Metal artifact reduction for total hip prosthesis in helical computed tomography: single energy metal artifact reduction versus forward projected model-based iterative reconstruction solution

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Aims and objectives

Population aging is a global phenomenon. In step with the aging of the population, it is expected that the chance of utilization of the total hip arthroplasty (THA) would increase. Several diseases, such as infection and carcinoma, arise in the pelvic region, and computed tomography (CT) is a useful tool in the diagnosis of these diseases. THA induces metal artifact and degrades image quality of pelvic CT, therefore metal artifact reduction in pelvic CT is a challenge to overcome.

For reducing metal artifact in pelvic CT, high tube current, high tube voltage (1,2) and virtual monochromatic image from dual energy CT (3,4) are available at scanning process. They have some advantages and drawbacks.

**High tube current and high tube voltage**

- the effects are limited
- result in increased radiation dose

**Virtual monochromatic image from dual energy CT**

- effectively reduce the beam hardening effect, especially at high keV
- soft tissue contrast is lowered in high keV image, which is a problem for evaluating pelvic organ diseases
- requires specific CT scanners and specific scanning protocols

At image reconstruction process, metal implanting methods and full iterative reconstruction algorithms are gaining attention, recently.

**Single energy metal artifact reduction**

- belongs to the metal implanting method (5)
- was reported to reduce metal artifact effectively in clinical cases (6,7). However, this technique had been available for only volume scan data and clinical reports that had been made were based on volume scan data. Z-axis range of up to 16cm could be scanned with a volume scan, which might not be enough for examinations of body region, and complex scanning protocol had been required (e.g. for CT examination of chest to pelvis, helical scan for chest to abdomen plus volume scan for pelvis is required).
- has become available for helical scan, recently

**Forward projected model-based Iterative Reconstruction SoluTion (FIRST)**
• is a full iterative reconstruction algorithm which has become available recently
• might reduce metal artifact, because metal artifact reduction with model-based iterative reconstruction (MBIR), which is also a full iterative reconstruction algorithm available for GE CT scanner, has been reported (8)

To our knowledge, the degree of metal artifact reduction with single energy metal artifact reduction for helical scan and FIRST has not been investigated.

The aim of this study was to compare the degree of metal artifact reduction in patients with total hip prosthesis scanned with single energy helical CT between single energy metal artifact reduction and FIRST.
Methods and materials

About this study

• retrospective clinical study
• approved by our Institutional Review Board
• the requirement to obtain informed consent from study patients was waived

Subjects

A radiologist searched picture archiving and communication system for patients

• with total hip prosthesis
• who underwent helical CT with Aquilion ONE (Toshiba Medical Systems, Tokyo, Japan) including pelvic region

Exclusion criteria

• patients who have metals other than total hip prosthesis in pelvic region
• patients who were scanned in excretory phase after injecting contrast enhancement media

From June 2015 to September 2015, 47 patients were included.

• mean age, 67.0 ± 11.4 years
• 6 men and 41 women
• location of THA; 14 patients with both sides, 18 patients with right side, 15 patients with left side
• contrast enhancement; 35 patients with unenhanced CT and 12 patients with enhanced CT

CT scan

The following scanning parameters were used

• scan mode, helical
• helical pitch (beam pitch), 0.8125
• gantry rotation time, 0.5s
• detector configuration, 0.5mm×80
• tube voltage, 120kVp
• tube current, automatic exposure control was used (noise index of 13.0)

The mean CT dose index volume and dose-length product (with scan range) were described in table 1.
Table 1 Scan range and radiation dose of the subjects

<table>
<thead>
<tr>
<th>Scan range</th>
<th>Number of patients</th>
<th>CT dose index volume (mGy)</th>
<th>Dose-length product (mGy-cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>abdomen to pelvis</td>
<td>5</td>
<td>8.8 ± 1.4</td>
<td>443.1 ± 130.8</td>
</tr>
<tr>
<td>pelvis to lower extremities</td>
<td>26</td>
<td>9.9 ± 1.6</td>
<td>678.0 ± 127.7</td>
</tr>
<tr>
<td>abdomen to lower extremities</td>
<td>1</td>
<td>7.7</td>
<td>742.2</td>
</tr>
<tr>
<td>chest to pelvis</td>
<td>9</td>
<td>11.4 ± 4.2</td>
<td>763.6 ± 302.3</td>
</tr>
<tr>
<td>neck to pelvis</td>
<td>5</td>
<td>9.2 ± 2.3</td>
<td>756.1 ± 207.1</td>
</tr>
<tr>
<td>neck to lower extremities</td>
<td>1</td>
<td>7.4</td>
<td>1198.7</td>
</tr>
</tbody>
</table>

CT image reconstruction

Up to now, single energy metal artifact reduction is available in conjunction with adaptive iterative dose reduction and filtered back projection (FBP); FIRST with single energy metal artifact reduction is not available. Because adaptive iterative dose reduction is effective for reducing noise and is widely used in clinical settings, following reconstruction algorithms were used to obtain axial images;

- adaptive iterative dose reduction 3D enhanced standard without single energy metal artifact reduction, FC03 kernel
- FIRST, body standard
- adaptive iterative dose reduction 3D enhanced standard with single energy metal artifact reduction, FC03 kernel

Afterward, we describe these three algorithms as AIDR, FIRST and SEMAR, respectively.

The followings were kept constant between different algorithms;

- z-axis range, from iliac crest to ischial tuberosity
- slice thickness, 3.0mm
- slice interval, 3.0mm
- field of view, 35 - 40cm (adjusted to body size)

Qualitative image analyses

A radiologist who was blinded to patient data and reconstruction algorithm evaluated images with a commercial viewer (Vue PACS; Carestream, Tokyo, Japan). All image sets were randomized and were evaluated with a soft tissue window setting (window level of 40 Hounsfield Unit (HU) and window width of 400 HU).
The degree of metal artifact and the depiction of structures (bladder, prostate/uterus and vagina, pelvic side wall, gluteus medius and rectovesical/rectouterine pouch) were evaluated with a 4-point scale.

Scores for metal artifact

- 4 = no or minimal artifact
- 3 = moderate metal artifact
- 2 = severe metal artifact in a small area
- 1 = severe metal artifact in a large area

Scores for depiction of structures

- 4 = good depiction
- 3 = slightly decreased depiction
- 2 = moderately decreased depiction
- 1 = poor depiction (e.g. dark band) for some part

As for depiction of pelvic side wall and gluteus medius, the side ipsilateral to THA was evaluated. If both sides are status after THA, the right side was evaluated.

**Quantitative image analyses**

A radiologist placed regions of interest (ROIs) on bladder and recorded CT attenuation and standard deviation using a commercial viewer (Vue PACS). He viewed three reconstructed images in a side-by-side way and placed ROIs so that they did not include wall of the bladder. ROIs were placed at the same location with the same size between different reconstruction algorithms using copy and paste function.

**Statistics**

Results are shown as mean ± standard deviation unless otherwise indicated. Scores of qualitative image analyses were compared using sign test between each reconstruction algorithm. The variance of CT attenuation of the bladder was assessed by using Levene test. The standard deviations of the bladder were compared using paired Student's t-test. For comparing multiple groups, the Bonferroni correction was applied and p<0.0167 (=0.05/3) was considered as a significant difference.
Results

Images of representative cases are shown in Fig. 1 on page 9 and Fig. 2 on page 9.

Qualitative image analyses

The results of qualitative image analyses are shown as graphs in Fig. 3 on page 10. SEMAR significantly improved image quality in all evaluated terms (p<0.0001) compared to AIDR and FIRST.

There was no significant difference between AIDR and FIRST in all evaluated terms (p=0.1892-1.0000).

The scores of qualitative image analyses in patients with status after THA on both sides or one side are shown in table 2.

Table 2 Results of qualitative analyses for patients with THA on both sides/ one side

<table>
<thead>
<tr>
<th></th>
<th>THA on both sides</th>
<th>THA on one side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AIDR</td>
<td>FIRST</td>
</tr>
<tr>
<td>metal artifact</td>
<td>0/0/0/14</td>
<td>0/0/0/14</td>
</tr>
<tr>
<td>depiction of structures</td>
<td>0/0/0/14</td>
<td>0/0/0/14</td>
</tr>
<tr>
<td>bladder</td>
<td>0/0/0/14</td>
<td>0/0/0/14</td>
</tr>
<tr>
<td>prostate</td>
<td>0/0/2/12</td>
<td>0/0/0/14</td>
</tr>
<tr>
<td>pelvic side wall</td>
<td>0/0/0/14</td>
<td>0/0/0/14</td>
</tr>
<tr>
<td>gluteus medius</td>
<td>0/0/0/14</td>
<td>0/0/0/14</td>
</tr>
<tr>
<td>rectovesical/rectouterine pouch</td>
<td>0/4/5/5</td>
<td>0/12/2/0</td>
</tr>
</tbody>
</table>

Quantitative image analyses

The median (with interquartile range) values of CT attenuation of the bladder were -26.2 HU (-45.0 - -11.5 HU), -21.6 HU (-42.2 - -4.2 HU) and 5.5 HU (-2.2 - 14.7 HU) for AIDR,
FIRST and SEMAR, respectively. The variation of the CT attenuation of the bladder was the lowest for SEMAR and the highest for AIDR (p=0.0071) (Fig. 4 on page 11).

The standard deviations of the bladder were 43.5 ± 49.5, 42.2 ± 48.6 and 18.5 ± 14.5 for AIDR, FIRST and SEMAR, respectively. Significant differences were seen between SEMAR vs AIDR (p=0.0011) and SEMAR vs FIRST (p=0.0016). There was no significant difference between FIRST vs AIDR (p=0.1314).

Table 3 Results of quantitative analyses for patients with THA on both sides/ one side

<table>
<thead>
<tr>
<th>bladder</th>
<th>THA on both sides</th>
<th>THA on one side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AIDR</td>
<td>FIRST</td>
</tr>
<tr>
<td>CT attenuation (HU)</td>
<td>-17.1 (-52.4 - 19.2)</td>
<td>-14.7 (-44.3 - 16.6)</td>
</tr>
<tr>
<td>CT standard deviation</td>
<td>83.1 ± 76.9</td>
<td>80.8 ± 75.6</td>
</tr>
</tbody>
</table>

For bladder CT attenuation, median (with interquartile range) is shown.
Fig. 1: Axial images of a 73-year-old woman who was status after total hip arthroplasty on the right side; reconstruction algorithms of AIDR (a), FIRST (b) and SEMAR (c). The degree of metal artifact was graded as 2 (severe metal artifact in a small area)/2/3 (moderate metal artifact) for AIDR/FIRST/SEMAR, respectively.

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Fig. 2: Axial images of a 78-year-old woman who was status after total hip arthroplasty on both sides; reconstructed algorithms of AIDR (a), FIRST (b) and SEMAR (c). The degree of metal artifact was graded as 1 (severe metal artifact in a large area)/1/3 (moderate metal artifact) for AIDR/FIRST/SEMAR, respectively.

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Fig. 3: For metal artifact, scores indicate 4 (no or minimal artifact) - 1 (severe metal artifact in a large area). And for depiction of structures, scores indicate 4 (good depiction) - 1 (poor depiction for some part). Vertical axes indicate numbers of patients. *, statistically significant difference

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Fig. 4: Box plots for CT attenuation of the bladder. Some outliers are seen in AIDR and FIRST. The variability of CT attenuation of the bladder is smaller with SEMAR compared to those with AIDR and FIRST.

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Conclusion

Discussion

- Metal artifacts were significantly reduced with SEMAR compared to FIRST and AIDR, in qualitative and quantitative analyses.
- The depiction of structures in pelvic region were significantly improved with SEMAR compared to FIRST and AIDR.
- The degree of metal artifact reduction and depiction of structures were not statistically different between FIRST and AIDR. According to Boudabbous (8), metal artifact reduction with MBIR was achieved. They compared MBIR and FBP in a side by side way, which might enable recognitions of minute differences between MBIR and FBP. And the evaluated reconstruction algorithm also differs between their study and our study; MBIR vs FBP and FIRST vs AIDR. AIDR belongs to hybrid iterative reconstruction algorithm and is widely used in clinical settings, therefore we evaluated AIDR rather than FBP.
- For reconstructing images of SEMAR and FIRST, it takes around 5 minutes, while images of AIDR can be reconstructed nearly in real time.

Limitations

- We did not investigated diagnostic performance for diseases in pelvic region, such as urolithiasis, diverticulitis and bladder carcinoma and so on. Because we showed that metal artifacts are significantly reduced and depiction of structures improved with SEMAR, future studies on this topic using SEMAR are expected.
- FIRST is a full iterative reconstruction algorithm and depiction of structures in areas without metal is expected to be sharper with FIRST compared with AIDR or FBP. However, we did not investigated this issue, because the purpose of this study was to assess metal artifact reduction. Because image quality and diagnostic performance with FIRST has not been investigated thoroughly, future studies are expected.
- We did not performed subgroup analyses for patient group of THA on both sides or one side, because the number of patients with THA on both sides was small and there are risks of increased $\alpha$ errors and $\beta$ errors.

Conclusion

For reducing metal artifact and to improve image quality in pelvic region in patients with total hip prosthesis, SEMAR would be preferable to FIRST.
References


8 Boudabbous S, Arditi D, Paulin E, Syrogiannopoulou A, Becker C, Montet X. Model-based iterative reconstruction (MBIR) for the reduction of metal artifacts on CT. AJR. 2015;205:380-5.