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An evaluation of three commercial metal artifact reduction methods for CT simulations in radiation therapy treatment planning

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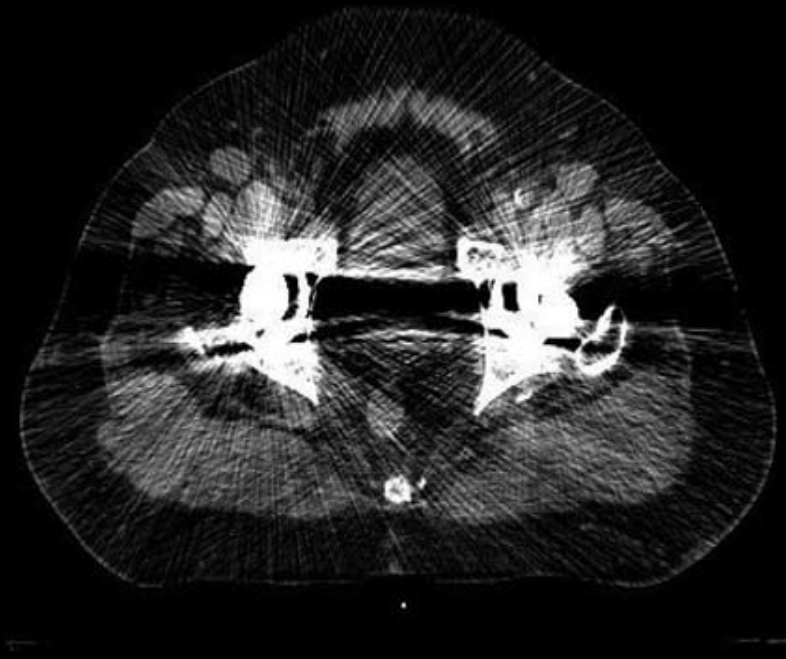
Introduction

- 1-4% of RT patients have metal implants that could affect their treatment (TG-63)
- Streak artifacts pose challenges for treatment planning
  - Difficult to contour the target and surrounding organs
  - CT number errors → density errors → dose calculation errors



Purpose

To evaluate metal artifact reduction (MAR) methods using criteria relevant for treatment planning and dose calculation accuracy:

1. Accuracy of CT numbers
2. Reduction in the severity of streak artifacts
3. Accuracy in the representation of the size of metal objects

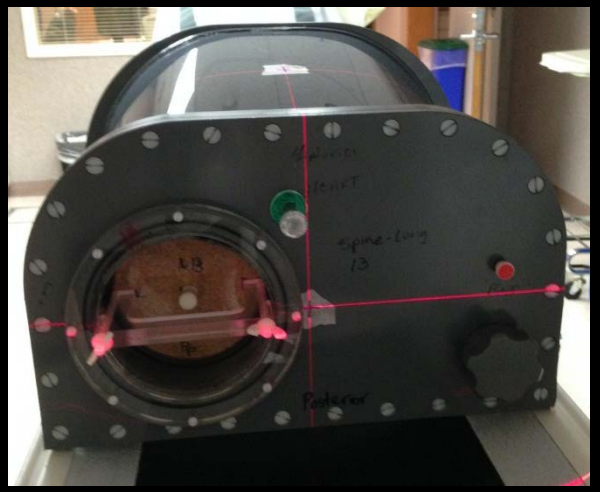
Metal artifact reduction (MAR) methods

1. Philips algorithm for orthopedic implants (O-MAR)
2. GE monochromatic Gemstone Spectral Imaging (GSI)
   - Dual energy CT (Discovery™ CT750 HD)
   - Reconstructed monochromatic images (40 to 140keV)
   - Focus on 140keV for this study
3. GE monochromatic Gemstone Spectral Imaging with metal reduction software applied (GSI-MARs)

Anthropomorphic phantoms

IROC pelvic phantom with hip prosthesis

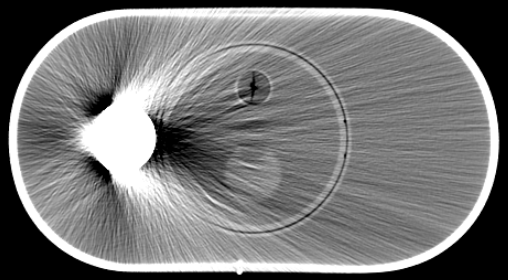
IROC thoracic phantom with titanium rods



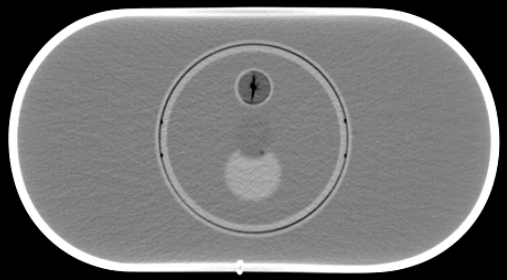
CIRS head phantom with dental fillings

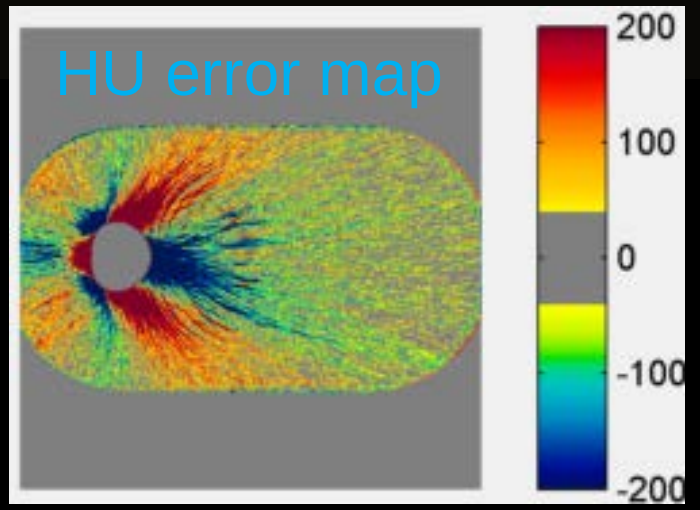
Streak artifact severity and CT number accuracy

Metal scan



Baseline scan





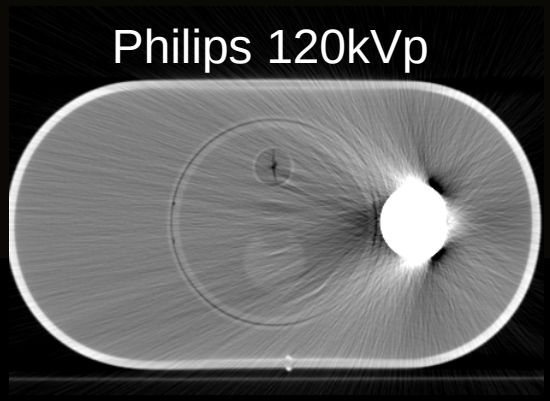
Quantitative evaluation metrics:

1. *% bad pixels* (HU error > 40)
   - 40 HU error corresponds to approximately 1-2% dose calculation error for a 6MV photon treatment (Kilby et al. 2002)
2. M_{error} takes into account magnitude of errors

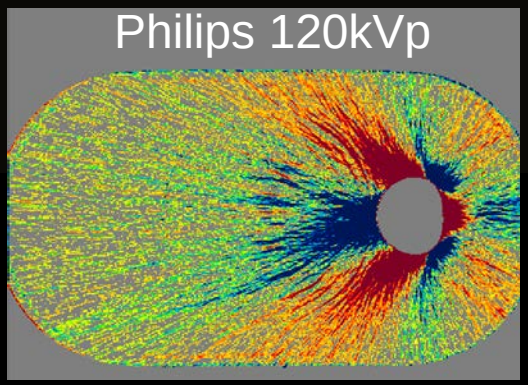
$$M_{error} = \frac{\%\ bad\ pixels}{100} * \overline{\Delta HU_{badpixels}}$$

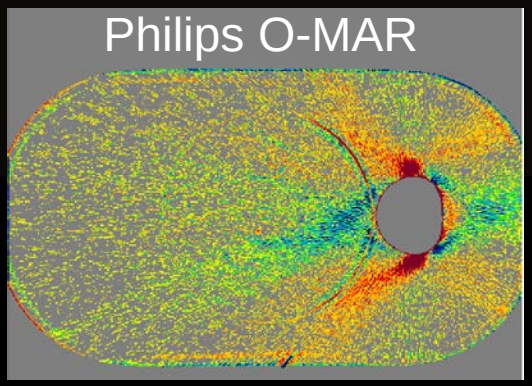
   - Example: 50% of pixels in image are “bad pixels” (HU error > 40) and the mean absolute error of these pixels is 80 HU → M_{error} = 40

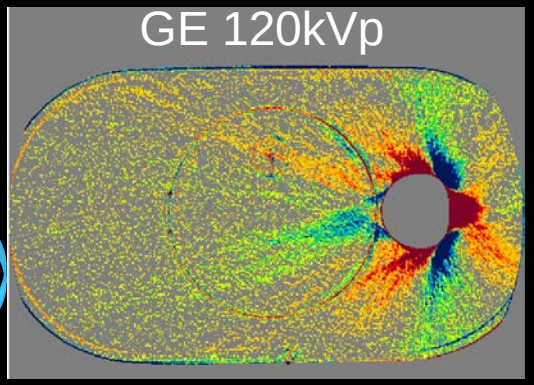
– Both metrics averaged over slices spanning the metal implant

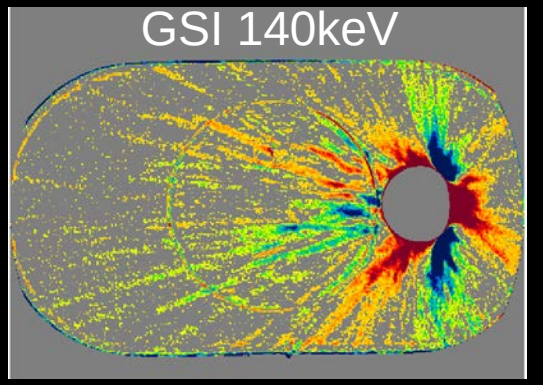


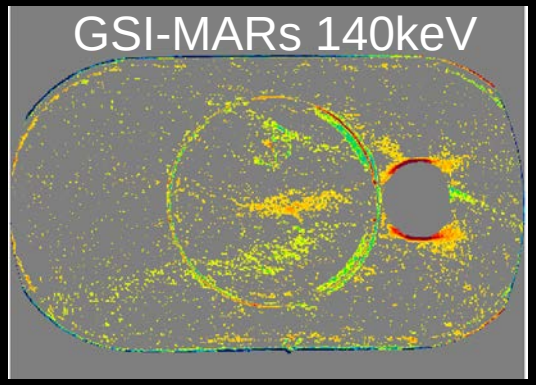
Imaging technique	% bad pixels	M_{error}
Philips 120kVp	46.6	61.0
Philips O-MAR	31.6	29.6
GE 120kVp	36.8	38.0
GSI 140keV	29.2	32.5
GSI-MARs 140keV	12.1	10.0

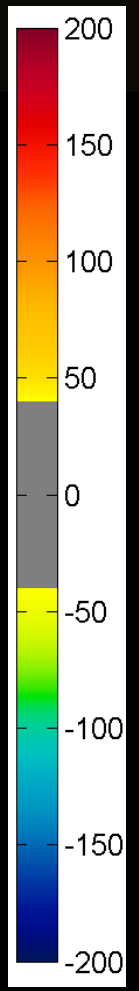


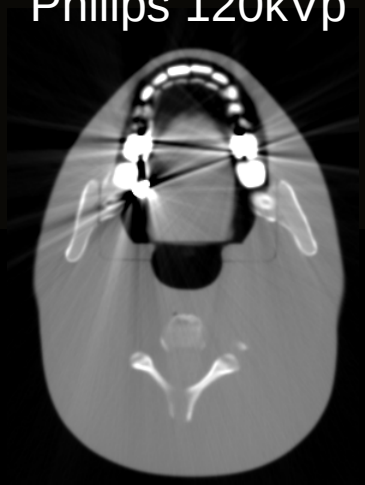




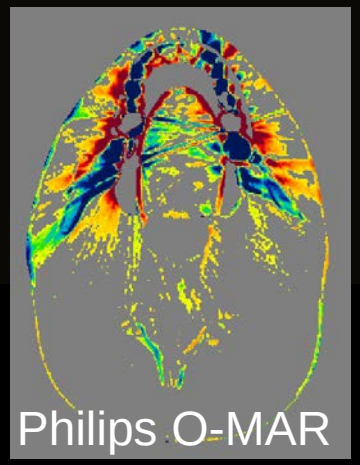


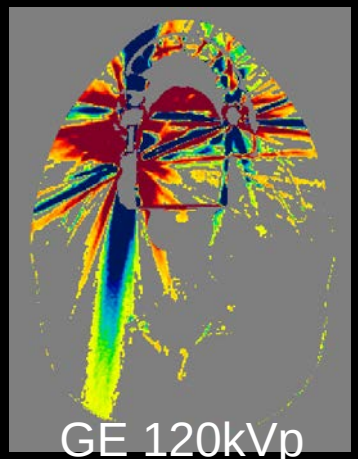


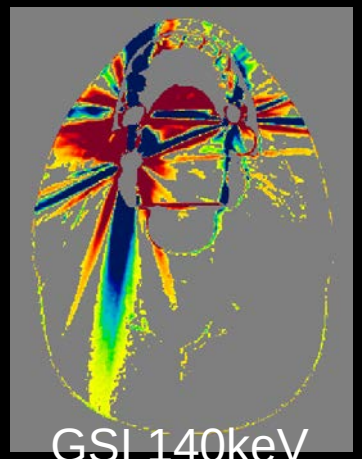


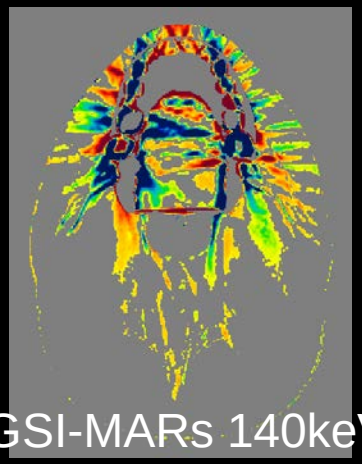


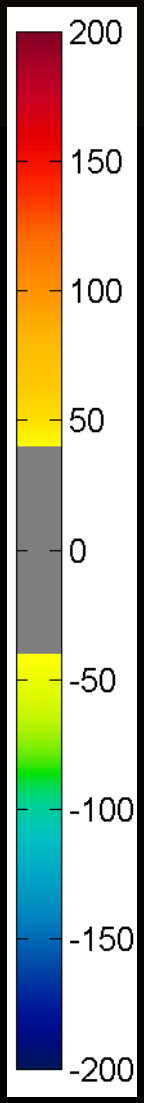
Imaging technique	% bad pixels	M_{error}
Philips 120kVp	27.2	50.1
Philips O-MAR	25.0	41.0
GE 120kVp	22.4	41.7
GSI 140keV	20.4	38.0
GSI-MARs 140keV	24.7	35.5





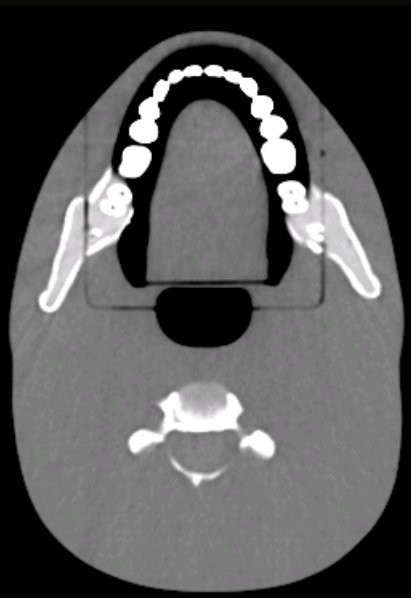


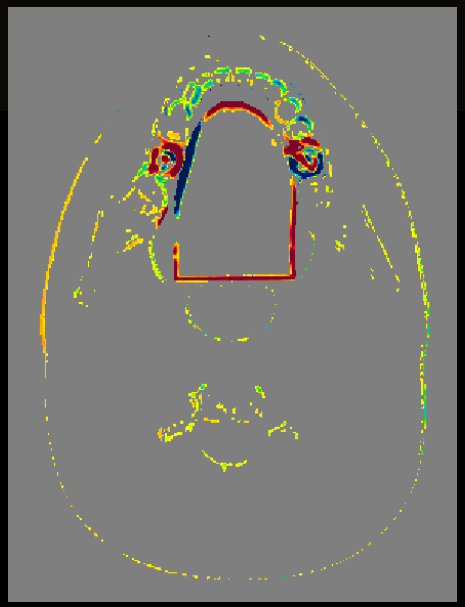




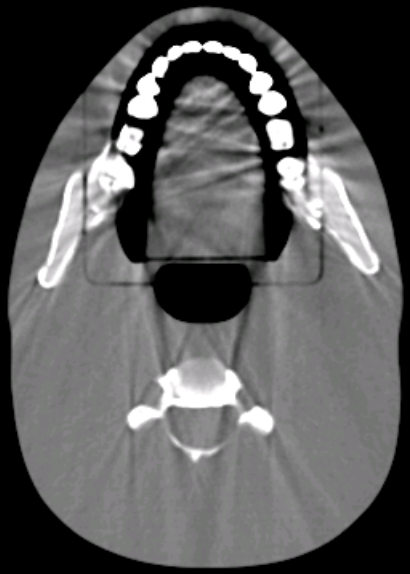
GSI-MARs out-of-plane artifacts

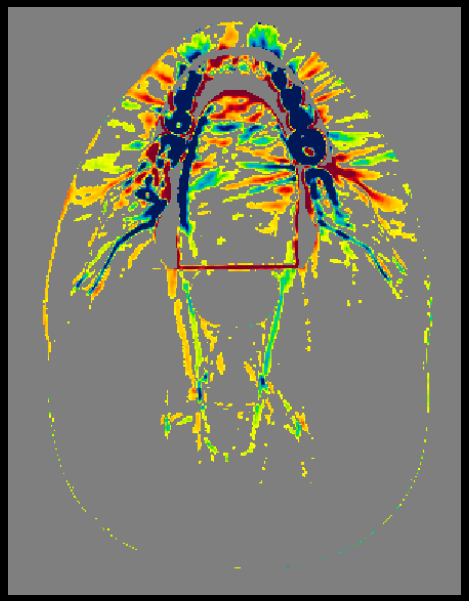
GSI
140keV

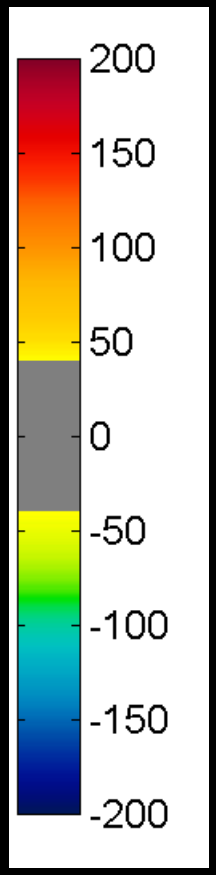


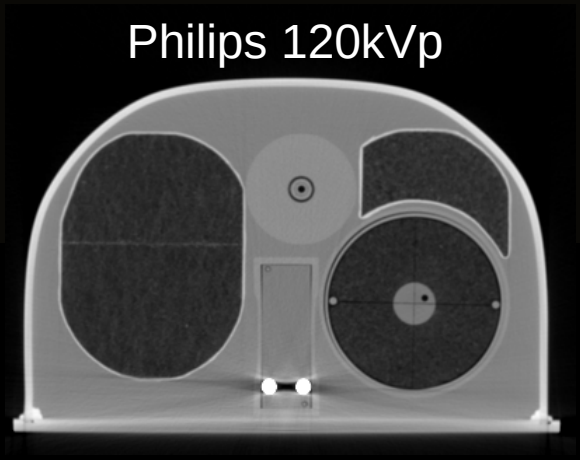


GSI
140keV
+MARs

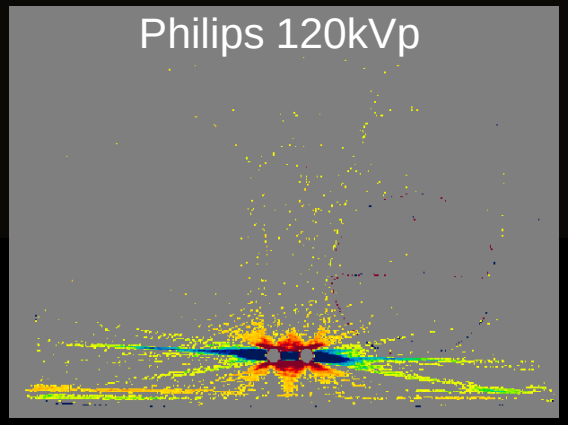


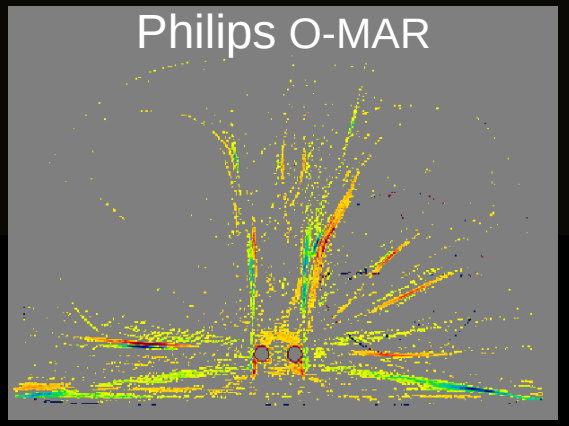


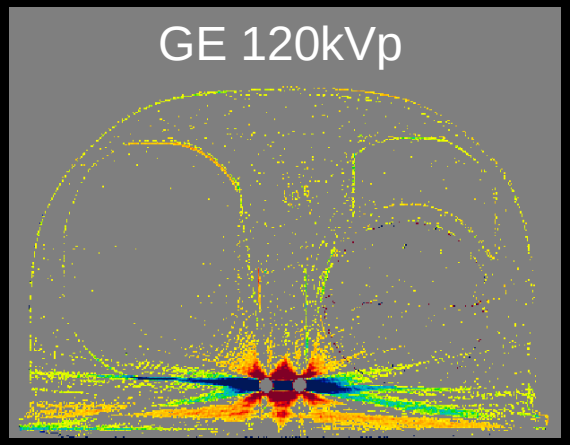


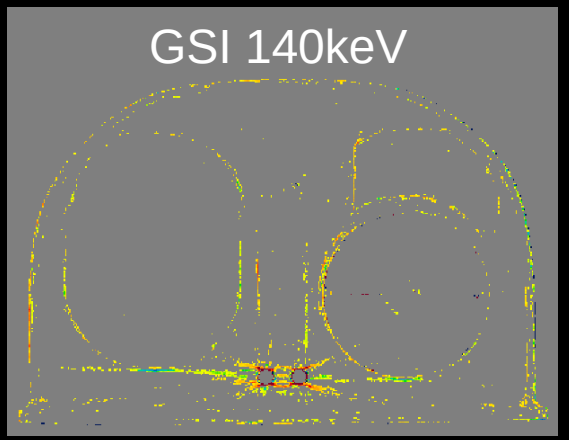


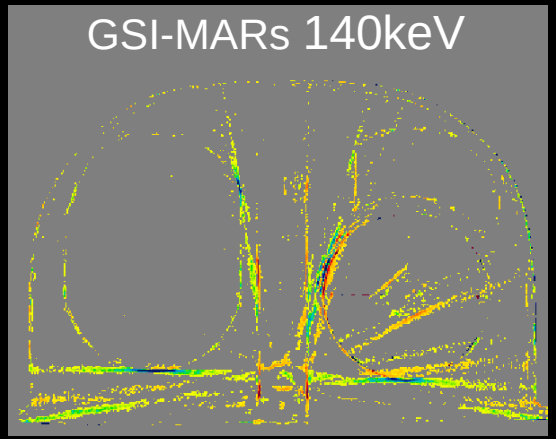
Imaging technique	% bad pixels	M_{error}
Philips 120kVp	6.9	7.9
Philips OMAR	9.1	7.2
GE 120kVp	12.2	12.9
GSI 140keV	5.9	4.3
GSI-MARs 140keV	11.6	8.0











Metal Size Accuracy

- HU threshold (1/2 max metal HU) used to identify metal pixels
- Metal area used to calculate diameter of metal rods

Imaging technique	Diameter error [mm]	
	Stainless Steel (28.6 mm)	Titanium (9.5 mm)
Philips 120kVp	1.4	0.9
Philips O-MAR	1.1	0.8
GE 120kVp	1.2	0.9
GSI 140keV	1.3	0.2
GSI-MARs 140keV	-1.4	-2.6

Summary of results

	Pelvic	Head	Thoracic	Weaknesses/Drawbacks
O-MAR	✓✓	✓	✓	• Induced artifacts for thoracic phantom
GSI 140keV monochromatic imaging	✓	✓	★	• No major drawbacks identified
GSI 140keV monochromatic imaging + MARs	★	X	✓	• Underestimation of metal size and possible distortion of metal shape • Induced “out-of-plane” artifacts for dental fillings • Induced artifacts for thoracic phantom

✓ = small reduction in streak artifacts

✓✓ = more substantial reduction streak artifacts

★= highly successful / best MAR method for a particular site

X = MAR not recommended for use at a particular site

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