Image Quality of Commercial CT Metal Artifact Reduction Algorithms and a Novel In-House Algorithm for Head and Neck (H&N) Cancer and the Dosimetric Implications On Proton Therapy

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Introduction

High Z materials, such as metal amalgams, are common sources of artifacts in Head and Neck (HN) images. The vast majority of commercial artifact reduction algorithms are based on the subtraction of metal data points, followed by the interpolation and replacement of the missing data by estimated (sometimes inaccurately) data, possibly causing additional artifacts.

Purpose: To investigate the diagnostic and proton dosimetric performance of four major commercial metal artifact reduction algorithms (Philips, Siemens, GE and Toshiba) and an in-house technique (AMPP) that is **not based on direct interpolation methods.**

The Algorithm

The algorithm developed (AMPP) makes use of two angled CT scans to generate one artifact-reduced image set. In simple terms, the reconstruction technique is performed in the image space and is based on the combination of the superior portion of a superiorly tilted scan with the inferior portion of an inferiorly tilted scan (Fig.1).

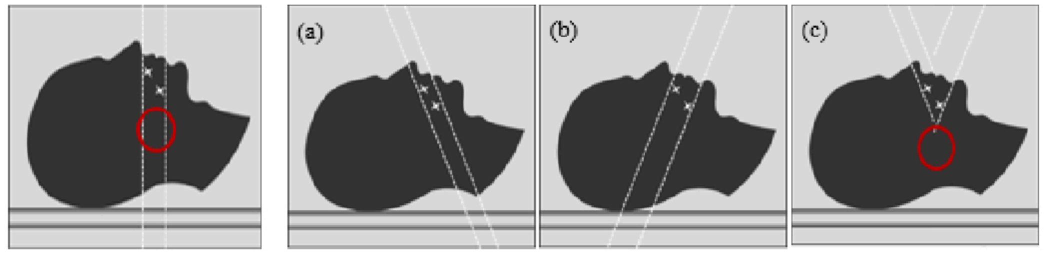


Figure 1: Diagram representing a patient with HN disease with the range of CT slices affected by the dental work. The red circle shows the region of typical HN disease that gets affected by artifacts resulting from metal in the mouth. Sagittal view with the CT gantry tilted superiorly (a) and inferiorly (b) showing the artifact-affected slices. In the final artifact-reduced image (c), the posterior region (red circle) is clear, and the artifacts are focused on the anterior region.

Methodology

A H&N anthropomorphic phantom composed of proton tissue equivalent materials, human skull, air cavities and a removable jaw was used. The removable jaw allowed for the exchange of bone equivalent and metal teeth for the creation of a baseline *Figure 2(a)* and artifact-filled scans *Figure 2(b)*. The phantom was scanned using Philips, Siemens, GE and Toshiba scanners where each metal scan was reconstructed with its respective vendor's MAR algorithm. Algorithms were evaluated for severity of artifacts (percentage of bad pixels: HU error outside ±20 HU) and CT number accuracy (mean HU number differences and standard deviations inside volumes). Clinically realistic proton treatment plans were designed for a range of target sizes and anatomical locations on the baseline scan. The optimized plans were then copied onto each respective vendor's MAR scans and the doses were recalculated without reoptimization. DVH and plan quality metrics were evaluated for each.

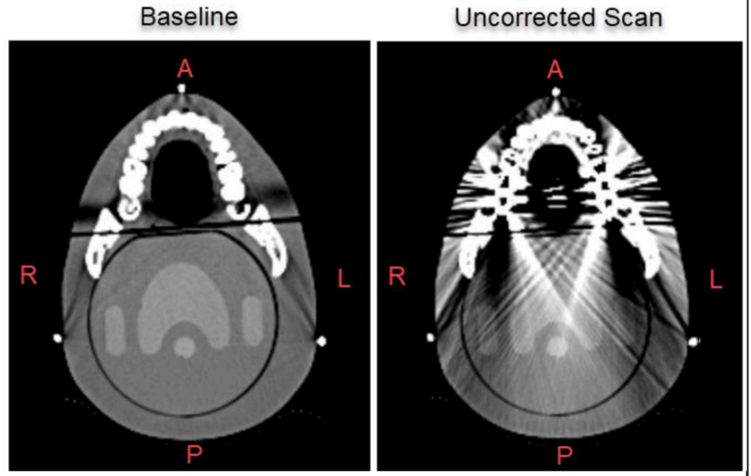
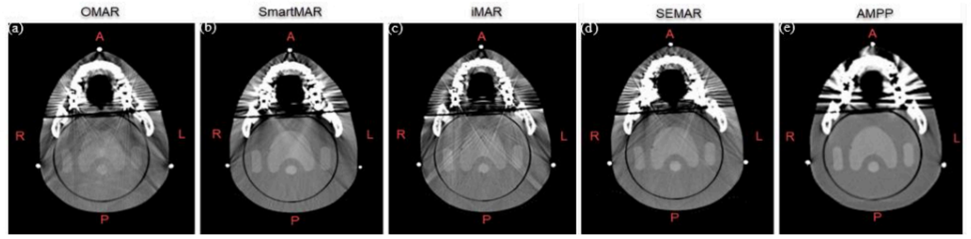


Figure 2: Axial CT views of the modified phantom containing a central target and 3 healthy structures, and a jaw insert (left). Holes were drilled in the molars in the jaw insert; these were filled with bone-equivalent materials showing metal artifacts generated by the capsules (right).

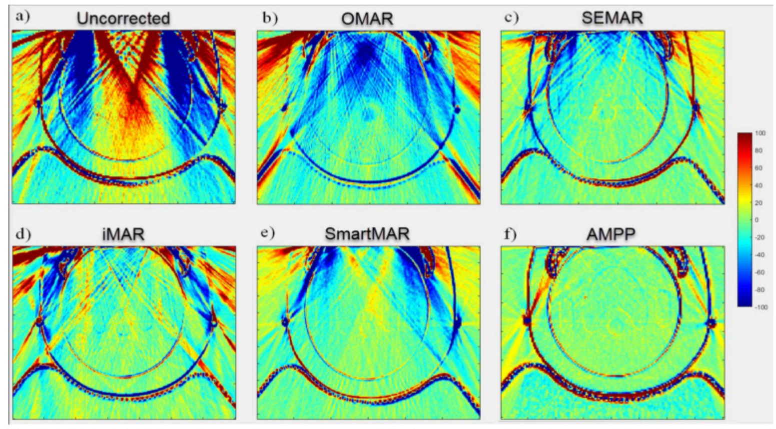
Results - Imaging



Key take-homes (MAR Algorithms)

- Each MAR algorithm diminished the severity of the artifacts in the uncorrected images but with varying, and sometimes limited, success.
- AMPP-corrected image was nearly identical to the corresponding baseline image posterior to the oral cavity.

HU Difference Maps



MAR Technique	% Bad Pixels
Uncorrected	78.1
OMAR	65.5
SEMAR	29.1
iMAR	25.5
SmartMAR	27.9
AMPP	4.2

Key take-homes (HU Difference Maps)

- Each MAR algorithm diminished the severity of the artifacts in the uncorrected images but with varying, and sometimes limited, success.
- AMPP-corrected image was nearly identical to the corresponding baseline image posterior to the oral cavity.
- Severe differences displayed by the dark red and dark blue colors on the uncorrected image, representing differences of over 100 HU.
- All MAR algorithms reduced the percentage of bad pixels, at varying degrees of efficacy.

Key take-homes (Mean HU error)

- Commercial MAR algorithms showed inconsistent performance in retrieving HU number.
- AMPP outperformed the commercial solutions regardless of location: improved the HU accuracy to nearly the same as baseline scan (differences close to 0).

Mean HU error within Structure Volume (HU)

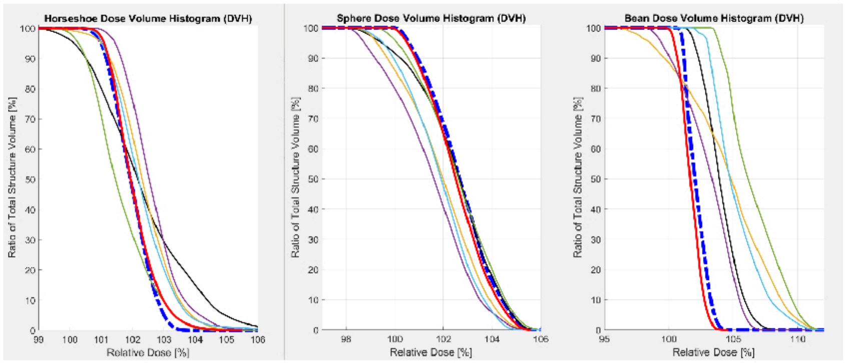
	Uncorrected Scan	OMAR corrected	SmartMAR corrected	iMAR corrected	SEMAR corrected	AMPP corrected
PTV	39	-18	2	-15	-3	-2
Spinal Cord	36	-13	3	-13	-1	-1
Right Parotid	-67	-34	-15	3	-20	2
Left Parotid	-63	-36	-24	-4	-19	1

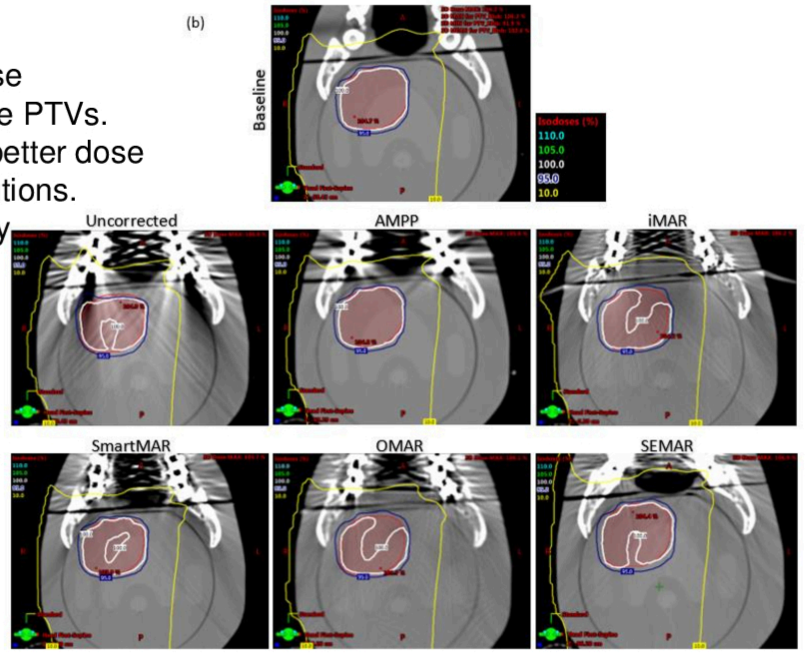
Results – Proton Therapy

Protons treatment plans were designed for several targets but the DVH of three of them and dose distributions of one are shown here as representatives of the data.

Key take-homes

- None of the commercial MAR algorithms were found to affect the dose distributions in a consistent manner, either by over or underdosing the PTVs.
- Instances where the uncorrected (i.e. full artifact) image set yielded better dose distributions than the ones corrected by some of the commercial solutions.
- AMPP-corrected images, provided dose distributions that consistently
- best agreed with the baseline dose distribution, for all five targets.





Conclusion

AMPP was also compared to 4 currently available major commercial algorithms; OMAR, SmartMAR, iMAR and SEMAR using an anthropomorphic HN phantom.

- Although commercial MAR algorithms generally reduced the severity of metal artifacts in HN CT scans, their performance was inferior to AMPP.
- In addition to improving visualization, a proton therapy dosimetric analysis showed that AMMP provided the best image set to treatment plan on.

Unlike other existing algorithms, AMPP:

- ✓offers the improvement of not requiring the replacement of deleted metal thresholded data with artificially interpolated data.
- ✓is independent of the CT scanner provider and therefore can be used in any scanner that allows for gantry tilts.
- ✓is applied in the image space, and therefore does not require the need to acquire and manipulate the proprietary raw data from vendors. No need for research agreements!
- ✓does not require information about the type and size of the metals in the image, making it easily applicable to any patients with dental work.

Future Work – Patient Studies

Investigate the performance of the AMPP technique on actual patient anatomy.

- Inter- and intra-observer contouring variability
- Target coverage
- Dose calculation accuracy
- Patient motion in between scans (breathing or moving of the tongue)
- Improvement in radiation treatment workflow
- No need for dosimetrists to manually override artifact-filled HU values