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Feasibility of Metal Artifact Reduction on CT Angiography for Planning Direct Surgery of Tentorial dAVF after Onyx Embolization

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Abstract

Although Onyx is approved as an embolic material for arteriovenous malformation (AVM) and dural arteriovenous fistula (dAVF), metal artifacts due to Onyx on CT remain problematic. We report the feasibility of a metal artifact reduction (MAR) algorithm on CT angiography (CTA) in the planning of direct surgery of dAVF after transarterial Onyx embolization. A 45-year-old male patient presented with right pulsatile tinnitus, and cerebral angiography demonstrated right tentorial dAVF. As the dAVF had not completely disappeared even after Onyx transarterial embolization, we planned direct surgery. Evaluation of the lesion was difficult on normal preoperative CTA because of Onyx artifacts, but CTA using MAR enabled a detailed planning of direct surgery. Direct surgery was performed through right retrosigmoid craniotomy. Referencing CTA using MAR, we identified the draining veins originating from the main drainer, which were coagulated and cut, achieving complete occlusion of the dAVF. His symptoms disappeared with no postoperative complications. CT angiography using MAR was useful for planning direct surgery after Onyx embolization. As the incidence of direct surgery after transarterial Onyx embolization for AVM or dAVF is increasing, MAR on CTA will become more important.

Keywords
- direct surgery
- tentorial dAVF
- Onyx embolization
- smart metal artifact reduction

Introduction

Although Onyx (Micro Therapeutics, Inc., Irvine, CA, USA) is approved as an embolic material for arteriovenous malformation (AVM) and dural arteriovenous fistula (dAVF) with good outcomes,[1,2] metal artifacts due to Onyx on CT remain problematic after embolization.[3,4]

We report the feasibility of CT angiography (CTA) using a metal artifact reduction (MAR) algorithm in the preoperative evaluation for direct surgery after transarterial Onyx embolization of tentorial dAVF.

Case Report

A 45-year-old male patient had right pulsatile tinnitus and visited a nearby hospital. By cranial magnetic resonance imaging, right tentorial dural arteriovenous fistula (dAVF) was suspected and he was referred to our department.

Cerebral angiography demonstrated arteriovenous shunts on the tentorial dura of the right petrous bone. The marginal tentorial artery (MTA), the posterior convexity branch of the right middle meningeal artery (MMA), the right accessory meningeal artery (AMA), and the mastoid branch of the right

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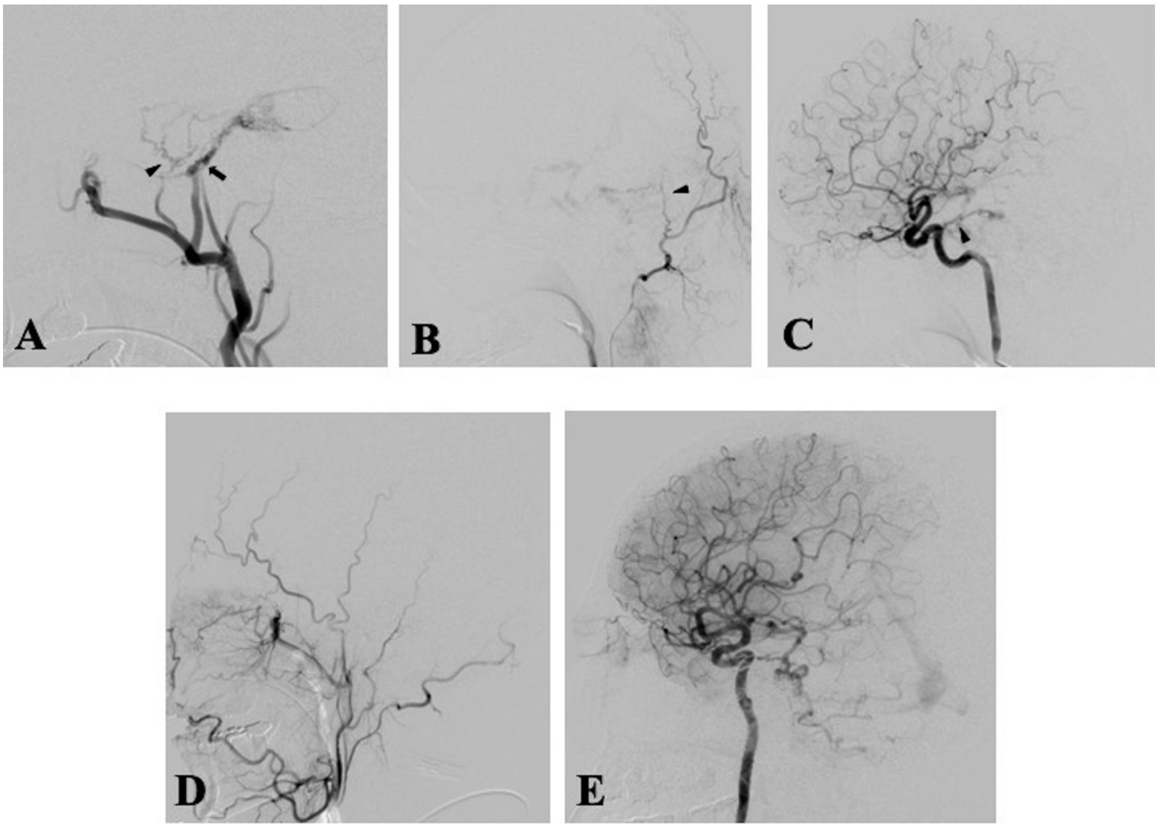

Fig. 1 Angiograms of the right internal maxillary artery (**A**), right OA (**B**), right internal carotid artery (ICA) (**C**) demonstrated right tentorial dAVF fed by the posterior convexity branch of the right MMA (**A**: *arrow*), the right AMA (**A**: *arrow head*), the mastoid branch of the right OA (**B**: *arrow head*), and the right MTA (**C**: *arrow head*). The dAVF drained into the right petrous veins, and the shunt flow was refluxed backward to the veins of the cerebellum and basal veins. After transarterial embolization, the angiogram of the right ECA (**D**) and right ICA (**E**) showed the disappearance of feeding arteries from the right ECA and a surviving feeder from the right MTA.

occipital artery (OA) were the main feeders, and the right petrous veins were draining veins. The shunt flow was refluxed backward to the veins of the cerebellum and basal vein (Borden type III, Cognard type III, Lawton type V)[5–7] (►**Fig. 1A–C**).

As the first-line treatment, we performed transarterial embolization. During the first session, we selected the branch of the right MMA and injected 0.27 mL of Onyx-18 into the dAVF, followed by 0.47 mL of Onyx-18 into the branch of the right AMA. During the second session, the branch of the right MMA and the branch of the right OA were selected for embolization, into which 0.36 and 0.57 mL of Onyx-18, respectively, was injected. After two sessions of transarterial embolization, feeding arteries from the right external carotid artery (ECA) disappeared, but the dAVF was still fed by the right MTA, and the petrous veins still refluxed backward to the veins of the cerebellum and basal vein (►**Fig. 1D, E**).

Aiming at a complete cure of dAVF, we planned direct surgery. We performed CTA as a preoperative evaluation of direct surgery. CTA was performed by high-definition CT (Revolution EVO; General Electric Healthcare, Chicago, IL, USA). The patient was in the supine position. A bolus of contrast material (Iopamidol, Oypalomin 370 mgI/mL; Fuji Pharma Co., Ltd. Tokyo, Japan) was injected into the median cubital vein at a flow rate of 3 mL/s for 25 seconds. The raw data were reconstructed conventionally or with a commercial MAR algorithm (Smart MAR; General Electric Healthcare, Chicago, IL, USA) and transferred to the Aquarius NET Thin Client Viewer (TeraRecon, Foster City, CA, USA). Although evaluation of the lesion was difficult on normal CTA because of artifacts by Onyx (►**Fig. 2A**), CTA using MAR enabled a detailed planning of the direct surgery of the lesion (►**Fig. 2B, C**). On CTA images using MAR, we were able to recognize the three petrosal veins as the draining veins originating from the main drainer at the cerebellopontine angle, one of which was filled with Onyx (►**Fig. 2B, C**).

Direct surgery was performed through right retrosigmoid craniotomy. The main drainer of the dAVF originated at the petrosal surface (►**Fig. 3A**). We coagulated it at the site that penetrated the dura to reduce its volume (►**Fig. 3B**). Referencing CTA images using MAR, we identified the three petrosal veins originating from the main drainer. They were coagulated and cut (►**Fig. 3C–E**), leading to complete occlusion of the dAVF (►**Fig. 3F**).

After surgery, the right-sided pulsatile tinnitus disappeared with no postoperative complications. Angiogram performed 1 week later confirmed no residual dAVF (►**Fig. 4A, B**).

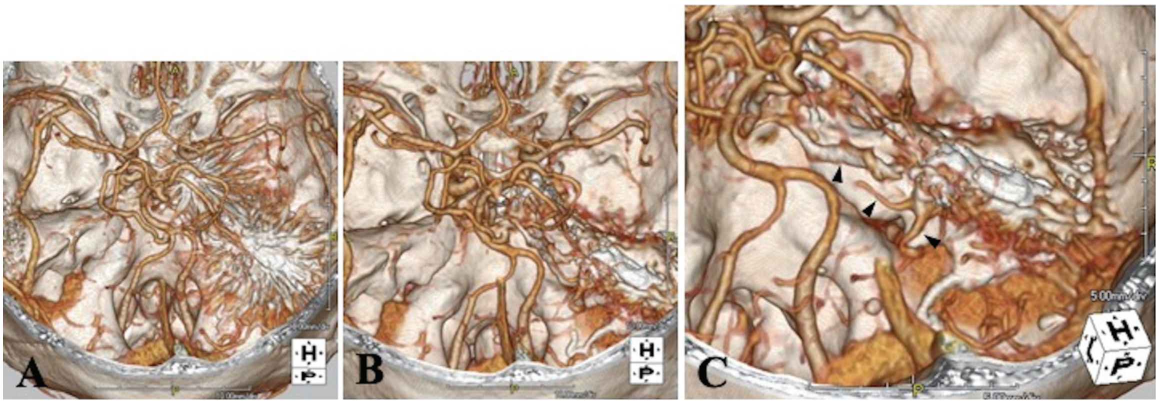

Fig. 2 On standard CTA (**A**), evaluation of the lesion was difficult because of strong artifacts by Onyx. However, on CTA using MAR (**B**), we were able to assess the lesion in detail and recognize the three petrosal veins as the draining veins (**C**) (*arrowheads*).

Discussion

Tentorial dAVF is a relatively rare type of dAVF, accounting for less than 4% of all intracranial dAVF.[8] Compared with dAVF in other regions, tentorial dAVF has a higher risk of intracranial hemorrhage, venous infraction, and aggressive neurological behavior. Furthermore, those characterized by cortical venous drainage often have a high incidence of aggressive behavior, hence the need for immediate and accurate treatment.[9,10] Although treatment options include surgical interruption of the draining vein,[7] stereotactic radiosurgery,[11] endovascular procedure,[12–15] and a combination of these options,[16,17] no optimal treatment has been established.

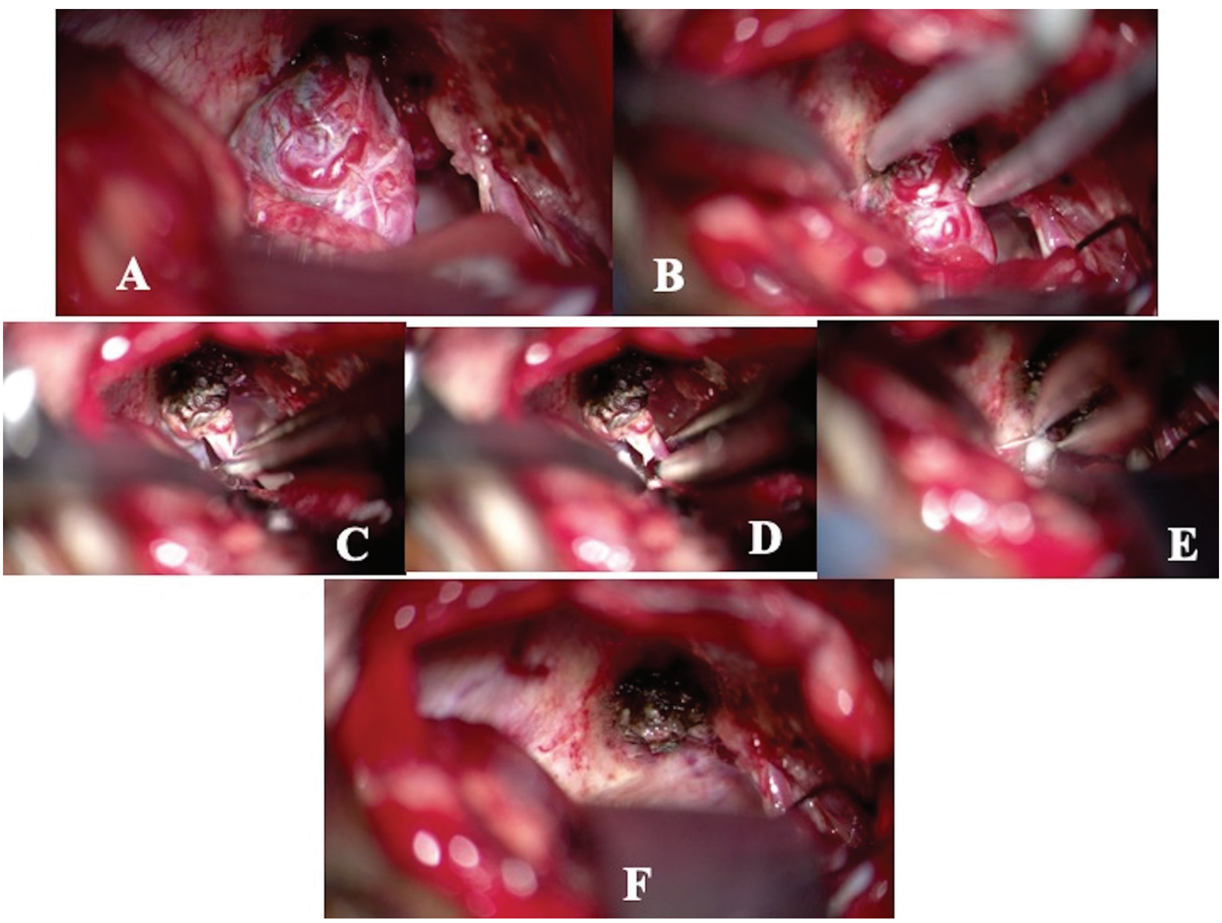

Fig. 3 Intraoperative findings. The main drainer of the dAVF originated at the petrosal surface (**A**). It was coagulated to reduce its volume (**B**). Referencing CTA images using MAR, three petrosal veins originating from the main drainer were coagulated and cut (**C–E**), leading to complete occlusion of the dAVF (**F**).

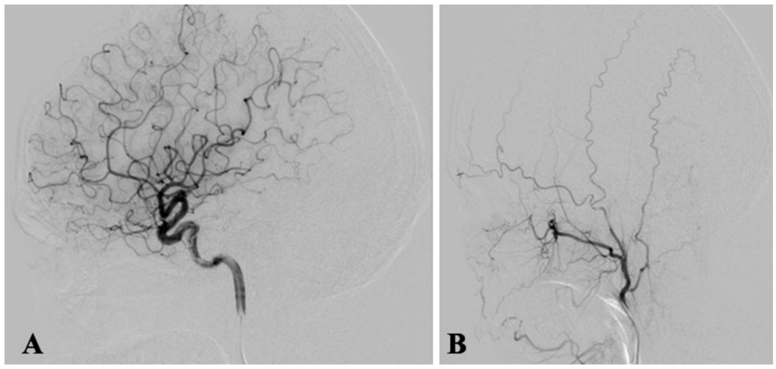

Fig. 4 Angiograms of the right ECA (**A**) and right ICA (**B**) demonstrated the obliteration of the fistula.

As endovascular procedures, we have strategies involving transvenous embolization and transarterial embolization. The transvenous approach that sacrifices the dural sinus has a high cure rate, but using this approach for tentorial dAVF is often difficult because most directly drain into cortical veins without the main sinus.[15] Therefore, transarterial embolization is the main endovascular procedure. To achieve complete cure by transarterial embolization, it is important that embolic material is injected beyond the shunt point to penetrate the vein side. If endovascular therapy is inappropriate or ineffective, surgical disconnection of the fistula is the most efficacious treatment.[17]

In the present study, as the first-line treatment, we selected transarterial embolization. After two sessions of transarterial embolization, we considered the complication risk of transarterial embolization via MTA. Based on pathological analyses of tentorial dAVF, the surgical approach is more likely to be curative and has a lower risk of postoperative complications.[7,12,13,15]

Onyx was approved in Japan as "an embolic material for dAVF for which transvenous embolization is difficult" in 2018. Onyx is liquid embolic matter of the separation type and it is not adhesive. It is easy to control more embolic material, and one of the advantages is that immediate judgment is not necessary.[15,18,19] Although transarterial Onyx embolization for tentorial dAVF has a higher complete cure rate and is safer than conventional embolization, there have only been a few cases of permanent cure by only transarterial Onyx embolization.[12,13,15]

Although the gold standard diagnostic method for dAVF is DSA, CTA has been reported to be feasible as a less-invasive imaging technique.[20] CTA provides excellent visualization of small vascular details and their relationship with the cranial bone in planning of craniotomy. Even in the planning of direct surgery for dAVF, CTA is useful to understand the location of the shunt point and drainers in relation to the cranial bone.[21]

However, for patients with a history of Onyx embolization, conventional CTA is not useful for follow-up because it cannot precisely depict the status of dAVF due to artifacts from Onyx. Evaluation of intracranial vessels is hampered by beam-hardening and photon starvation artifacts caused by Onyx.[3] The underlying reason for the artifact production by Onyx on CT imaging is the high absorption of photons by the admixed high-atomic number material tantalum (anatomic number 73), resulting in beam hardening, scatter, and noise, which are visible as dark and bright streaks in the reconstructed CT image. The higher degree of artifact production by Onyx can accordingly be explained by the higher atomic number of tantalum.[3]

Several studies regarding CTA with commercially available metal artifact reduction algorithms, including Smart MAR, have been reported.[22–28] With Smart MAR, platinum coil artifacts were greatly reduced, and we previously reported that the status of treated aneurysms was able to be depicted for patients with a history of clipping of recurrent aneurysms after coil embolization.[29] Our report may be the first that confirms the feasibility of MAR for the reduction of metal artifacts on CTA after transarterial Onyx embolization for dAVF. Due to the increase in the incidence of direct surgery after transarterial Onyx embolization for AVM or dAVF, CTA using MAR may become more important.

Conflicts of Interest
None declared.

Acknowledgments
Dr. Toyota, Dr. Taki, and Dr. Nakagawa contributed to the conception and design of the study. Dr. Toyota, Dr. Shimizu, Dr. Murakami, Dr. Taki, and Dr. Nakagawa recruited the patient and performed the operation. Dr. Toyota and Dr. Nakagawa contributed to writing the manuscript.

References

1 Elsenousi A, Aletich VA, Alaraj A. Neurological outcomes and cure rates of embolization of brain arteriovenous malformations with n-butyl cyanoacrylate or Onyx: a meta-analysis. J Neurointerv Surg 2016;8(03):265–272
2 Sadeh-Gonike U, Magand N, Armoiry X, et al. Transarterial Onyx embolization of intracranial dural fistulas: a prospective cohort, systematic review, and meta-snalysis. Neurosurgery 2018;82 (06):854–863
3 Vollherbst DF, Otto R, Do T, et al. Imaging artifacts of Onyx and PHIL on conventional CT, cone-beam CT and MRI in an animal model. Interv Neuroradiol 2018;24(06):693–701
4 Pop R, Mertz L, Ilyes A, et al. Beam hardening artifacts of liquid embolic agents: comparison between Squid and Onyx. J Neurointerv Surg 2019;11(07):706–709

5 Borden JA, Wu JK, Shucart WA. A proposed classification for spinal and cranial dural arteriovenous fistulous malformations and implications for treatment. J Neurosurg 1995;82(02):166–179
6 Cognard C, Gobin YP, Pierot L, et al. Cerebral dural arteriovenous fistulas: clinical and angiographic correlation with a revised classification of venous drainage. Radiology 1995;194(03):671–680
7 Lawton MT, Sanchez-Mejia RO, Pham D, Tan J, Halbach VV. Tentorial dural arteriovenous fistulae: operative strategies and microsurgical results for six types. Neurosurgery 2008;62(03, Suppl 1):110–124, discussion 124–125
8 Byrne JV, Garcia M. Tentorial dural fistulas: endovascular management and description of the medial dural-tentorial branch of the superior cerebellar artery. AJNR Am J Neuroradiol 2013;34(09):1798–1804
9 Awad IA, Little JR, Akarawi WP, Ahl J. Intracranial dural arteriovenous malformations: factors predisposing to an aggressive neurological course. J Neurosurg 1990;72(06):839–850
10 van Dijk JM, terBrugge KG, Willinsky RA, Wallace MC. Clinical course of cranial dural arteriovenous fistulas with long-term persistent cortical venous reflux. Stroke 2002;33(05):1233–1236
11 Takeuchi S, Kawaguchi T, Nakatani M, Satou K. Two cases of tentorial dural arteriovenous fistula successfully managed by gamma knife radiosurgery. Surg Cereb Stroke (Jpn) 2009;37(05):384–389
12 Lv X, Jiang C, Li Y, Yang X, Wu Z. Transarterial embolization of tentorial dural arteriovenous fistulas with onyx 18. Neuroradiol J 2008;21(03):406–414
13 Puffer RC, Daniels DJ, Kallmes DF, Cloft HJ, Lanzino G. Curative Onyx embolization of tentorial dural arteriovenous fistulas. Neurosurg Focus 2012;32(05):E4
14 Kim HJ, Yang JH, Lee HJ, Lee HJ. Tentorial dural arteriovenous fistula treated using transarterial Onyx embolization. J Korean Neurosurg Soc 2015;58(03):276–280
15 Huang Q, Xu Y, Hong B, Li Q, Zhao W, Liu J. Use of onyx in the management of tentorial dural arteriovenous fistulae. Neurosurgery 2009;65(02):287–292, discussion 292–293
16 Kortman HG, Boukrab I, Bloemsma G, et al. Tentorial dural arteriovenous fistulas: a single-center cohort of 12 patients. J Cerebrovasc Endovasc Neurosurg 2017;19(04):284–290
17 Tomak PR, Cloft HJ, Kaga A, Cawley CM, Dion J, Barrow DL. Evolution of the management of tentorial dural arteriovenous malformations. Neurosurgery 2003;52(04):750–760, discussion 760–762
18 Cognard C, Januel AC, Silva NA Jr, Tall P. Endovascular treatment of intracranial dural arteriovenous fistulas with cortical venous drainage: new management using Onyx. Am J Neuroradiol 2008;29(02):235–241
19 Nogueira RG, Dabus G, Rabinov JD, et al. Preliminary experience with onyx embolization for the treatment of intracranial dural arteriovenous fistulas. Am J Neuroradiol 2008;29(01):91–97
20 Biswas S, Chandran A, Radon M, et al. Accuracy of four-dimensional CT angiography in detection and characterisation of arteriovenous malformations and dural arteriovenous fistulas. Neuroradiol J 2015;28(04):376–384
21 Paolini S, Lanzino G, Colonnese C, Venditti E, Cantore G, Esposito V. Three-dimensional computed tomography angiography in presurgical planning for treatment of infratentorial dural arteriovenous fistulas. J Neurosurg 2009;110(01):85–89
22 Sunwoo L, Park SW, Rhim JH, et al. Metal artifact reduction for orthopedic implants: brain CT angiography in patients with intracranial metallic implants. J Korean Med Sci 2018;33(21):e158
23 Huang JY, Kerns JR, Nute JL, et al. An evaluation of three commercially available metal artifact reduction methods for CT imaging. Phys Med Biol 2015;60(03):1047–1067
24 Mennecke A, Svergun S, Scholz B, Royalty K, Dörfler A, Struffert T. Evaluation of a metal artifact reduction algorithm applied to post-interventional flat detector CT in comparison to pre-treatment CT in patients with acute subarachnoid haemorrhage. Eur Radiol 2017;27(01):88–96
25 Pjontek R, Önenköprülü B, Scholz B, et al. Metal artifact reduction for flat panel detector intravenous CT angiography in patients with intracranial metallic implants after endovascular and surgical treatment. J Neurointerv Surg 2016;8(08):824–829
26 Prell D, Kyriakou Y, Struffert T, Dörfler A, Kalender WA. Metal artifact reduction for clipping and coiling in interventional C-arm CT. Am J Neuroradiol 2010;31(04):634–639
27 Kidoh M, Utsunomiya D, Ikeda O, et al. Reduction of metallic coil artefacts in computed tomography body imaging: effects of a new single-energy metal artefact reduction algorithm. Eur Radiol 2016;26(05):1378–1386
28 Guilfoile C, Rampant P, House M. The impact of smart metal artefact reduction algorithm for use in radiotherapy treatment planning. Australas Phys Eng Sci Med 2017;40(02):385–394
29 Kuroda H, Toyota S, Kumagai T, et al. Feasibility of smart metal artifact reduction algorithm on computed tomography angiography for clipping of recurrent aneurysms after coil embolization. World Neurosurg 2019;127:e1249–e1254

