Online June 13, 2024
Journal of Neuroendovascular Therapy 2024; 18: 213–218
DOI: 10.5797/jnet.oa.2023-0095

Original Article

A Comparison and Evaluation of Two Commercially Available Metal Artifact Reduction Applications

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Objective: The angiography systems A (A) and B (B), both incorporated at our hospital, are equipped with metal artifact reduction (MAR) applications. In clinical practice, it is crucial to understand the characteristics of MAR in both systems given that endovascular treatments are occasionally administered with both. In this study, we compared the artifact reduction effects of MAR on equipment A and B and clarified the differences between the two systems.
Methods: An artifact evaluation phantom was created using a cylindrical water phantom and an iodine contrast medium. The phantom was imaged, MAR processing was performed on the obtained images, and an isotropic quantitative evaluation of artifacts was performed by extreme value statistical analysis using the Gumbel distribution.
Results: The MAR reduction effects were approximately 45% and 40% for equipment A and B at concentrations of 8300 and 6000, respectively. The MAR reduction effect in both devices exhibited different trends depending on the concentration.
Conclusion: In clinical procedures that make use of absorbents in medium concentrations of approximately 3000–5000, such as n-butyl-2-cyanoacrylate and Onyx, it is necessary to understand the MAR characteristics of both devices and consider the use of alternative devices as an option.

Keywords▶ metal artifact reduction applications, cone-beam computed tomography, streak artifact, extreme value statistics

Introduction

There are challenges in the use of cone-beam computed tomography (CBCT) in discerning the position of stent struts, aneurysm necks, and mother vessel walls, as well as the presence of postoperative cerebral hemorrhage due to the presence of metal artifacts such as coils and liquid embolic material. Metal artifact reduction (MAR) methods have been developed by four manufacturers, with effectiveness being a required feature. However, in actual clinical practice, the effectiveness of MAR varies depending on the type and amount of metal, as well as on the model in which MAR is used. Onyx-containing metals and n-butyl-2-cyanoacrylate (NBCA), which may show absorption values similar to those of Onyx depending on the ratio of the mixture, may also cause differences in the degree of effectiveness of MAR. CBCT images may lead to misdiagnosis. We believe that the risk of misdiagnosis can be reduced by clarifying the optimal settings of MAR according to the model and the situations in which MAR is effective and making clinicians aware of these settings. Currently, no report quantitatively examines the differences in MAR between different models in the same experimental system. Therefore, as the first report of this study, we focused on the concentration value of highly absorbent objects and compared the effect of MAR on artifact reduction when the concentration value is varied between two

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Received: December 25, 2023; Accepted: May 17, 2024
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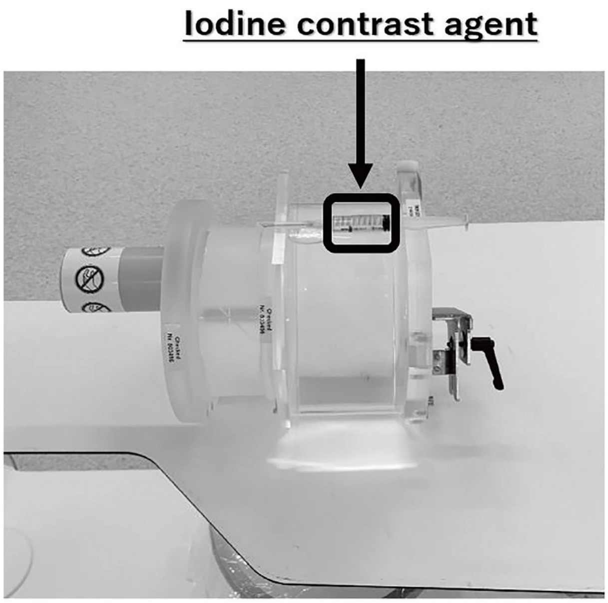

Fig. 1 Streak artifact evaluation phantom and its arrangement.

manufacturers introduced in our hospital. Streak artifacts, such as metallic artifacts, were evaluated visually.[1] However, as visual evaluation may involve subjective factors, it is desirable to evaluate them in conjunction with objective quantitative values. For the quantitative evaluation of streak artifacts, Imai et al. devised a method that evaluates streak artifacts using the position parameter, which is a representative value of the Gumbel distribution, after clarifying that the CT value displacement of streak artifacts follows the Gumbel distribution of extreme value statistics[2–4] (**Fig. 1**). We believe that this method is useful (**Fig. 1**) for the extreme value statistical analysis using the Gumbel distribution to compare the artifact reduction effects of the MAR methods on equipment A and B and to clarify the differences between the two systems.

Materials and Methods

The need for a formal ethical review was waived because the study was conducted using phantoms.

Equipment used

The angiography systems used were the Artis Q BA twin (A) (Siemens, Munich, Germany) and Azurion 7 B15/20 (B) (Philips, Amsterdam, Netherlands). A cylindrical water phantom (Siemens, Munich, Germany) supplied with an X-ray CT system and a 5-mL syringe with 370 mg/mL iodine contrast medium were used as phantoms to evaluate streak artifacts. **Figure 1** shows an overview of a phantom made from a cylindrical water phantom and a 5-mL syringe containing an iodine contrast medium. A syringe containing the iodine contrast medium was placed 0° above the phantom surface to create a phantom that generated streak artifacts in only one direction. The iodine contrast medium in 5 mL syringes was prepared by dilution to achieve six concentrations (2300, 3300, 4500, 5000, 6000, and 8300). Note that the concentration value of 2300 is assumed to be a clip. Concentrations of 3300, 4500, and 5000 are liquid embolic substances, such as NBCA and Onyx, while concentrations of 6000 and 8300 are coils.

Analysis method of images for streak artifact evaluation: extreme value statistical analysis by region-of-interest rotation method[5]

In the region-of-interest rotation method, the region of interest was first set at the target analysis site. The left and right CT value displacements were calculated for all the pixels in the region of interest, and the maximum difference in the CT value displacements was scanned in the X-direction. The absolute value of the scanned maximum difference was considered the extreme value, which was obtained for the number of pixels in the Y-direction. Next, we rotated only the region of interest by 1° and acquired extreme values for the number of pixels in the Y-direction in the same manner. This was performed at 1° intervals until the region of interest was rotated from 0° to 359°, and the extreme values were plotted on a Gumbel probability paper (**Fig. 2**). The interpolation of pixels owing to the rotation of the region of interest was performed using nearest-neighbor interpolation.[6] We used self-developed software (Microsoft Visual Basic 6.0; Microsoft, Redmond, WA, USA) for the analysis.

Comparison of both systems by changing concentration values

Using the CBCT protocol for the brain parenchyma in both systems (**Table 1**), a phantom for artifact evaluation was imaged for each of the six concentrations, and evaluation images containing the artifacts were acquired. MAR processing was performed on the obtained images, and an isotropic quantitative evaluation of artifacts was performed on images with and without MAR.

Comparison by changes in image characteristics (in equipment A)

The images for artifact evaluation acquired with equipment A were reconstructed using three patterns of image quality

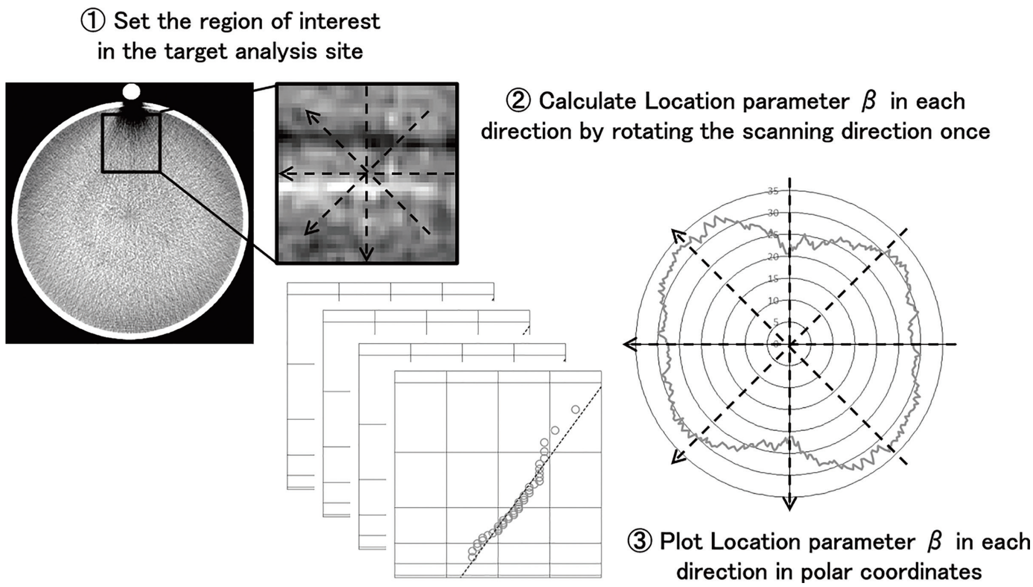

Fig. 2 Region-of-interest rotation method.

Table 1 CBCT protocols for both devices

Setting items (equipment A)	Time	Tube voltage (kVp)	Tube current (mA)	System dose (μGy/f)	Number of views	Pixel size (μm)	Collection angle (°)	Additional filter
	20 sec	109	Auto	1.82	496	308	200	Without
Setting items (equipment B)	Time	Tube voltage (kVp)	Tube current (mA)	Pulse width (ms)	Number of views	Pixel size (μm)	Collection angle (°)	Additional filter
	20 sec	120	250	5.0	620	392	210	0.4 mmCu + 1.0 mmAl

CBCT: cone-beam computed tomography

characteristics (very smooth, smooth, and normal), and the resulting images were subjected to an isotropic quantitative evaluation of artifacts. Because equipment B does not allow changing the image quality characteristics, this item was examined only in equipment A.

Results

Comparison of the two systems by a change in concentration value

Equipment A had a higher value than equipment B (equipment A: 6000 >equipment B: 3300). The reductions in location parameters for equipment A (45% and 38%) and equipment B (44% and 39%) at concentration values of 6000 and 8300, respectively, were similar between the two systems. Furthermore, the reductions in location parameters for equipment B at concentration values of 3300, 4000, and 5000 were 18%, 25%, and 32%, respectively (**Fig. 3**). In terms of absolute artifact values, a comparison of the two systems based on the location parameter values showed that equipment B had lower absolute artifact values than equipment A (**Fig. 4**).

Comparison by changes in image characteristics (in equipment A)

By changing the image characteristics of equipment A from normal to smooth, the location parameter value became significantly lower and artifacts were reduced. Furthermore, when the image characteristics changed from smooth to very smooth, the location parameter values decreased. However, the rate of decrease was lower than that of the change from normal to smooth.

Discussion

CBCT has become an indispensable tool in endovascular treatment, especially in cerebrovascular treatment, to discern the shape of the stent and verify the degree of adhesion

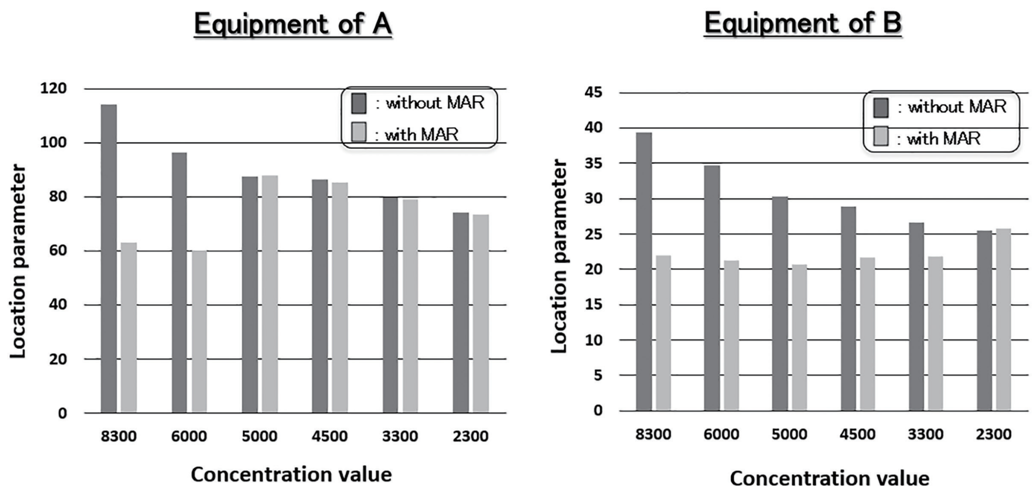

Fig. 3 Effects of MAR of both devices as a function of concentration value. MAR: metal artifact reduction

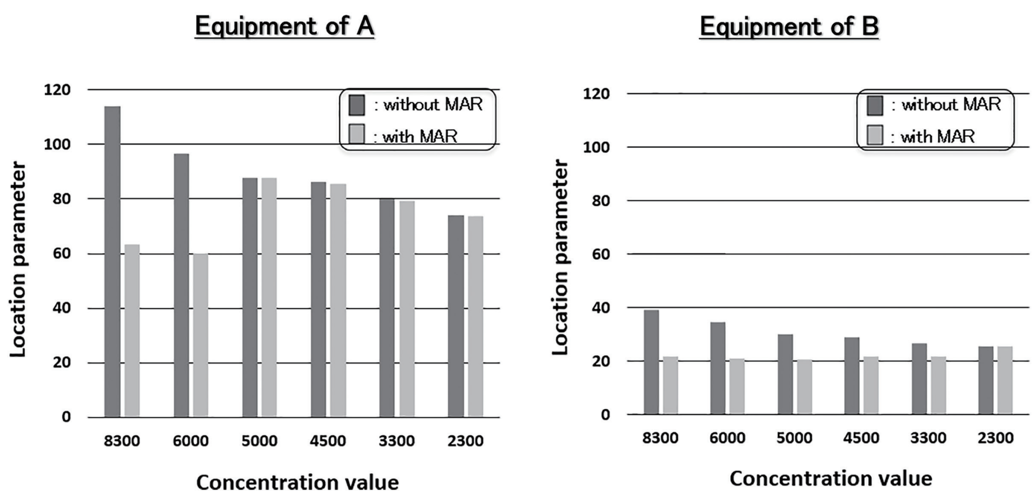

Fig. 4 Comparison of the two devices by the absolute value of the artifact. MAR: metal artifact reduction

between the stent and the vessel wall. Nevertheless, there have been situations where metal artifacts, such as coils, degrade the image quality, thereby impeding an accurate diagnosis.[7] Based on this background, we proposed that it is necessary to understand the characteristics of each manufacturer's MAR and to use them optimally to provide valuable diagnostic images to neurosurgeons. In this study, we compared and examined MAR methods implemented by two manufacturers in our hospital.

Streak artifacts, such as metallic artifacts, were evaluated visually. However, as visual evaluation may involve subjective factors, it is desirable to evaluate them in conjunction with objective quantitative values. Several methods have been reported,[8,9] such as setting a region of interest in the streak artifact area and evaluating it using the standard deviation of CT values, setting a threshold of CT values for the artifact area, and counting the extracted pixels; however, this may change the evaluation of the streak artifacts depending on the threshold value. In addition, because evaluating streak artifact area using the standard deviation of CT values provides a representative value that expresses the characteristics of a population with a normally distributed standard deviation, it is considered to have limited validity as a quantitative measure unless the statistical properties of streak artifacts are clarified. However, the method devised by Imai et al.,[2] which evaluates streak artifacts using the aforementioned position parameters, is considered useful. Furthermore, we believe that the method devised by Nakane et al.[5] for setting the region of interest in the

Table 2 Effective energy of CBCT protocol for both devices

	Time	Tube voltage (kVp)	Additional filter	Effective energy
Setting items (equipment A)	20 sec	109	Without	61.9 keV
Setting items (equipment B)	20 sec	120	0.4 mmCu + 1.0 mmAl	42.1 keV

CBCT: cone-beam computed tomography

streak artifact area of a CT image, rotating the region of interest, and performing extreme-value statistical analysis using all pixels in the region of interest is a useful method that can be performed without subjective intervention. In this study, we performed statistical analysis of the Gumbel distribution using the rotated region-of-interest method.

Equipment B recognized higher absorbers and processed artifact reduction at lower concentrations than equipment A. This may be due to equipment B's lower threshold for recognizing metals during MAR processing. A lower threshold value may be expected to cause processing failure at higher concentrations; however, no difference was observed up to a concentration of 8300, which was the highest concentration examined in this study.

The absolute value of artifacts was lower in equipment B than in equipment A because the location parameter value was lower in equipment B. This may be because the equipment B CBCT has a higher effective energy owing to the higher tube voltage and additional filter inserted, which suppresses noise, including artifacts (**Table 2**). The magnitude of the absolute value indicates the magnitude of the artifact. Therefore, in clinical imaging, equipment B CBCT images are expected to have fewer noticeable artifacts than equipment A CBCT images. However, the higher effective energy of equipment B makes it more difficult to obtain contrast resolution; therefore, further studies are needed for a comprehensive evaluation.[10,11]

The location parameter value became significantly lower, and artifacts decreased when the image characteristics changed from normal to smooth and then to very smooth. Equipment A MAR does not apply artifact reduction processing to medium-density absorbers with concentrations between 3000 and 4500. However, by changing the image characteristics from normal to smooth or very smooth, it is possible to suppress the artifacts generated by medium-density absorbers and provide images that can be used for diagnosis.

Limitation

This study only compared the MAR methods of products from two manufacturers. Further studies are required to compare and evaluate the MAR methods for all four makers. The phantom used in this study was created to generate artifacts in only one direction. Therefore, it is necessary to evaluate the effect of MAR processing on images in which artifacts are generated from two or more directions. In addition, there is room for discussion regarding the validity of the contrast medium concentration setting, the size and shape of the high absorber, and the artifact evaluation method. In this study, only false positives, such as evaluation of cerebral hemorrhage in the vicinity of the high absorber, were mentioned, but there is a possibility of false negatives, such as missing residual or recurrent aneurysms due to artifacts, and related issues need to be discussed.

Conclusion

This study showed that the reduction in metal artifacts using both MAR methods tends to differ depending on the concentration. In clinical procedures using absorbers with medium concentration values of approximately 3000–5000, such as NBCA and Onyx, it is necessary to understand the MAR characteristics of both devices and consider the use of different devices.

Acknowledgments

In conclusion, I would like to thank the doctors of the Department of Neurosurgery, Aichi Medical University School of Medicine, and the members of the Central Radiology Department of Aichi Medical University Hospital for their cooperation in this study.

Disclosure Statement

The first author and all co-authors declare no conflicts of interest.

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