ORIGINAL ARTICLE

Vascular assessment after clipping surgery using four-dimensional CT angiography

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Abstract
Recent advances in computed tomography angiography (CTA) enable repeated imaging follow up for post-clipping surgery. The purpose of this study was to clarify the critical volume and configuration of the aneurysmal clip in the postoperative evaluation using volume rendering (VR) imaging, and present four-dimensional (4D)-CTA for these larger metal artifacts. A total of 44 patients with cerebral aneurysm, treated using clipping surgery, were included in this study. The metal artifact volume was assessed using CTA and the association between the type of clips and its metal artifact volume was analyzed. A VR image and a 4D-CTA were then produced, and the diagnostic accuracy of arteries around the clip or residual aneurysm on these images was evaluated. In the receiver operating characteristic (ROC) curve analysis, the cutoff value for metal artifacts was 2.32 mm^3 as determined through a VR image. Patients were divided into two groups. Group 1 included patients with a simple and small clip, and group 2 included patients with multiple, large or fenestrated clips. The metal artifact volume was significantly larger in group 2, and the group incorporated the cutoff value. Post-clipping status on the VR image was significantly superior in group 1 compared with group 2. In group 2, the imaging quality of post-clipping status on 4D-CTA was superior in 92.9% of patients. The metal artifact volume was dependent on the number, size, or configuration of the clip used. In group 2, evaluation using a 4D-CTA eliminated the effect of the metal artifacts.

Keywords Cerebral aneurysm · Clipping · Metal artifact

Introduction

Although optimal management of cerebral aneurysms depends on its individual aneurysmal characteristics, such as location, access, and morphology [4, 10, 36], clipping surgery is one of the most long-standing fundamental therapies. The efficacy and long-term prognosis are established [3, 8, 22, 31], and recurrence of cerebral aneurysm or a de novo aneurysm is rare [2, 19, 35]. An aneurysm remnant is reported in 2.3–14%

of initial clipping surgeries [5, 17, 23, 25, 29, 33, 37]. The incidence of aneurysm remnant growth is 13.6–25% [2, 5], and that of de novo aneurysm after clipping surgery is 0.89% per year [36]. Therefore, a long-term follow up is necessary, especially in patients with a long life expectancy. Evaluation with time of flight magnetic resonance angiography (MRA) is convenient because it is performed without a dose of radiation or contrast medium [36]. However, it is difficult to evaluate the residual neck or de novo aneurysm around the previous clip due to residual metal artifacts [15, 16]. Digital subtraction angiography (DSA) is ideal for detecting recurrence, but it is not realistic to perform DSA repeatedly because it is invasive. Alternatively, three-dimensional (3D) computed tomography angiography (CTA) to evaluate clipping after surgery has been widely used. Using a volume rendering (VR) image, assessment of an aneurysm remnant and detection of the relevant parent artery stenosis showed increased accuracy of CTA compared with DSA [13, 38]. Therefore, evaluation is frequently performed using CTA only. In terms of the accuracy of post-clipping status, 3D-DSA should be evaluated exactly [12, 20]. However, although the complication rate of DSA

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using modern techniques has been low at experienced centers [9, 41], DSA requires special skills, is costly, requires a high dose of radiation, and is time-consuming. Thus, CTA may be an alternative to DSA.

Recent advancements have been made in the multidetector-row CT (MDCT), and the rapid spread of this technology has enhanced the diagnostic use of perfusion imaging by enabling the evaluation of vascular lesions by [18]. Moreover, there is potential for vascular lesions to be evaluated using four-dimensional (4D)-CTA [11, 21, 40]. In this study, the association between the type of aneurysmal clips and their metal artifact volume was analyzed. Then, we established the critical volume and configuration of the aneurysmal clip in the evaluation using VR imaging, and demonstrated the clinical potential of 4D-CTA.

## Patients and methods

Patients

This study included all consecutive patients with a cerebral aneurysm who underwent clipping surgery and upon whom postoperative evaluation with 4D-CTA was performed at our hospital between January 2011 and December 2016. During the same periods, 68 patients with cerebral aneurysm were treated surgically in our institute. Of these, 24 patents were excluded because 16 patients underwent 3D-CTA evaluation using another MDCT scanner, 4 patients underwent clipping surgery with cobalt alloy clip, 3 patients were previously treated with coil embolization, and 1 patient was allergic to iodine. A total of 44 patients (12 males and 32 females) were enrolled, and their data were analyzed retrospectively. The median patient age (interquartile range) at the time of surgery was 66.5 (57.5–71.8) years (range, 13–82 years). Of the 44 patients, 7 had a ruptured aneurysm and 37 had an unruptured aneurysm.

The locations of the aneurysms were as follows: middle cerebral artery, 20 patients; internal carotid artery, 13 patients; anterior cerebral artery, 13 patients; and vertebro-basilar artery, 2 patients. In four patients, clipping surgery was performed for adjacent aneurysms during the same craniotomy, and the metal artifacts overlapped in these patients. In this circumstance, patients were considered as one case. In these patients, neck clipping was performed except for two patients with aneurysms who underwent trapping and bypass. Two kinds of titanium alloy clips were used to treat the aneurysms: SugitaClip Titanium II (MIZUHO Corp., Tokyo, Japan) and YASAGIL aneurysm clip system (B.BRAUN, Melsungen, Germany). The volume of metal artifact was assessed in these clips. A cutoff value for the metal artifact volume was then examined, which affected the evaluation of the parent artery, distal artery, or residual aneurysm using a VR image. These 44 patients were divided into two groups according to the clip configuration. Then, the volume of the metal artifact and image quality around the clip on the VR image was compared between the two groups. Efficacy of 4D-CTA in cases with larger metal artifact was also assessed.

CTA study

CTA examination was performed using an MDCT scanner with 320 rows (Aquilion™ ONE, Toshiba Medical Systems, Tokyo, Japan). The following CTA scanning parameters and protocol for the contrast material injection has been previously described [18]. The volume of the metal artifact was evaluated using a workstation (SYNAPSE VINCENT, Fuji Film Corp., Tokyo, Japan). In each slice, a region of interest (ROI) was created, including the metal artifact for eliminating cerebrospinal fluid spaces as shown in Fig. 1. The creation of ROI was performed in every slice containing a metal artifact. The total volume data of ROI was estimated from the sum of ROI area. Then, the threshold was set at 0–25 for strict

Fig. 1 a Photographs representing the ROI of the metal artifact evaluated in this study. Each slice shows a metal artifact and b the ROI (yellow) was identified manually. For extraction of the metal artifact, the threshold was set at 0–25, and the total volume was calculated
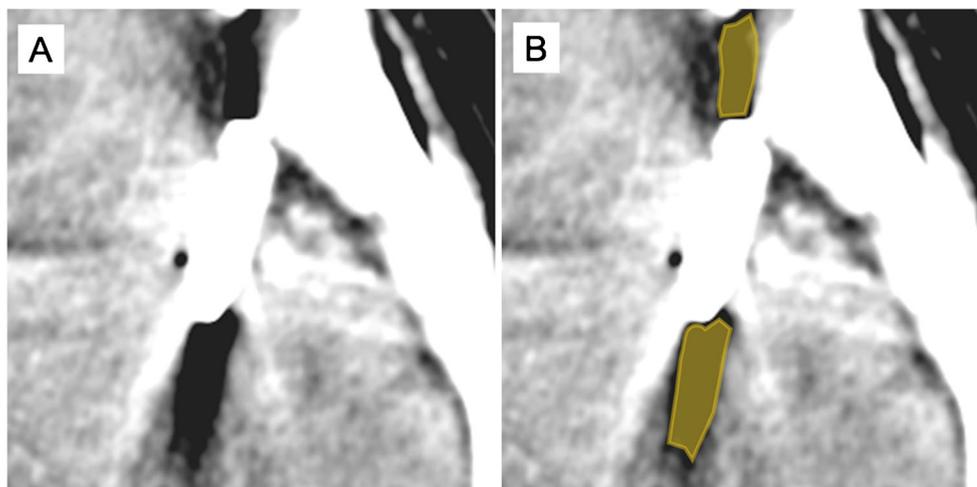
measurement and extraction of the metal artifact and the resultant metal artifact volume (mm^3) was calculated (Fig. 1).

The CT information was transferred to a workstation (ZIOSTATION 2, Ziosoft Inc., Tokyo, Japan), and 3D multicolored VR images were produced. Metal artifact reduction software was used for post-processing. Image creation was performed in the real clinical practice, and the resultant image was used for this study. Image quality of the postoperative VR image was evaluated by two neurosurgeons (Y.K., T.M.) independently to determine the quality of image around the clip: visualization of the parent artery and distal artery, and the presence of a remnant neck. If these data could be evaluated by two neurosurgeons, the image quality was categorized as "superior." In cases where one neurosurgeon judged these items as difficult to evaluate, the image quality was categorized as "fair." If there was a discrepancy between the two readings, the image quality was re-evaluated. Final decision of evaluation of the postoperative VR image was carried out via two-reader consensus. The number of "fair" images and the VR image cutoff value for "fair" were calculated. Forty-four patients were divided into two groups. Group 1 included a small (blade length ≤ 10 mm) and simple (number ≤ 3) clip,

and group 2 included large (blade length > 10 mm), numerous (number > 3), or fenestrated clips. In group 2, 4D-CTA was also carried out (Fig. 2). The 4D-CTA is a unidirectional oblique image positioned along the parent artery to the distal artery around the clip. The 4D-CTA was not performed in all cases because group 1 cases could be evaluated with VR image at a satisfactory level thus far, and additional image analysis required additional time during the real clinical practice. Therefore, the 4D-CTA was carried out in group 2 only. Adjacent to the peak of the time density curve, this image was taken every 0.1 s. This frame advance image was evaluated as an animation. The 4D-CTA was carried out for every direction of the distal artery around the clip. Similarly, the image was evaluated by three neurosurgeons for completeness of clipping, visualization of the parent artery and distal artery, and the presence of a residual aneurysm.

Statistical analysis

Data are presented as the median (interquartile range). The box graph shows the median and quartile distribution (Fig. 4). Receiver operating characteristic (ROC) analysis
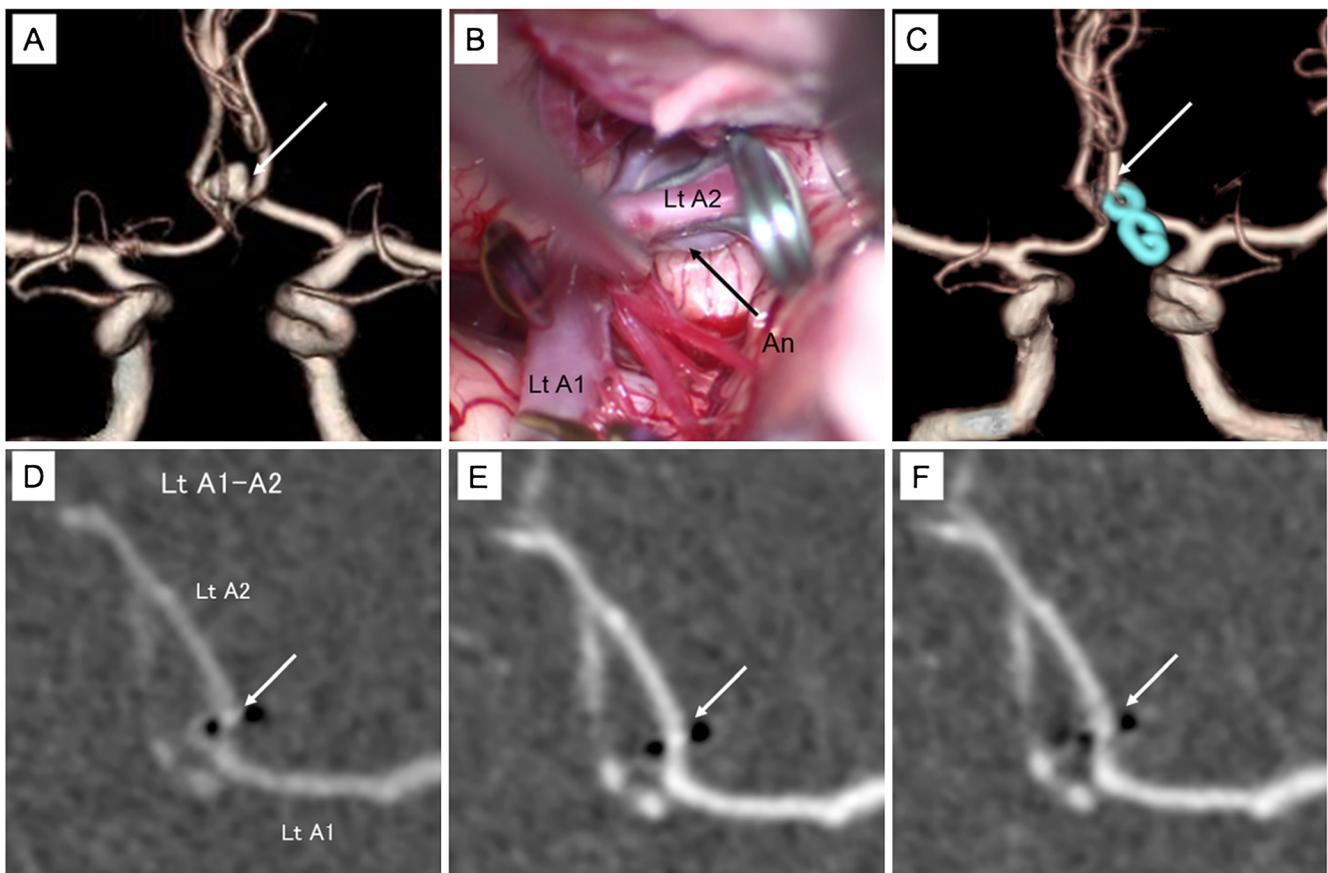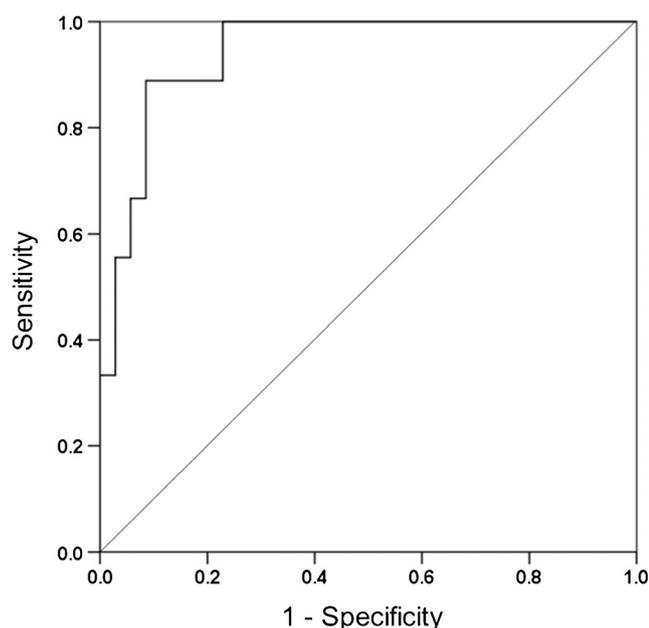

Fig. 2 **a** A 59-year-old male with an unruptured anterior communicating artery aneurysm. **b** A ring clip was used toward the anterior communicating aneurysm, and **c** visualization of the A2 segment was "fair" in the postoperative VR image. **d–f** The postoperative 4D-CTA enables visualization of the left A2 segment

was used to determine the most feasible cutoff value of the metal artifact volume for evaluation of image quality of VR image, based on the shortest distance from the curve to the upper-left corner. The Mann-Whitney U test was used to compare the volume of the metal artifact between the two groups (group 1 and group 2). The Pearson's chi-squared test was used for comparing the number of "fair" images between the two groups (group 1 and group 2) in the two methods (VR image and 4D-CTA). Statistical analysis was performed using SPSS statistical software (version 22, IBM Corp., Armonk, USA). Statistical significance was defined as a p value <0.05.

Result

Overall, the median volume of the metal artifact was 1.57 (0.78–2.32) mm^3. In this series, the median number of used clips per aneurysm was 2.0 (1.0–2.8). Neck remnant was recognized in two patients of large aneurysms on VR image, and image quality by the postoperative VR image was "fair" in nine patients. Then, vascular status around the clip was confirmed in 35 patients using a VR image. Figure 3 shows the ROC curves based on the metal artifact volume, which was recommended for adequate assessment of postoperative clip status as evaluated by the VR image. In this analysis, the cutoff value for the metal artifact volume was 2.32 mm^3, based on the shortest distance from the upper-left corner (sensitivity, 0.889; specificity, 0.914).

Group 1 included 29 patients and group 2 included 15 patients. The median volume of the metal artifact in group 1 was 0.85 (0.56–1.58) mm^3, and image quality around the clip used in the VR image was "fair" in one patient (3.4%). The median volume of the metal artifact in group 2 was 3.11 (2.10–12.33) mm^3, and image quality around the clip used in the VR image was "fair" in eight patients (53.3%). The volume of the metal artifact was significantly larger in group 2 compared with group 1 ($p < 0.001$, Mann-Whitney U test; Fig. 4). The quartile distribution of the metal artifact was higher in group 2 than in group 1, and the statistical dispersion was higher in group 2 than in group 1. Group 2 incorporated the cutoff value as mentioned above, and this indicates that our categorization was appropriate for the indication of additional 4D-CTA.

The number of "fair" images obtained through VR imaging was significantly higher in group 2 compared with group 1 ($p < 0.001$, Pearson's chi-squared test). These results reveal that evaluation using only VR image is difficult in patients with large (blade length > 10 mm), numerous (number > 3), or fenestrated clips. Of the 15 patients in group 2, evaluation by 4D-CTA was available in 14 patients. The number of "fair" images obtained through 4D-CTA was only 1 (7.1%). The number of "fair" images obtained though through 4D-CTA was lower than that in the VR image, though the difference was not significant ($p = 0.299$, Pearson's chi-squared test).

Figure 1a shows a representative patient, a 59-year-old male who was admitted to our hospital because of an unruptured anterior communicating artery aneurysm (8 mm). Neck clipping was performed with a ring clip toward the anterior communicating aneurysm (Fig. 2b). In the postoperative
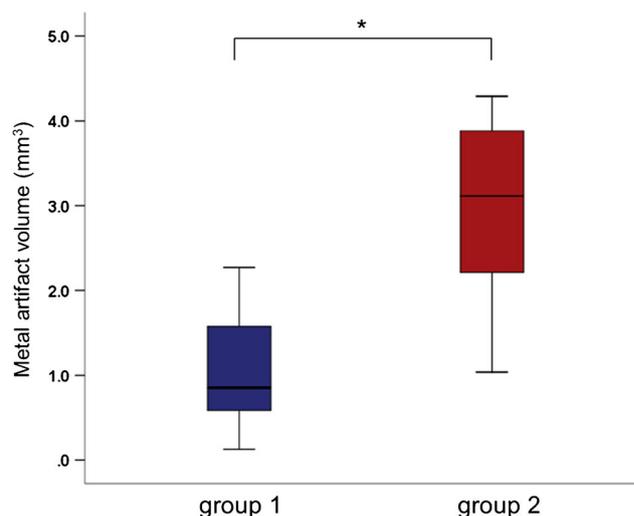

Fig. 3 Receiver operating characteristic curve analysis for evaluating metal artifacts. In the analysis, the cutoff value for the metal artifact was 2.32 mm^3 for evaluation by VR imaging alone. The sensitivity was 0.889 and the specificity was 0.914

Fig. 4 The volume of metal artifacts in groups 1 and 2. Group 1 included small (blade length ≤ 10 mm) and simple (number ≤ 3) clips and group 2 included large (blade length > 10 mm), numerous (number > 3), or fenestrated clips. The volume of the metal artifact in group 1 was significantly lower than that of group 2

evaluation, the visualization of the A2 segment was "fair" in the VR image (Fig. 2c), but the aneurysm could be evaluated using a 4D-CTA (Fig. 2d–f). With our evaluation, using one image, the metal artifact was avoided (Fig. 2e), and the flow of the parent artery was confirmed using animation (video).

Discussion

Recent progress with CTA

Evaluation of post-clipping status using CTA is not absolute, but it is important to know the characteristics of metal artifacts and they should be managed appropriately. Recent development of MDCT enables a thin slice and high-quality image, which is considered to be reliable for post-clipping evaluation [43]. Additionally, the majority of aneurysms have been treated with titanium alloy clips instead of cobalt alloy clips, which are considered to produce fewer metal artifacts [14, 30, 43]. Satisfactory images could be obtained using CTA for some titanium alloy clips [32, 43], although DSA should still be necessary in cases involving multiple and fenestrated clips [34].

The results of our study showed the critical volume and form of the aneurysmal clip in the evaluation using VR imaging. In cases of a large (blade length > 10 mm), numerous (number > 3), or fenestrated clip, evaluation is difficult using only the VR image in the current MDCT because the metal artifacts from the clips disturbs the quality of the examination. Various techniques and optimizing image parameters have been considered to improve the diagnostic accuracy [27, 39]. Metal artifacts decrease with an increasing clip-gantry angle [1], although Pechlivanis et al. reported that the clip-gantry angle does not significantly influence the image quality [32]. The head tilt technique used for increasing the clip angle was also introduced at our institute and an improvement in image quality was obtained in some cases, but we have not evaluated the degree of the improvement. For the number of clips, the current study suggested that cases with < 3 clips per aneurysm should be visualized sufficiently using CTA [24, 32]. Our data also suggested that the metal artifact volume is dependent on the number of clips, the clip size, and the clip configuration, which influenced the VR image quality. Conversely, metal artifact volume could be estimated by the characteristics of the clip used in the surgery, and necessity of additional examination such as 4D-CTA should be considered. This has clinical significance.

Efficacy of 4D-CTA

In this study, the potential benefit of 4D-CTA is shown. 4D-CTA has become available for use in the clinical practice in recent years [21]. The use of 4D-CTA to evaluate intracranial lesions has been reported for vascular malformations and hemorrhagic and ischemic stroke [11, 40]. Our results suggest that 4D-CTA is useful for evaluating the artery around the metal. For visualizing around the metal, we propose the following hypothesis: a difference in temporal resolution between the VR image and the 4D-CTA. The 4D-CTA was obtained from the data from 1 s per rotation, and the VR image was obtained from the combined data of eight dynamic acquisitions. Each dynamic acquisition has a different artifact angle because of the physical motion or respiration. Of these, there are a few images where the metal artifacts were eliminated. By creating an animation using these dynamic acquisitions, the beam-hardening artifact replaces the other eliminated image. Contrast medium in an artery should then be considered. The position of the tube ball should also be considered as in each dynamic acquisition, the tube ball is in a different position. Therefore, the appearance of a metal artifact might not be the same even at the same position. However, there is a difficulty with spatial resolution of using 4D-CTA. VR images are fused images, composed of eight dynamic acquisitions, as mentioned above, and subtle evaluation is difficult. Future developments are expected to address improvements to these issues.

The radiation dose between CTA and DSA cannot compare unqualifiedly because geometries of the X-ray are different [28]. In addition, radiation exposure is reported by using different units of measurement. The cumulative dose of 4D-CTA is usually substantially higher than that in conventional CTA. Our data do not contradict these previous data, and radiation dose in 4D-CTA was 210–220 mGy and in conventional CTA was 80–90 mGy. However, radiation dose in bolus tracking monitoring was 100–120 mGy, and this was not performed in 4D-CTA. These data did not consider relative biological effectiveness (RBE). Effective radiation dose of 4D-CTA is relatively higher than that of DSA [21]. However, the cumulative dose of 4D-CTA is usually substantially lower than that in 3D-DSA (250–350 mGy).

Recent development of dual-energy CT enables metal artifact reduction, and its usefulness for post-clipping evaluation has been reported by some institutes [6, 7, 26]. Current single-energy CT scans are made with one tube voltage (normally 120 kVp), and the CT value information is obtained. In this machine, CT values include inaccuracy resulting from a beam-hardening artifact. However, dual-energy CT scans with two kinds of X-ray vary in the tube voltage. With this technology, virtual single color X-ray images suppress the beam-hardening artifact [42]. This technology is applied to the artifact reduction during post-clipping evaluation. In future work, this technology would be widely used, and there would be a clearer depiction around the clip.

Limitations

This study had several limitations. Firstly, the threshold for metal artifacts is set at 0–25, and the high-density area is excluded from the measurement. A small part of the metal artifact that has a high-density area might be included though the size was not influenced upon vascular evaluation. Secondly, there were only a small number of patients with aneurysm remnants that were evaluated using CTA. The presence of a residual aneurysm was confirmed using a microscope and indocyanine green videoangiography, although DSA was performed in a few patients. There is a possibility that more patients with aneurysm remnants might be included in this series. However, no additional treatments are required for a small aneurysm remnant. We consider that DSA could be performed in some patients, and further discussion about the evaluation of the post-clipping status using CTA will facilitate future work. Thirdly, the 4D-CTA was performed only in group 2, and the comparison between VR image and 4D-CTA did not reach statistical significance as the study is underpowered. If the 4D-CTA was performed in all cases, including group 1, statistical significance might be reached. In this study, the 4D-CTA was performed only in group 2 because the additional image analysis required additional time in clinical practice. Image creation was not appended later for preventing bias. However, group 1 could be evaluated with only VR image without 4D-CTA, and the necessity of 4D-CTA is not always valid. Our data should be interpreted taking this consideration into account.

Conclusion

In this study, the volume of the metal artifact was measured in patients who underwent aneurysmal clipping using a titanium alloy clip. This result suggests that the volume of the metal artifact is dependent on the metal artifact volume, and VR imaging is difficult when clips that are large (blade length > 10 mm), numerous (number > 3), or fenestrated are used. In these patients, evaluation using a 4D-CTA was a useful method for eliminating the metal artifact.

Authors' statement No funding has been received for this study. This study is a retrospective analysis of a consecutive case collection, and the operative technique represents a standard procedure in the neurosurgical department of the Sapporo Medical University. We declare that this study has been approved by the Ethics Committee of Sapporo Medical University Hospital and has been performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments. We declare that all patients gave informed consent prior to inclusion in this study.

Compliance with ethical standards

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