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FULL PAPER

Gemstone spectral imaging reduced artefacts from metal coils or clips after treatment of cerebral aneurysms: a retrospective study of 35 patients

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Objective: This study aimed to evaluate the effect of gemstone spectral imaging (GSI) for metal artefact reduction in cerebral artery CT angiography (CTA) after metal coils or clips treatment.

Methods: 35 patients with cerebral aneurysms were treated with metal coils or clips and underwent CTA using gemstone spectral CT between February and December 2013. The data were reconstructed into three image groups including Group A (quality check images with 140kVp), Group B (monochromatic image sets in the range of 40–140keV) and Group C [monochromatic image sets with metal artefacts reduction software (MARS GE Medical Systems, Waukesha, WI)]. CT attenuation value of cerebral artery, contrast-to-noise ratio (CNR), signal-to-noise ratio (SNR) and the subjective score of all images were measured and compared statistically.

Results: CT attenuation value of cerebral artery decreased in Groups B and C as the photon energy increased. The average energy levels of 60.05 ± 5.37 and 59.93 ± 5.57 keV presented the best CNR in Groups B and C, respectively. CNR values, SNR values and the subjective scores of the image quality of the two sets were higher than those of Group A.

Conclusion: GSI reduced metal artefact and improved the image quality of CTA after metal coils or clips treatment in patients with cerebral aneurysm. The monochromatic images at the average energy level of 60.05 ± 5.37 keV with MARS and 59.93 ± 5.57 keV without MARS were suggested to be the optimal parameters.

Advances in knowledge: GSI could reduce metal artefact after metal coils or clips treatment in patients with cerebral aneurysm.

INTRODUCTION

Metal coils or clips treatment is a commonly used method for patients with cerebral artery aneurysm. Reliable examinations before treatment and after treatment are important. CT angiography (CTA) is a convenient, non-invasive and reliable method for evaluation before treatment and after coiling or clipping treatment.^{1,2} When metal coils or clips are placed in the cerebral artery, artefacts from metals may be produced, which usually influences the post-operative evaluation, especially the detection of residual aneurysm. Digital subtraction angiography is invasive and expensive even though it is the gold standard for diagnosis of the vascular diseases.^{3,4}

Gemstone spectral imaging (GSI), with only one tube and one detector, can produce dual energy because of the fast kilovoltage (kVp)-switching technique.⁵ Specifically, in the dual-energy mode (GSI mode) of GE's DECT system

(Discovery™ CT750 HD; GE Healthcare, Milwaukee, WI), “fast kVp switching” is employed during the data acquisition. The X-ray source switches rapidly between high and low kVp in adjacent projections, producing high and low kVp projections nearly simultaneously at the same locations and therefore minimizing the influence of patient or organ motion.^{5,6} For each rotation, two complete sets of projection data of high and low kVp are obtained. After calibration and correction, the high and low kVp projections are mapped onto the material density projections of the selected basis material pair, which represent the amount of the two materials that are needed to achieve the observed attenuation in the high and low kVp projections.⁵ A monochromatic energy projection can be synthesized by the weighted sum of the material density projections using their corresponding mass attenuation coefficients at a given energy as the weighting factors.^{6,7} Density images of the two basis materials, as well as monochromatic images at

different energy levels, can be reconstructed.⁵ Thus, GSI can produce monochromatic image sets, which can improve image quality,⁸ differentiate material,^{4,9} detect the small lesion,¹⁰ identify the tumour nature,¹¹ analyse plaque¹² and reduce artefacts.¹³ Especially, GSI is able to reduce beam-hardening and other metal-related artefacts with its monochromatic spectral imaging and metal artefacts reduction software (MARS).¹⁴ The software has potential limitations in producing virtual monochromatic images. For example, if the dual kVp acquisitions are each polychromatic, it is possible that spectral overlap may cause problems for tissue cancellation algorithms or for the production of virtual monochromatic image sets.

The GSI-MARS technology has the potential to correct the metallic artefacts by segmentation and reconstruction based on a CT number threshold.¹⁵ The application of CTA in cerebral aneurysms has been reported in several studies.^{2,8} There are some reports on improving image quality and reducing artefacts by spectral CT. However, as far as we know, the effect of artefact reduction from metal coils or clips by using GSI in patients with cerebral aneurysms has not been described in detail. Artefacts reduction from metal coils or clips by using GSI in patients with cerebral aneurysms has not been described in detail.^{14,16}

Therefore, the purpose of this study was to investigate the effect of GSI and MARS in reducing artefacts from metal coils or clips and determine the optimal parameters.

METHODS AND MATERIALS

Patients

This study was approved by the Ethics Committee of the First Affiliated Hospital of Harbin Medical University, Harbin, China. Written informed consents from all patients were obtained.

35 patients with cerebral aneurysm were treated with metal coils or clips in the hospital between February and December 2013.

The patients underwent cerebral artery CTA. Inclusion criteria were as follows: patients should be above 18 years of age, conscious and with stable blood pressure. Patients who were pregnant or who had acute cardiovascular and cerebrovascular diseases, renal inadequacy, thyroid disorder or hypersensitivity reactions to iodinated contrast media were excluded.

CT angiography scan protocol

The examination was performed using a single tube and fast kVp-switching technique between 80 and 140 kVp on a high-definition CT (Discovery™ CT750 HD; GE Healthcare). GSI was obtained. Patients were in the supine position. A bolus of 60–80 ml contrast material (Ultravist 370, 370 mg iodine ml⁻¹; Bayer Schering Pharma, Berlin, Germany) was injected into the median cubital vein at a flow rate of 4–5 ml s⁻¹ via a high-pressure injector with binocular tube (Ulrich, Germany). It was followed by 30 ml saline flush. The scan range was from the mandibular inferior margin to the calvaria. The GSI scan parameters were as follows: helical scan mode with 80/140 kVp tube voltage fast switching and 630 mA tube current, 0.5 s tube rotation time, 0.625 mm slice thickness and interval, 0.984 pitch and 25 cm field of view.

CT data reconstruction

The raw data of each case were reconstructed into three groups: Group A, quality check images with a polychromatic set corresponding to 140-kVp tube voltage only; Group B, monochromatic image sets in the range of 40–140 keV with the interval of 5 keV; and Group C, monochromatic image sets with MARS in the range of 40–140 keV with the interval of 5 keV. All images were transferred to an advanced workstation (AW 4.5) with GSI Viewer software package (GE Medical Systems, Waukesha, WI) for further analysis.

Image analysis

The regions of interest (ROIs) in the centre of the cerebral arteries adjacent to the metal coils or clips on all axial images

Figure 1. The best contrast-to-noise ratio (CNR) for cerebral artery and cerebral parenchyma with the CNR plot of GSI Viewer software package. (a) Regions of interest in cerebral artery and cerebral parenchyma on an axial image with artefacts from the metal coil. (b) The optimal monochromatic energy of 53 keV for the best CNR of cerebral artery to cerebral parenchyma.

Table 1. Patient characteristics

Patient characteristics	Number
Sex	
Female	20
Male	15
Age (years)	50.71 ± 7.85 (32–73)
Coils ^a	11
Clips ^a	36
Position of metal clips or coils ^a	
Internal carotid–posterior communicating artery	14
Anterior communicating artery	12
Middle cerebral artery	15
Anterior cerebral artery	1
Basilar artery	2
Posterior cerebral artery	1
Vertebral artery	2

^aFour patients had two metal clips, three patients had three clips, one patient had two metal coils and one patient had one clip and one coil simultaneously.

were determined. It is worth noting that ROI was placed on the axial image with the maximum artefacts from the metal coil or clip, avoiding plaques or coils or clips in the vessel wall. Meanwhile, the same ROI in the peripheral cerebral parenchyma, without vessel involvement, on the same slice and of the same background value was obtained. Noise was defined as the standard deviation (SD) of attenuation of the cerebral parenchyma. To evaluate the overall degree of contrast in the cerebral artery, the mean contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) were calculated. CNR and SNR were calculated as follows:

$$\text{CNR} = \frac{\text{CT}(\text{Vessel}) - \text{CT}(\text{Background})}{\text{Noise}(\text{Background})}$$

$$\text{SNR} = \frac{\text{CT}(\text{Background})}{\text{Noise}(\text{Background})}$$

CNR and SNR values of the three groups were obtained for the evaluation of cerebral artery CTA after metal coils or clips treatment. Furthermore, the CNR plot of the GSI Viewer software package could automatically calculate and display the optimal single energy level for generating the best CNR between the cerebral artery and cerebral parenchyma (Figure 1).

The image quality assessments were performed by two independent radiologists (both with experience of more than 5 years in CTA) blinded to the groups. Each radiologist gave a score to the three groups in each case on a four-point scale,¹⁷ which included diagnostic reliability of the images, the degree of the artefacts from the metal coils or clips, the visible level of the artery, the sharpness of cerebral artery margins and the contrast degree between the cerebral artery and cerebral parenchyma. For these above criteria, one stood for fully acceptable, two for probably acceptable, three for only acceptable under limited conditions and four for unacceptable. This was defined as a subjective score.

Statistical analysis

All data were presented as mean ± SD. The data were analysed statistically using SPSS® 13.0 (IBM Corporation, Armonk, NY; formerly SPSS Inc., Chicago, IL). The CNR, SNR and score of image quality among the three groups were analysed by paired *t*-test. *p* < 0.05 was considered statistically different.

RESULTS

35 cases (47 metal coils or clips) met the inclusion criteria and completed CT scans. No complications were observed. The characteristics of the patients are shown in Table 1.

Figure 2. CT attenuation value of cerebral artery, contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) changed as the photon energy increased. (a) CT attenuation value of cerebral artery decreased as the photon energy increased from 40 to 140 keV in both Groups B and C. (b) CNRs of Groups B and C were higher than that of Group A as the photon energy increased from 45 to 75 keV. (c) SNRs of Groups B and C were higher than that of Group A when the photon energy was <80 and 90 keV, respectively.

Table 2. Comparison of the results among the three groups

Image quality	Group A	Group B	Group C	<i>p</i> -value ^a	<i>p</i> -value ^b	<i>p</i> -value ^c
CNR	23.68 ± 12.70	38.98 ± 26.82	36.66 ± 26.82	<0.05	<0.05	0.59
SNR	11.06 ± 7.49	13.45 ± 10.07	12.80 ± 8.54	<0.05	<0.05	0.70
Subjective score	3.15 ± 0.36	1.43 ± 0.50	1.53 ± 0.51	<0.001	<0.001	0.52

CNR, contrast-to-noise ratio; SNR, signal-to-noise ratio.

^aComparison between Groups A and B.

^bComparison between Groups A and C.

^cComparison between Groups B and C.

CT attenuation value of the cerebral artery decreased as the photon energy increased from 40 to 140 keV in both Groups B and C (Figure 2a). CNR and SNR changed as the photon energy increased (Figure 2b,c). The average energy level of 60.05 ± 5.37 keV and 59.93 ± 5.57 keV provided the best CNR for displaying the cerebral arteries in Groups B and C, respectively. CNR and SNR values of the two sets were higher than those of Group A ($p < 0.05$) (Table 2). There were no statistical differences of CNR and SNR between Groups B and C (p was 0.59 and 0.70, respectively). As for the subjective scores of Groups B and C, 1.43 ± 0.50 and 1.53 ± 0.51 , respectively, provided the best CNR, each of which was significantly lower than that of Group A ($p < 0.001$) (Figures 3 and 4, Table 2). There was no statistical difference between the optimal energy level of Group B and that of Group C ($p = 0.52$).

DISCUSSION

This study investigated the effect of GSI and MARS in reducing artefacts from metal coils or clips and determined the optimal parameters. The results revealed that monochromatic spectral imaging at the energy levels of 60.05 ± 5.37 keV with MARS or 59.93 ± 5.57 keV without MARS, respectively, provided the best CNR for displaying the cerebral arteries.

Metal-related artefacts include photo starvation and beam-hardening artefacts, which may change with the size, shape and density of the metal implants.^{13,15} Photo starvation could be

attributed to the full absorption of the X-ray quanta, which causes little or zero transmission projection.¹³ The beam-hardening artefacts from the metal implants are produced when conventional CT with the polychromatic energy of X-ray was used, and the absorption coefficient decreases with the increase of the X-ray energy.¹⁸ So the lower-energy X-rays are strongly absorbed by the object and the higher-energy X-rays which penetrate the object are detected. Thus, the X-ray energy spectrum changes as it penetrates the object and the beam-hardening artefacts are generated.¹⁵ The artefacts from the metal implants may obscure the targeted area because the metal implants are always placed at the lesion site, such as the bone fracture, the joint replacement and the bleeding site of cerebral aneurysm. These areas are usually evaluated after treatment. For example, it is important to know whether the reposition and fixation of the bone fracture is successful, whether there is infection in the prosthetic joint or whether there is residual aneurysm after metal coils or clips treatment.^{19,20} Although some methods are summarized by Matsumoto et al¹⁶ and Brook et al,¹⁴ the problem of artefacts is not yet completely solved.

Since the advent of the gemstone spectral CT in 2008, there have been great changes in CT imaging. The spectral CT has many advantages including clear material-decomposed images, generation of a set of monochromatic images with a range of 40–140 keV energies, reduction of beam-hardening artefacts and image quality improvement.^{10,21} Moreover, spectral CT can be used simultaneously with GSI, with short reconstruction time.¹⁵

Figure 3. Evaluation of cerebral artery volume-rendering images of a patient with a metal coil in the basilar artery (black arrows). (a) Polychromatic energy image shows obvious artefacts from the metal coil with the image score four. (b) 60-keV monochromatic energy image with metal artefacts reduction software demonstrates that the artefacts were reduced significantly, and the metal coil and its surrounding arteries were clearly observed. This image was scored as one.

Figure 4. Volume-rendering images of cerebral artery of a patient with a metal coil in the right internal carotid-posterior communicating artery. (a) Polychromatic energy image shows that the cerebral arteries were not enhanced well and there were artefacts from the metal coil. (b) 70-keV monochromatic energy image shows the cerebral arteries clearly but with artefacts. (c) 63-keV monochromatic energy image shows the best contrast-to-noise ratio for cerebral artery and cerebral parenchyma. There was almost no artefact from the metal coil, and the cerebral arteries were clearly observed.

In this study, we analysed the monochromatic images with and without MARS. The results showed that the CT attenuation value of the cerebral artery decreased steadily as the photon energy increased from 40 to 140 keV in both Groups B and C, which was consistent with the previous studies.^{16,21} Therefore, the contrast resolution between cerebral artery and cerebral parenchyma is higher at the lower energy, but the image noise is expected to increase. In contrast, the image noise was lessened at the range of higher energy, but the CT numbers of cerebral artery decreased and the contrast resolution between the cerebral artery and cerebral parenchyma decreased. On the other hand, the optimal monochromatic energy allows the best CNR for cerebral artery and surrounding cerebral parenchyma in both Groups B and C. The results in this study showed that the average energy levels of 60.05 ± 5.37 and 59.93 ± 5.57 keV provided the best CNR for displaying the cerebral artery images of Groups B and C, respectively. The subjective scores of the two sets were higher than that of Group A. Moreover, this study indicated that MARS was useful for artefacts reduction from metal coils or clips in patients with cerebral artery, as reported in previous studies.^{14,15} Although there was no statistical difference between the objective/subjective evaluations of Groups B and C in this study, the monochromatic images of Group C showed the real shape and location of the metal coils or clips more clearly on observation.

There were some limitations in the present study. Firstly, the artefacts from metals were related to the material, size, shape and location of the metal coils or clips in the cerebral artery, which was not taken into consideration. The cases should be sorted according to the metal coils and metal clips and be analysed separately. Secondly, there was little evaluation of the surgery. Actually the comparison between pre-operative and post-operative cerebral artery and branches should also be performed. Lastly, we did not depict the radiation dose in this study. The GSI was used and the radiation dose might be a little higher than the dose for the common mode or conventional CT.²²

In conclusion, GSI with MARS could reduce metal artefacts and improve the image quality of cerebral artery CTA after metal coils or clips treatment. The monochromatic images at the average level of 60.05 ± 5.37 keV with MARS and 59.93 ± 5.57 keV without MARS probably provide the best CNR for displaying the cerebral arteries.

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