Reduction of metallic coil artefacts on computed tomography scans: effects of a new single-energy metal artefact reduction algorithm

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Aims and objectives

Minimally invasive endovascular coiling techniques can be used to treat cerebral or abdominal visceral artery aneurysms. Endovascular coiling yields positive outcomes in patients subjected to aneurysmal embolization and shortens their recovery time [1]. However, long-term imaging follow-up is critically important to determine whether additional treatment is needed to address aneurysm recurrence or recanalization [2-4].

Although conventional digital subtraction angiography (DSA) is the gold standard for monitoring the results of embolization therapy, computed tomography angiography (CTA) has emerged as the technique of choice at most institutions [5]. Its advantages over conventional DSA include the following: it is minimally invasive with no procedure-related complications, reduces patient discomfort and inconvenience and is less expensive. However, artefacts from the metallic coils due to x-ray beam hardening and photon starvation in the shadow of a metal object pose problems on CTA images [6]. Streak artefacts degrade the image quality and are superimposed on other structures of interest. This impairs diagnostic confidence and may result in missed findings. Therefore, an optimal metal artefact reduction reconstruction algorithm that yields artefact-free images or images with the least artefacts possible is needed for a reliable and accurate image-based diagnosis.

An updated artefact reduction technique, the single-energy metal artefact reduction (SEMAR) algorithm, was clinically introduced on a second-generation 320-row CT scanner. This innovative raw data-based iterative reconstruction (IR) technique, which helps to mitigate artefacts from metal objects on computed tomography (CT) images, has not been fully evaluated in the literature. To the best of our knowledge, this is the first clinical study that to evaluate the SEMAR algorithm for coil metal artefact reduction. The purpose of this study was to determine whether SEMAR could improve the quality of CT images obtained for evaluation of post-coil embolization complications.

Methods and materials

This retrospective review was approved by our institutional review board. We obtained informed consent from all patients.

Patient population

Using our radiologic database between January 2014 and August 2014, we retrospectively reviewed the head and abdominal contrast-enhanced CTA images of 22 patients with metallic coils (11 men, 11 women; mean age 65.0 ± 13.8 years; age range 29-85 years). The patient characteristics are shown in Table 1.
Data acquisition

Contrast-enhanced CT images were obtained on a second-generation 320-detector row CT scanner (Aquilion ONE ViSION, Toshiba Medical Systems, Otawara, Japan) in 22 patients who had undergone coil embolization (head CTA: 5 patients, thoracic or abdominal CTA: 17 patients).

The data acquisition parameters for head CTA were as follows: sequential acquisition, 320 × 0.5-mm detector collimation, 0.5-s tube rotation time, 300-mA tube current and 120-kVp tube voltage. In all head CTA examinations, a total of 50 mL of 370-mgI/mL iodinated contrast material was delivered via a 20-gauge catheter inserted into the antecubital vein at 5.0 mL/s using a power injector (DUAL SHOT GX; Nemoto-Kyorindo, Tokyo, Japan). This was followed by the administration of 35 mL of saline solution delivered at the same injection rate as the contrast material. A bolus tracking technique was used to optimize the scanning delay for the arterial scans.

The scan parameters for thoracic or abdominal CTA were as follows: sequential acquisition, 320 × 0.5-mm detector collimation, 0.5-s tube rotation time and 120-kVp tube voltage. Automatic exposure control (SURE Exposure3D, Toshiba) was used to determine the tube current. A dose of 420 mgI/kg of contrast medium was delivered over 15 s. This was followed by the administration of 35 mL of saline solution delivered at the same injection rate as the contrast material. A bolus tracking technique was used to optimize the scanning delay for the arterial scans.

Image reconstruction

The CT images were reconstructed as 1.0-mm sections at 1.0-mm intervals for head CTA and as 3.0-mm sections at 3.0-mm intervals for thoracic or abdominal CTA using the adaptive iterative reconstruction technique (AIDR 3D, Toshiba, Otawara, Japan). Before analysis, 2 data sets were reconstructed using conventional (non-SEMAR) and SEMAR algorithms for all patients.

The SEMAR technique is a raw data-based algorithm that uses various steps of data segmentation and IR with forward and backward projections on the basis of projection and image data. An initial image is generated with standard filtered back projection (FBP). The metal devices are then segmented from this image and metal-only data are forward projected to generate a sinogram of metal-only data. The metal data points in the sinogram are then subtracted from the original sinogram and replaced with interpolated values that simulate tissue in place of the metal. The interpolated sinogram is reconstructed with FBP, and the resulting image volume is then segmented to further exclude residual metal artefacts. The resultant data is forward projected and again linear interpolation is used to fill in the data gaps. Finally, an image volume is reconstructed with FBP from the last sinogram. To obtain the final image, the last image is blended with the metal devices from the first segmentation.

Quantitative evaluation
Two board-certified radiologists measured the CT attenuation values using a circular region of interest (ROI) based on consensus. Image noise was defined as the standard deviation (SD) in Hounsfield units (HU). Five ROIs were placed on each image around the coil mass (Fig.1). We considered the average image noise around the coil as the index of metal artefact. Attempts were made to select an ROI area of approximately 100 mm2 for chest and abdomen, and 50 mm2 for head; i.e. not so small as to be affected by pixel variability and not so large as to approach bone or air. The ROI setting was consistent between the non-SEMAR and SEMAR algorithms. In addition, the maximum diameters of the artefacts were measured in transverse planes; the areas of artefacts were defined as the areas of darkness caused by beam hardening.

Qualitative evaluation

All images were reviewed on an image processing workstation (Vitrea ver. 6.4, Toshiba) by two board-certified radiologists with 15 and 7 years of experience. The window level and window width were 150 HU and 350 HU for head CTA images, respectively, and 50 HU and 300 HU for thoracic and abdominal CTA images, respectively. We intermixed the CT images acquired with the conventional and SEMAR reconstructions, and the reviewers were blinded to the reconstruction methods and the identity of the patients. Visual assessment regarding metal artefacts and depiction of adjacent structures was graded as follows: 4 (excellent) = minimal artefacts, excellent depiction of adjacent structures, provides very useful diagnostic information; 3 (good) = mild artefacts, good depiction of adjacent structures, provides sufficient diagnostic information; 2 (fair) = strong artefacts, faint depiction of adjacent structures, provides limited diagnostic information and 1 (poor) = extensive artefacts, no depiction of adjacent structures. In addition, the image texture was graded as either acceptable or blotchy. When the two reviewers disagreed, the discrepancy was settled through a consensus review that included a third senior radiologist with 33 years of experience.

Statistical analysis

All data are reported as mean ± SD. The quantitative evaluation results were compared using the paired Student's t-test. The visual evaluation results were compared with McNemar's test. The degree of agreement between the two observers regarding the visual evaluation results was measured using kappa statistics. All statistical analyses were performed using the statistical software package JMP 9.0.2 (SAS Institute, Cary, NC, USA). A P-value of <0.05 was considered to be statistically significant.

Images for this section:
**Fig. 1**: ROIs setting of CT image. Five ROIs were placed around the coil mass. The ROI setting was consistent between non-SEMAR and SEMAR.
Results

Quantitative evaluation

The mean image noises for the conventional and SEMAR reconstruction methods were 59.2 ± 42.6 HU and 27.6 ± 11.6 HU, respectively. The differences were statistically significant (P < 0.001). The measured maximum diameters of the artefacts from coils are shown in Table 1. The average maximum diameters of the artefacts were significantly smaller with the SEMAR reconstruction method than with the conventional reconstruction method (14.5 ± 26.3 mm vs 167.8 ± 59.6 mm, P < 0.001). Representative cases are shown in Figs. 2 and 3.

Qualitative evaluation

The interobserver agreement with regard to the visual evaluation of metal artefacts was moderate (kappa value = 0.84). The final evaluation scores were 1.0 ± 0 and 3.1 ± 0.6, respectively, for the conventional and SEMAR reconstruction methods, and the difference was statistically significant (P < 0.001). The image texture was graded as natural for all images with both the SEMAR and non-SEMAR reconstruction.

Table 1. Patient data with visual scores of the effectiveness of metal artefact reduction on CTA.

<table>
<thead>
<tr>
<th>Case</th>
<th>Age/sex</th>
<th>Location of metallic coil</th>
<th>Visual score of effectiveness of metal artefact reduction</th>
<th>Maximum diameters of artefacts from coils (mm)</th>
<th>Mean SD values (HU)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Without SEMAR</td>
<td>With SEMAR</td>
<td>Without SEMAR</td>
</tr>
<tr>
<td>1</td>
<td>73/F</td>
<td>Celiac artery aneurysm</td>
<td>1</td>
<td>3</td>
<td>130</td>
</tr>
<tr>
<td>2</td>
<td>60/M</td>
<td>Basilar tip aneurysm</td>
<td>1</td>
<td>4</td>
<td>133</td>
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<tr>
<td>3</td>
<td>62/M</td>
<td>Pancreatoduodenal artery aneurysm</td>
<td>106</td>
<td>0</td>
<td>50</td>
</tr>
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<td>---</td>
<td>---</td>
</tr>
<tr>
<td>4</td>
<td>78/F</td>
<td>Anterior communicating artery aneurysm</td>
<td>3</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>73/F</td>
<td>Splenic artery aneurysm</td>
<td>3</td>
<td>101</td>
<td>0</td>
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<tr>
<td>6</td>
<td>50/M</td>
<td>Gastroduddenal artery aneurysm</td>
<td>2</td>
<td>121</td>
<td>13</td>
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<tr>
<td>7</td>
<td>29/M</td>
<td>Vertebral artery aneurysm</td>
<td>2</td>
<td>151</td>
<td>50</td>
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<tr>
<td>8</td>
<td>37/M</td>
<td>Posterior inferior cerebellar artery aneurysm</td>
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<td>129</td>
<td>35</td>
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<td>9</td>
<td>64/F</td>
<td>Internal carotid aneurysm</td>
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<td>87</td>
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<tr>
<td>10</td>
<td>80/F</td>
<td>Gastric vein aneurysm</td>
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<td>258</td>
<td>0</td>
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<tr>
<td>11</td>
<td>52/F</td>
<td>Renal arteriovenous malformation</td>
<td>3</td>
<td>91</td>
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<tr>
<td>12</td>
<td>65/F</td>
<td>Endoleak after endovascular aneurysm repair</td>
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<td>226</td>
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<td>13</td>
<td>85/M</td>
<td>Common hepatic artery aneurysm</td>
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<tr>
<td>14</td>
<td>68/F</td>
<td>Gastric vein aneurysm</td>
<td>3</td>
<td>203</td>
<td>0</td>
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<tr>
<td>15</td>
<td>77/M</td>
<td>Internal iliac artery aneurysm</td>
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<tr>
<td>16</td>
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<td>Postoperative pseudoaneurysm</td>
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<tr>
<td>17</td>
<td>68/F</td>
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<td>186</td>
<td>0</td>
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<tr>
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<td>0</td>
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<tr>
<td>19</td>
<td>70/F</td>
<td>Renal artery aneurysm</td>
<td>4</td>
<td>219</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>66/M</td>
<td>Intracranial dural arteriovenous fistula</td>
<td>3</td>
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<td>0</td>
</tr>
<tr>
<td>21</td>
<td>53/M</td>
<td>Splenic artery aneurysm</td>
<td>3</td>
<td>236</td>
<td>0</td>
</tr>
<tr>
<td>22</td>
<td>79/F</td>
<td>Splenic artery aneurysm</td>
<td>4</td>
<td>242</td>
<td>0</td>
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</table>

Average (± SD)  

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<tbody>
<tr>
<td>1 ± 0</td>
<td>3 ± 1</td>
<td>168 ± 60</td>
<td>± 14 ± 26</td>
<td>59 ± 43</td>
<td>28 ± 12</td>
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</table>

Images for this section:
Fig. 2: A 60-year-old man with a coiled basilar tip aneurysm. (a) non-SEMAR axial thin MIP (maximum intensity projection) image and (b) SEMAR axial thin MIP image. Follow-up CTA studies were performed two weeks after embolization with the coil packing technique. CTA assessment was hampered by artefacts on non-SEMAR CT images. No artefacts were present on SEMAR images. On the non-SEMAR image the left middle cerebral artery appears narrow due to beam hardening artefacts (arrow). The SEMAR images clearly demonstrate patency of the middle and posterior cerebral arteries. No residual aneurysm neck growth or coil migration was observed on the SEMAR image. The application of the SEMAR algorithm increased confidence in the identification and assessment of vessels around the metallic coils. The mean image noise around the coil was 28 HU and 57 HU for SEMAR and non-SEMAR image.
**Fig. 3:** A 79-year-old female with a coiled splenic artery aneurysm (arrow). (a) non-SEMAR axial image, (b) SEMAR axial image. Follow-up CTA study was conducted one month after coil embolization by combined isolation and packing techniques. The CTA image shows complete occlusion of the aneurysm without metal artefacts. On the non-SEMAR image strong metal coil artefacts are seen around the coiled aneurysm. Structures adjacent to soft tissue such as the spleen and the small intestine could be evaluated on SEMAR images. The mean image noise around the coil was 25 HU and 53 HU for SEMAR and non-SEMAR image.
Conclusion

Our study revealed that an IR-based metal artefact reduction technique, the SEMAR algorithm, improved the objective and subjective image quality of CTA after coil embolization. Compared with the non-SEMAR algorithm, SEMAR drastically reduced image noise and maximum diameters of the artefacts in an objective image analysis. Furthermore, the SEMAR algorithm enabled the depiction of structures in areas in which this was not previously possible because of metallic artefacts in a subjective image analysis. The SEMAR technique can potentially increase the performance of CT used for the evaluation of post-coil embolization complications.

Aneurysmal neck recanalization, growth of the neck or body remnant, organ infarction and coil migration are occasionally seen after coil embolization of arterial aneurysms [3, 7, 8]. Therefore, it is advisable to perform careful and long-term follow-up by CTA studies. However, artefacts from metallic coils often render CT images non-diagnostic, and potentially crucial lesions could be overlooked. Consequently, the follow-up of patients with metallic coils on CTA images remains challenging.

The value of corrective methods to reduce streak artefacts from metal implants has been studied [9]. Earlier metal artefact reduction techniques fall into the projection completion category (interpolation-based methods) [10, 11]. Using surrounding uncorrupted sinogram information, interpolation-based methods for metal artefact reduction replace metal-corrupted projection data with surrogate data from interpolation. However, despite their popularity, the reliability of many pure interpolation-based approaches decreases considerably in the presence of multiple large metal implants. The IR techniques are superior to the FBP reconstruction process, especially in terms of reconstruction from any corrupted or missing sinogram data. However, these techniques require the processing of massive quantities of raw projection data. This category of algorithm is much more computationally expensive than projection completion methods and has only recently become available for clinical use.

The effectiveness of the algorithm for metal artefact reduction using IR techniques (O-MAR, Philips Healthcare, Cleveland, OH, USA) has been studied. It is optimized to correct for orthopaedic metal implants and not for other implants such as metallic coils [12-14]. Moreover, when the metal implant is in close proximity to air or to lung tissue, O-MAR induces artefacts that are absent on uncorrected images [13]. On the other hand, the SEMAR algorithm evaluated in our study tended to be more versatile, and the SEMAR images were not blotchy or plastic. We posit that the SEMAR technique has the advantage of a standardized application independent of the type of implanted metal device.

Earlier studies on the reduction of metal artefacts applied high keV mono-energy reconstruction for dual-energy CT [15, 16]. However, artefacts from large metal masses tend to be too strong for compensation by mono-energy reconstructions of dual-energy
CT images. Moreover, this technique requires a CT system capable of dual-energy acquisition and careful pre-scan planning. There is currently no consensus regarding the optimal scan parameters (such as kVp) for dual-energy metal artefact reduction protocols. The SEMAR algorithm, on the other hand, can be applied independent of the size of the metal mass, and the scan parameters are simple. The SEMAR image reconstruction of raw data can be performed at any time. Although a comparison of SEMAR and dual-energy metal artefact reduction methods is necessary, we believe that the former method may be more suitable for clinical use.

The SEMAR algorithm can be used only on axial scans. While this is a limitation, 320-detector row CT scanners yield 16-cm-wide volume data that may be adequate for evaluation of sites harbouring metal implants in humans. When the scan range is wider than 16 cm, the step-and-shoot technique can solve the problem. As the SEMAR algorithm can be set in the scan protocol, reconstructions are fully automatic and require no additional operator input. When the SEMAR algorithm is used, artefacts from devices such as metal prostheses and coils are significantly reduced and the diagnostic quality of the images is dramatically improved. We suggest that this will result in an increase in previously difficult follow-up CTA examinations in patients with coiled aneurysms or fistulas.

There are a few limitations in this study. First, we did not evaluate the diagnostic accuracy of our technique in comparison with conventional DSA as the "gold standard" for monitoring the results of embolization therapy. We rather focused on comparing the image quality. Second, this single-centre study included a small sample patient group, each with different numbers of metallic coils. Further studies to verify the clinical role of the SEMAR algorithm are imperative.

In conclusion, the SEMAR algorithm offers significant advantages over conventional CT reconstruction for metal artefact reduction and visualization of aneurysms and structures adjacent to metal coils. We believe this novel technique increases the performance of CT used for the evaluation of post-coil embolization complications.

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References


