# Quantitative Evaluation of Metal Artifact Reduction Techniques

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**Introduction:** Image distortions caused by differences in magnetic susceptibility have long been a problem in clinical MR imaging, especially in the presence of metal prostheses. Various techniques are used to reduce the severity of metal artifact, including increasing the image bandwidth (BW), or employing View Angle Tilting (VAT) [1]. A VAT spin echo sequence is identical to a conventional spin echo (CSE) sequence, except that the slice select gradient is reapplied concurrently with the frequency encoding gradient. VAT results in a marked reduction in the severity of the metal susceptibility artifact, can be employed without increasing the imaging time, and uses only standard reconstruction. Unfortunately, VAT introduces blur, and only reduces the artifact in one direction. These deficiencies are lessened in the Metal Artifact Reduction Sequence (MARS) [2], which employs VAT and increased image and slice select BWs. The effectiveness of MARS in reducing metal artifact in a clinical scan is illustrated in Figure 1.

It is difficult to quantitatively evaluate the capability of any given method of artifact reduction. Without a standard against which to measure the effectiveness of a technique, most studies have been limited to qualitative comparisons. In this work, such a standard was developed by creating a wax replica of a metal phantom, which has the advantages of being non-metallic and having a similar susceptibility to water. The difference between MR images of the metal phantom and of the wax replica was measured, and resolved into contributions from noise and metal artifact. The goal was to develop a technique to quantify artifact, and to use it to compare the effectiveness of several approaches to metal artifact reduction, including VAT and MARS, in terms of metal artifact reduction, noise, and blur.

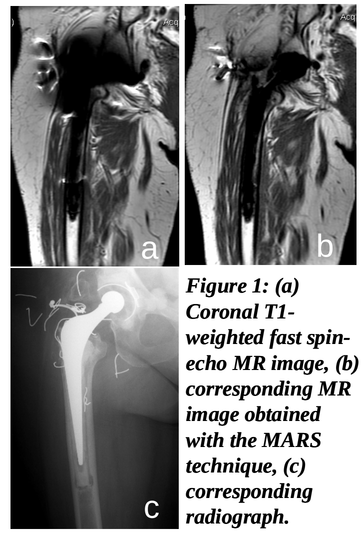


***Figure 1: (a) Coronal T1-weighted fast spin-echo MR image, (b) corresponding MR image obtained with the MARS technique, (c) corresponding radiograph.***

**Methods:** ***Phantoms*** - In order to measure the severity of the metal artifact remaining after the application of various metal artifact reduction techniques, four imaging phantoms were used. The first phantom was a typical stainless steel femoral hip joint replacement placed in a plastic container filled with water, and the second was a wax replica of the same prosthesis placed in the same position in the plastic container. As identical imaging parameters were used for both phantoms, the image of the wax replica acted as a "gold standard", containing no metal artifact. This was repeated with a titanium femoral hip joint replacement prosthesis and its respective wax duplicate.

***MR Experiments*** - Coronal images were obtained with a 1.5 T GE Signa MR scanner using the body coil (TR = 550ms, TE = 24ms, FOV = 32cm, 3mm slice, 256x256 matrix). Attempts to reduce artifact included varying the image BW (between +/- 8kHz and +/- 64kHz), varying the slice select BW by 20%, applying VAT, and various combinations thereof. In particular, MARS employed all three techniques: VAT, an image BW of +/- 64kHz, and a 20% increase in slice select BW.

***Image Analysis*** - In order to measure the artifact present in the image of the metal prosthesis, the difference between the metal image and the image of the wax replica was taken. The sum of the squares of the resulting pixels yielded a measure of the "*total energy*", equal to the total squared difference between the images with and without artifact. The total energy contained contributions from noise and artifact. The noise contribution was isolated by looking at a region outside of the container where no artifact should be present, so that the only difference between the images was noise. The total difference between the images minus the contribution from the noise provides the "*artifact energy*", a quantitative measurement of the artifact.

An evaluation of blur was obtained by scanning a phantom containing doped water and line pairs (Picker International) with a CSE pulse sequence and with each of the artifact reduction pulse sequences. The MR image obtained with the CSE sequence was subtracted from the image obtained using each of the other techniques, and the total energy and noise energy were determined as outlined above. Subtracting the contribution from noise and other sources associated with changing BWs yielded a measure of the "*blur energy*" for the pulse sequences that included VAT.

**Results and Discussion:** Images from various scans of the phantoms are shown in Figure 2, and the artifact energy present in the metal phantom MR images is depicted in Figure 3 for the various pulse sequences. As can be seen in Figure 3, increasing the image BW significantly decreased the artifact. However, we found the signal to noise ratio (SNR) to be proportional to the inverse square root of the image BW (as expected), so the gain in artifact reduction was somewhat diminished by a loss in SNR. Increasing the slice select BW had no such drawback, and still showed a mild improvement in artifact reduction compared to the CSE scan (BW +/- 16kHz). The VAT technique provided a much larger decrease in artifact, resulting in over 61% less artifact than using a CSE sequence. MARS, consisting of a combination of VAT, increased image BW, and increased slice select BW, yielded the least amount of artifact, reducing the artifact by over 76% compared to using a CSE sequence. From the blur analysis, MARS was found to decrease the blur energy by 89% over using VAT with BW +/- 16kHz.

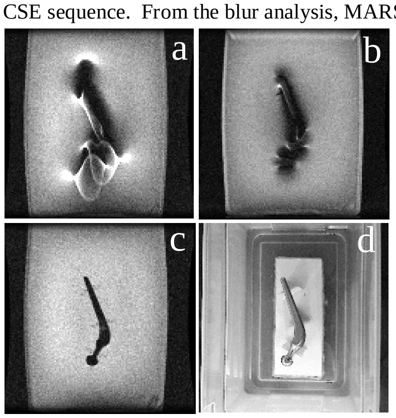


***Figure 2: (a) Stainless steel prosthesis imaged with a CSE pulse sequence (BW +/- 16 kHz), (b) corresponding slice obtained using the MARS sequence, (c) corresponding image of the wax prosthesis imaged with a CSE scan, (d) photograph of the phantom.***

Once quantification of noise, metal artifact, and blur has been accomplished, the results can be used to select the best metal artifact reduction strategy in a clinical setting with given imaging parameters. For example, although MARS is proficient at minimizing metal artifact and blur, the decreased SNR may require too many averages to be practical for some applications. Knowing the strengths and weaknesses of the various techniques allows for an informed choice for each situation.

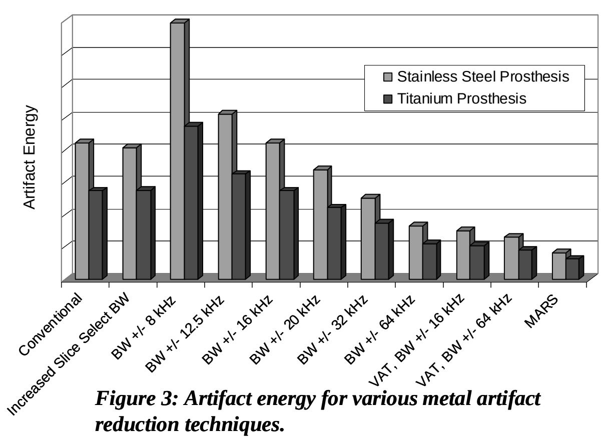


***Figure 3: Artifact energy for various metal artifact reduction techniques.***

**Conclusions:** The use of a non-metallic replica of a metal phantom was proposed and demonstrated to be an effective and direct way of quantitatively measuring metal artifact, which has traditionally been limited to qualitative studies. Use of these approaches proved the value of VAT and MARS as effective metal artifact reduction methods.

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**References:**

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[2] Lee MJ, et al. Skeletal Radiol 2001;30:398-401.