A Novel Metallic Artifact Reduction Technique When Using a Computed Tomography-Guided Percutaneous Metallic Antenna to Ablate Malignant Pulmonary Nodules: A Qualitative and Quantitative Assessment

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Background: Metallic microwave ablation (MWA) antenna-related artifacts are usually created in conventional CT images, and these artifacts can influence the effect of ablation. The aim of this study was to evaluate a new type of metal artifact reduction (MAR+) technique in CT-guided MWA for lung cancer.

Material/Methods: This retrospective study enrolled 30 lung cancer patients who received CT-guided MWA treatment from December 2017 to April 2018. Images after microwave antenna insertion into the tumor were reconstructed by the filter back projection (group A) and MAR+ reconstruction (group B). The CT values and standard deviations of the regions of interest (ROIs) on the chosen image were recorded, including the most significantly hypodense artifact (ROI1), hyperdense artifacts (ROI2), and chest muscles of the same layer (ROI3). The metal artifact indexes based on ROI1 and ROI2 (AI1, AI2) and the overall metal artifact index (A1) were calculated. Subjective image quality was graded on a five-point scale (1=worst, 5=excellent).

Results: The AI1 (74.14±76.32), AI2 (13.75±19.02) and A1 (54.12±54.82) of group B were lower than those of group A [(153.33±89.04), (30.63±26.42), (112.00±63.10), respectively] (P<0.001 for all). Both radiologists reported that the subjective image value of group B was significantly higher than that of group A (P<0.001). The subjective image quality scores evaluated by 2 observers showed excellent consistency (ICC=0.829).

Conclusions: The MAR+ imaging reconstruction significantly reduced metal artifacts, which helps radiologists to clearly observe the relationship between the ablation antenna and the lesion.

MeSH Keywords: Artifacts • Lung Neoplasms • Microwaves • Tomography, X-Ray Computed

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Background

Lung cancer is the most commonly diagnosed cancer (11.6% of all cancers) and the most common cause of cancer death (18.4% of all cancer deaths) worldwide [1]. In recent years, percutaneous microwave ablation (MWA), as a novel local treatment modality, has been widely used for lung cancer therapy [2–4]. MWA uses electromagnetic waves in the microwave energy spectrum to generate tissue- heating effects. The current MWA manufacturer uses a frequency of 2450 MHz. The polar molecules such as water molecules in tumor tissue generate extremely high-speed vibrations under the action of this microwave electromagnetic field, causing collisions and friction between molecules, and the thermal energy is then transferred to the adjacent tissues. When the temperature reaches 60–150°C in a short time, it causes irreversible damage to cells or coagulative necrosis [5,6]. Moreover, a single MWA probe covered a larger ablation volume than radiofrequency ablation (RFA) [7]. Computed tomography (CT) is currently the most accurate image-guidance technique for lung ablation.

The efficiency of MWA depends on the appropriate and accurate location of the microwave ablation antenna in the tumor. However, metal instruments used in interventional procedures can create significant artifacts in CT images [8]. The severity of metal artifacts depends on the material of the instruments used. MWA antenna-related artifacts are usually created in conventional CT images. Severe artifacts can cover the surrounding tissues and influence the exact location of the ablation antenna [9,10]. Therefore, reducing artifacts is very important for MWA.

To reduce these artifacts, the optimal acquisition and reconstruction method must be used for patients with various types of metal prostheses and implants. However, metal artifact reduction (MAR) techniques are rarely applied in interventional therapy. The aim of this study was to evaluate a new type of metal artifact reduction (MAR+) technique in CT-guided MWA for lung cancer.

Material and Methods

This retrospective study was approved by the Institutional Review Board of our hospital. The requirement for informed consent was waived for all subjects. We retrospectively reviewed patients with lung cancer who underwent CT-guided MWA using the MAR+ technique between December 2017 and April 2018. A total of 30 patients were identified.

CT-guided MWA procedure

All ablation processes for lung cancer were performed with the guidance of a NeuViz 128 CT (Neusoft Medical Company, Shenyang, China). The scanning parameters for the location were 120 kVp tube voltage, automatically modulated tube current (reference mAs: 180), 0.6 second gantry rotation time, 1.2 pitch, 128×0.625 mm collimation width, 360 mm field of view (FOV), 5 mm slice thickness, and 5 mm slice intervals. The effective dose-length product (DLP, mGy×cm) was recorded, and the effective dose (ED, mSv) was calculated for each ablation series using the equation: ED=DLP×k [k=0.014 (mSv×mGy−1×cm−1)].

Patients underwent a CT scan of the area of interest during suspended inspiration. The entry site was prepared and draped in a sterile fashion. All ablations were performed under local anesthesia consisting of an injection of 5–10 mL of 1% lidocaine hydrochloride. All ablations were performed by a microwave ablation system (2450 MHz generator, MICRO TECH, KANG YOU, Nanjing, China) and a 16-gauge antenna (made of stainless steel as biomedical material). The antenna was inserted into the lesion during a breath-hold. Five millimeters sections with image reconstruction were then obtained during the breath-hold to verify the location of the antenna (Figure 1A–1D). The ablation power and time were adjusted to the size and location of the tumor according to the manufacturer’s recommendations. All ablations were performed at a constant power of 50–60 W. The ablation time per tumor was 5–10 minutes. The procedure aimed to ablate the tumor plus at least a 5-mm margin.

After the ablation procedure, CT images were immediately acquired at the level of the ablation site to search for the presence of complications, such as pneumothorax or parenchymal hemorrhage.

Image postprocessing

The raw data of all available images after microwave antenna insertion into the tumor site were reconstructed by the filter back projection algorithm (group A) and MAR+ reconstruction (group B). The reconstruction parameters of group A and B were: group A with Clearview closed, MAR+ closed; group B with Clearview 40%, MAR+ open. Both groups were reconstructed with a slice thickness of 5 mm and a slice interval of 5 mm. Actual MWA procedures were performed under the guidance of group B images. The images of groups A and B were transferred to the advanced workstation (AVW 1.0.8, Neusoft Medical Company, Shenyang, China) for further analysis.

MAR+ technique is a kind of normalized MAR, which involves a special method to reduce the effect of the microwave antenna. The MAR+ algorithm was created in the following way: according to the geometric parameters of the system, the characteristics of the electronic components and the detector, the anatomical model, the front projection model, and the noise model are refined. The correction process based on the iterative
algorithm removes the noise caused by metal and restores the true anatomical structure around the metal object (Figure 2).

**Evaluation methods**

The images that included the tip of the microwave antenna and the lesion with the most severe artifacts were chosen for analysis by 2 radiologists (with 5 and 8 years of experience in chest imaging) independently in the soft-tissue window (window width: 300 HU, window level: 40 HU). Any disagreements were resolved by discussion and consensus.

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*Figure 1.* A 58-year-old man with the primary lung cancer who underwent MWA treatment. (A) An axial plain CT image before the ablation process showing an elliptical nodule of 3.4×2.4 cm in the basal right lower lobe in the lung window (red arrow). (B) The axial plain CT scan after filter back projection reconstruction presenting with poor quality, where the extensive metal artifacts impair the assessment of the antenna’s position within the nodule. (C) The axial plain CT scan after MAR+ reconstruction appearing with excellent quality where the metal artifacts are greatly reduced, allowing better visualization of the relationship of the antenna and lesion. (D) An axial plain CT scan after the biopsy procedure showing patchy areas of ground-glass opacity around the lesion (red arrows).

*Figure 2.* The flow of the MAR+ technique.
Subjective evaluation

Two radiologists, who were blinded to the imaging reconstruction method, graded on a five-point scale [11] in each patient based on an overall assessment of the severity of metal artifacts. The images were evaluated for subjective evaluation in the soft-tissue window setting (window width: 300 HU, window level: 40 HU). The specific standards were: 1-worst, severe metal-related artifacts that hardly reveals the surrounding lung cancer tissue; 2-bad, limited observation of the surrounding tissue; 3-medium, some artifact but acceptable visualization; 4-good, small enough artifact to clearly observe the relationship between the microwave antenna and the lesion; 5-excellent, almost no artifact.

Objective evaluation

The objective evaluation was performed by another radiologist with 3 years of experience in chest imaging in the soft-tissue window (window width: 300 HU, window level: 40 HU). The CT values in Hounsfield units (CT1, CT2, CT3) and standard deviations (SD1, SD2, SD3) of the elliptical regions of interest (ROIs) with the area of 30–40 mm2 were recorded, including the most significantly hypodense artifacts (ROI1) and hyperdense artifacts (ROI2) of the selected image, along with chest muscles (ROI3) of the same slice. The metal artifact indexes based on ROI1 and ROI2 (AI1, AI2) and the overall metal artifact index (AI) were calculated as shown below [12,13], respectively.

\[ AI_1 = \sqrt{SD_1^2 - SD_2^2}, \quad AI_2 = \sqrt{SD_2^2 - SD_3^2}, \quad AI = \sqrt{(AI_1^2 + AI_2^2) / 2} \]

Statistical analysis

Statistical analysis was performed with SPSS (version 20.0, SPSS Inc., Chicago, USA). The discrete variables are expressed as median and interquartile range, and the continuous variables are expressed as mean±SD. A paired t test was used to compare the differences in AI1, AI2, and AI between the 2 groups. The subjective scores were compared using a Wilcoxon signed-rank test. The consistency between the 2 readers was evaluated by the intraclass correlation coefficient (ICC) test with the following scale: poor (<0.40), moderate (0.40–0.60), good (0.60–0.75), and excellent (>0.75) [14]. P<0.05 was considered statistically significant.

Results

General characteristics

The general patient characteristics are summarized in Table 1. All 30 lung cancer patients underwent MWA therapy for a single lesion. Twenty-one cases (70%) were primary pulmonary cancers (adenocarcinoma, n=16; squamous cell carcinoma, n=5), and 9 cases were metastatic cancers (esophageal squamous cell carcinoma, n=1; hepatocellular carcinoma, n=3; colorectal adenocarcinoma, n=5). There were 7 women (23.3%) and 23 men (76.7%) with a mean age of (60.3±11.6) years (range 38–77 years). The median tumor size was (3.5±0.7) cm (range 2.3–4.9 cm). One MWA antenna was used for each patient during the ablation procedure. The mean ED was (2.74±0.43) mSv (range 2.23–3.17 mSv) per scan. The reconstructions utilizing MAR+ algorithms were processed in an average time of (3.2±0.4) seconds.

Table 1. Clinical characteristics of the patients.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Values</th>
</tr>
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<tbody>
<tr>
<td>Age (years)*</td>
<td>60.3±11.6 (38–77)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>23 (76.7%)</td>
</tr>
<tr>
<td>Female</td>
<td>7 (23.3%)</td>
</tr>
<tr>
<td>Histopathological types</td>
<td></td>
</tr>
<tr>
<td>Primary lung cancer</td>
<td>21 (70%)</td>
</tr>
<tr>
<td>Adenocarcinoma</td>
<td>15 (71.4%)</td>
</tr>
<tr>
<td>Squamous cell carcinoma</td>
<td>6 (28.6%)</td>
</tr>
<tr>
<td>Metastatic lung cancer</td>
<td>9 (30%)</td>
</tr>
<tr>
<td>Esophageal squamous cell cancer</td>
<td>1 (11.1%)</td>
</tr>
<tr>
<td>Hepatocellular carcinoma</td>
<td>5 (55.6%)</td>
</tr>
<tr>
<td>Colorectal adenocarcinoma</td>
<td>3 (33.3%)</td>
</tr>
<tr>
<td>Tumor size (cm)*</td>
<td>3.5±0.7 (2.3–4.9)</td>
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<tr>
<td>Complications</td>
<td></td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>4 (13.3%)</td>
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<tr>
<td>Pleural effusion</td>
<td>2 (6.7%)</td>
</tr>
<tr>
<td>Effective dose (mSv)*</td>
<td>2.74±0.43 (2.23–3.17)</td>
</tr>
</tbody>
</table>

* Data are the mean±standard deviation, and data in parentheses are the ranges or percentages.

Table 2. The values of AI1, AI2, and AI were significantly different between groups A and B.

<table>
<thead>
<tr>
<th>Group</th>
<th>AI1</th>
<th>AI2</th>
<th>Al</th>
<th>P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>153.33±89.04</td>
<td>74.14±76.32</td>
<td>&lt;0.001</td>
<td></td>
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<tr>
<td>Group B</td>
<td>30.63±26.42</td>
<td>13.75±19.02</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>112.00±63.10</td>
<td>54.12±54.82</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

Data are presented as the mean±standard deviation, and P<0.05 indicates statistical significance.
Table 3. Subjective image quality assessment between groups A and B by 2 radiologists.

<table>
<thead>
<tr>
<th>Radiologists</th>
<th>Patients</th>
<th>Score 1</th>
<th>Score 2</th>
<th>Score 3</th>
<th>Score 4</th>
<th>Score 5</th>
<th>Mean score*</th>
<th>P value</th>
</tr>
</thead>
<tbody>
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<td></td>
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<tr>
<td>Radiologist 1</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>30</td>
<td>20 (66.7%)</td>
<td>10 (33.3%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>1 (1, 2)</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Group 2</td>
<td>30</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>5 (16.7%)</td>
<td>15 (50%)</td>
<td>10 (33.3%)</td>
<td>4 (4, 5)</td>
<td></td>
</tr>
<tr>
<td>Radiologist 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>30</td>
<td>20 (66.7%)</td>
<td>10 (33.3%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>1 (1, 2)</td>
<td>P&lt;0.001</td>
</tr>
<tr>
<td>Group 2</td>
<td>30</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>4 (13.3%)</td>
<td>18 (60%)</td>
<td>8 (26.7%)</td>
<td>4 (4, 5)</td>
<td></td>
</tr>
</tbody>
</table>

* Data are the median and interquartile range and data in parentheses are the percentages.

Objective evaluation results

The objective evaluation results are summarized in Table 2. The A1, A2, and A3 of group B (74.14±76.32, 13.75±19.02, 54.12±54.82) were significantly lower than those of group A (153.33±89.04, 30.63±26.42, 112.00±63.10, all P<0.001).

Subjective evaluation results

Radiologist 1 evaluated that the subjective image value of group B was higher than that of group A, and the difference was statistically significant [4 (4, 5) vs. 1 (1, 2), P<0.001], which was consistent with the subjective assessment results of Radiologist 2. The subjective image quality scores evaluated by 2 observers showed excellent consistency (ICC=0.829) (Table 3, Figure 1A–1D).

MWA-related results

The technical success rate of MWA treatment for the 30 patients was 100%. The main complications were pneumothorax in 4 patients (13.3%) and pleural effusion in 2 patients (6.7%). No deaths were observed during the ablation process.

Follow-up contrast-enhanced chest CT examinations were used to detect local recurrence. No patients had local recurrence at the ablation site during the short follow-up period (3–6 months).

Discussion

Surgical lobectomy is viewed as the criterion standard treatment for lung cancer [15–17]. However, patients with high-risk conditions, such as cardiopulmonary dysfunction, impaired renal function, and hypertension, or who are elderly, are not good candidates for surgery. Currently, MWA has been widely used in patients with medically inoperable tumors [18]. Several studies have suggested that MWA is safe and effective in the treatment of primary pulmonary malignancies and pulmonary metastases [6,16,19,20]. The presence of metallic objects in the imaging field may deteriorate the image quality of CT scans and thus impact treatment [21]. The significance of reducing metallic artifacts is to allow the operator to clearly observe the location of the lesion and the ablation antenna, thus improving the image quality and providing more possibilities for accurate MWA procedures.

The causes of metal artifacts are complex and include beam hardening, photon starvation, and increased scatter and noise [22–24]. To reduce these artifacts, the optimal acquisition and reconstruction method must be used for patients with various types of metal prostheses and implants. Different CT vendors have their own specific MAR algorithms. For example, gemstone spectral (GSI) dual-energy CT (DECT) with or without metal artifact reduction software (MARS) from GE (GE Healthcare, USA) used projection-based reconstructions on 40–140 keV monochromatic images to reduce artifacts [24]. Iterative metal artifact reduction (IMAR) algorithms from Siemens (Siemens Healthcare, Germany) used an iterative frequency split technique to suppress metal-related artifacts [25]. Orthopedic metal artifact reduction algorithms (O-MAR) used the iterative reconstruction method developed by Philips (Philips Medical Systems, The Netherlands) [26,27]. Toshiba (Toshiba Medical Systems, Japan) developed the single-energy metal artifact reduction (SEMAR) procedure, which mainly removes the metal artifacts based on a linear interpolation in the blended sinogram [28]. NeuViz 128 CT is configured with the MAR+ technique to clearly remove the metal artifact in a reasonable time, to a certain extent, in case of the presence of complications. The procedure is carried out by creating a front projection model, an anatomic model, and a noise model according to the geometric parameters, electronic components, and detector characteristics, and then clearly removing the metal artifact based on the iterative correction method.

Metal artifact reduction techniques have been applied to evaluate the image visualization of patients with knee...
replacements [29], total or unilateral hip arthroplasty [30,31], dental implants [32], and spine metallic implants [33]. Few studies have explored how to decrease the artifacts produced by metallic ablation antennas during CT-guided MWA for patients with lung cancer. In our study, the results showed that MAR+ imaging reconstruction could reduce the MWA antenna-related metal artifacts subjectively and objectively. In images reconstructed with the MAR+ technique, the microwave ablation antenna was observed with a clearer delineation and the removal of metal artifacts at the needle edges. The removal of metal artifacts and the visualization of the soft-tissue region surrounding the antenna were critical, as they can enhance needle confirmation within the target lesion. Although switching to the bone window may partially reduce metal artifacts, the surrounding soft-tissue region is unclear. The MAR+ technique in the present study reduced metal artifacts in only approximately 3 seconds per scan, which is nearly a real-time correction of metal artifacts.

The limitations of this study include its retrospective nature and its fairly small sample size of 30 patients, which limits the generalization of the findings. This study mainly focused on image quality, and the follow-up time was relatively short. The survival and outcomes of the patients require further, long-term, follow-up.

Conclusions

In conclusion, the MAR+ imaging reconstruction algorithm from NeuViz 128 CT significantly reduced metal artifacts, which makes it possible for radiologists to clearly observe the relationship between the ablation antenna and the lesion and thus improves the efficiency and accuracy of MWA procedures.

Conflicts of interest

None.

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