, as assessed in previous studies (Gölitz P, J Neuroradiol. 2014, Pjontek R, J Neurointerv Surg. 2016). In those studies, rotational flat-panel tomography was performed in the angiography suite with intravenous contrast injection (ivACT), and it was concluded that both ivACT and MRA have high accuracy in detecting residual or recanalization after coil embolization. The accuracy of both ivACT and MRA was comparable to the accuracy of DSA [17, 18]. Both non-invasive modalities allowed a reliable assessment of the aneurysm occlusion rate and residual size [17]. Additionally, the prototype metal artifact reduction software significantly improved image quality in ivCTA datasets in patients after clipping or coil embolization, resulting in significantly better diagnostic value in this patient group [18]. While ivACT, like CTARaM, is a non-invasive examination, its costs are higher in relation to CTARaM due to the use of the catheterization laboratory, limiting its use to locations with an angiography suite. CTARaM, on the other hand, is available wherever there is a state-of-the-art CT scanner and metal artifact reduction software, as used by Pan YN Clin Neuroradiol. 2019 or Frederick J. A. Meijer Insights Imaging. 2019, which recently introduced algorithms for single-energy metal artifact reduction (SEMAR) or ultra-high-resolution CT (UHRCT) on a second-generation 320-detector CT scanner to reduce the influence of metal implants in CT images [19, 22]. Their studies concluded that SEMAR and UHRCT reconstruction algorithms allowed better visualization of structures surrounding the aneurysm and improved detection of postoperative complications such as aneurysm recanalization or coil compaction [19]. These findings align with our results where CTARaM sensitively and specifically identified residual and recanalization in coiled aneurysms.

This research successfully demonstrated how CTARaM can find a place in the follow-up of patients who have undergone coil embolization. In cases where economic, geographical, or contraindications hinder the feasibility of MRA or DSA, CTARaM emerges as a cost-effective alternative with greater accessibility [15, 16]. Particularly in developing countries, where MRA and DSA are expensive and less available outside major city reference centers. The study suggests incorporating CTARaM as an initial follow-up examination after 3 months post-coil embolization of cerebral aneurysms. If no signs of recanalization are observed, subsequent examinations at 6, 12, and 24 months can be conducted using CTARaM. DSA would be necessary only if any of these follow-ups show signs of aneurysm recanalization, as observed in Case No. 2. Furthermore, follow-ups beyond 36 and 60 months can be performed using CTARaM, but additional research is needed to compare MRA with CTARaM in the follow-up of endovascularly treated aneurysms.

Our study had several limitations. Firstly, the absence of rotational angiography with 3D reconstructions hindered precise interpretation of intracranial angiograms, particularly for detecting neck remnants. Various studies have reported the false negatives of 2D DSA due to the effect created by the radiopaque coil mass around recanalization, highlighting the necessity of rotational angiography [20]. This limitation might explain why certain cases did not show recanalization, despite minimal contrast flow observed within the aneurysm on CTARaM but not on angiography, this was evident in-Patient No. 2. Secondly, our findings are constrained as we primarily used a single type of coil for aneurysm treatment in our study population. Additionally, the sample size and the number of aneurysms with residue/recanalization were relatively small; therefore, future research could aim to include a larger series of aneurysms with a higher number of recanalizations for analysis. Thirdly, being a retrospective, non-randomized case series, there could be a selection bias. Fourthly, the technology used for CTARaM in our study has substantially improved in recent years, achieving even better results with new software [16, 22]. Thus, a future research direction could involve a larger patient cohort incorporating the latest technological advancements in CTARaM for endovascularly treated aneurysms.

Conclusion

This study suggests that CTARaM is a safe and valuable method for monitoring intracranial aneurysms treated with coils. This technique is at least as accurate as DSA in assessing and detecting flow, residue, and recanalization in intracranial aneurysms treated with coils. CTARaM allows for non-invasive vascular imaging with good detail, approaching the resolution seen during invasive DSA. With the application of optimized image filtering for metal artifact reduction, CTA can be employed in the follow-up of brain aneurysms treated with coils. Based on these observations, we propose that CTARaM can, in certain scenarios, replace or complement DSA for monitoring images of intracranial aneurysms treated with platinum coils. However, the added value of CTARaM still needs to be evaluated in future prospective cohort studies with larger populations and incorporating new technologies.

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