Impact of Metal Artifact Reduction (MAR) in Treatment Planning: Comparison of Dose Calculation Algorithms

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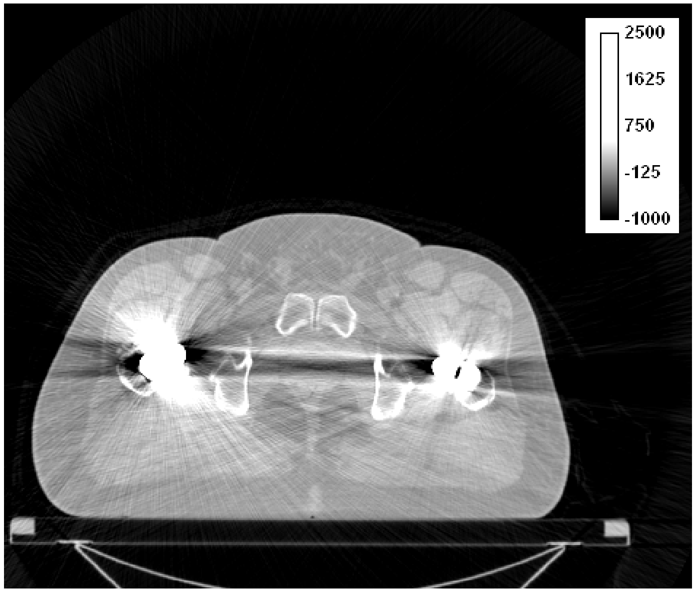
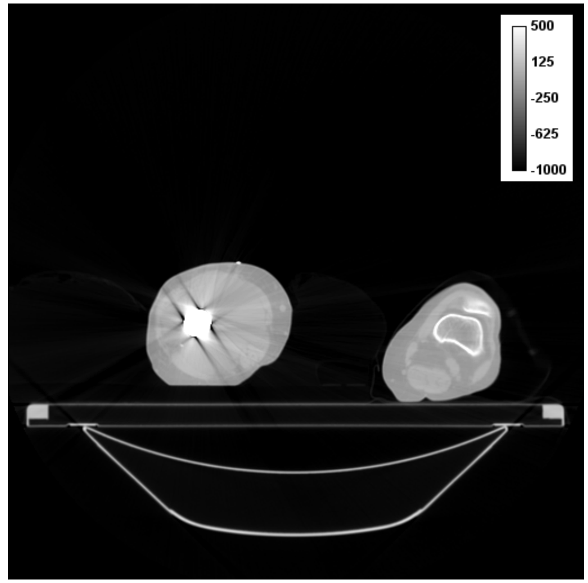
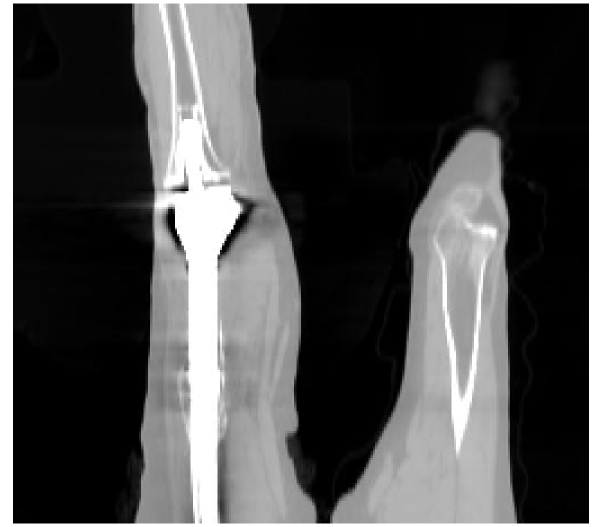
Disclosures

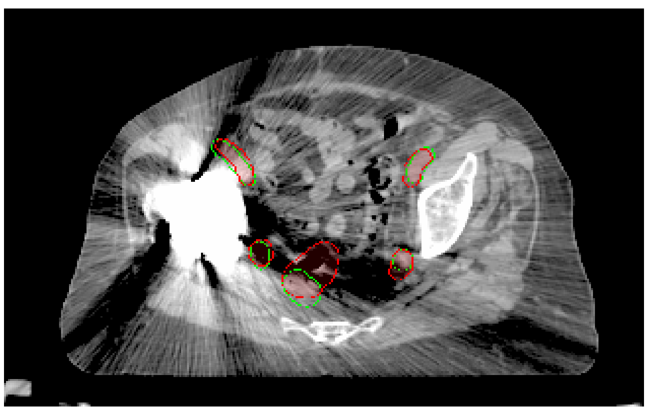
- Henry Ford Health Systems holds research and beta testing agreements with Philips Medical Systems.

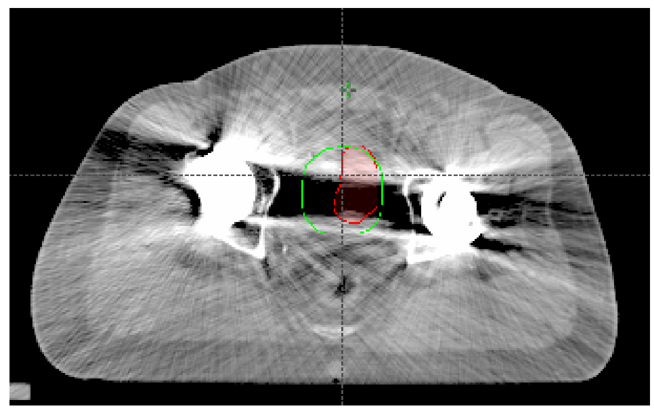
Motivation: Metal Artifact





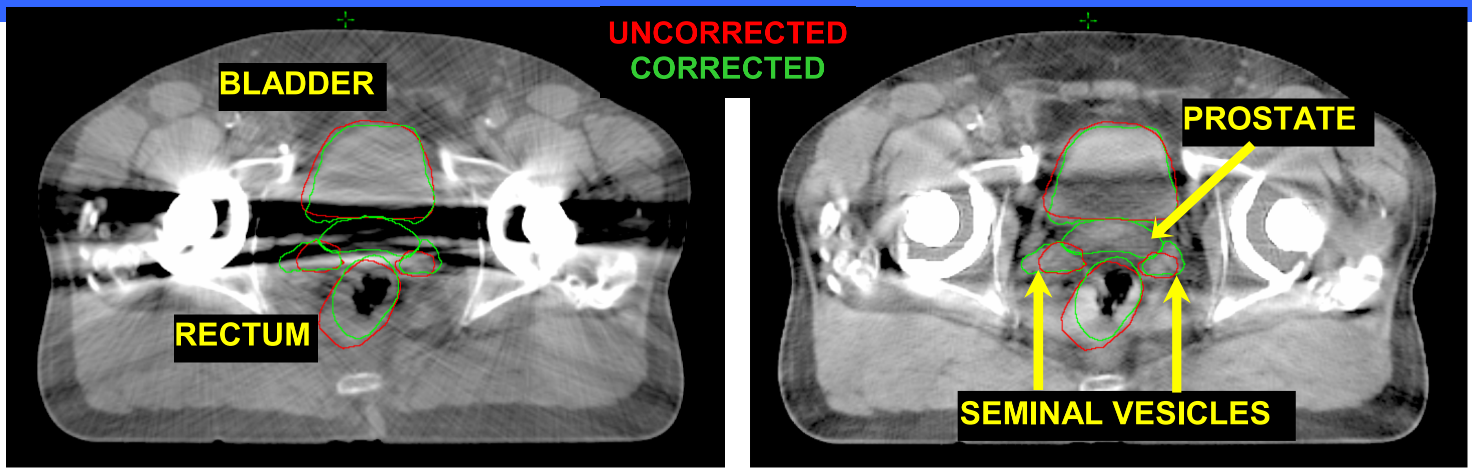






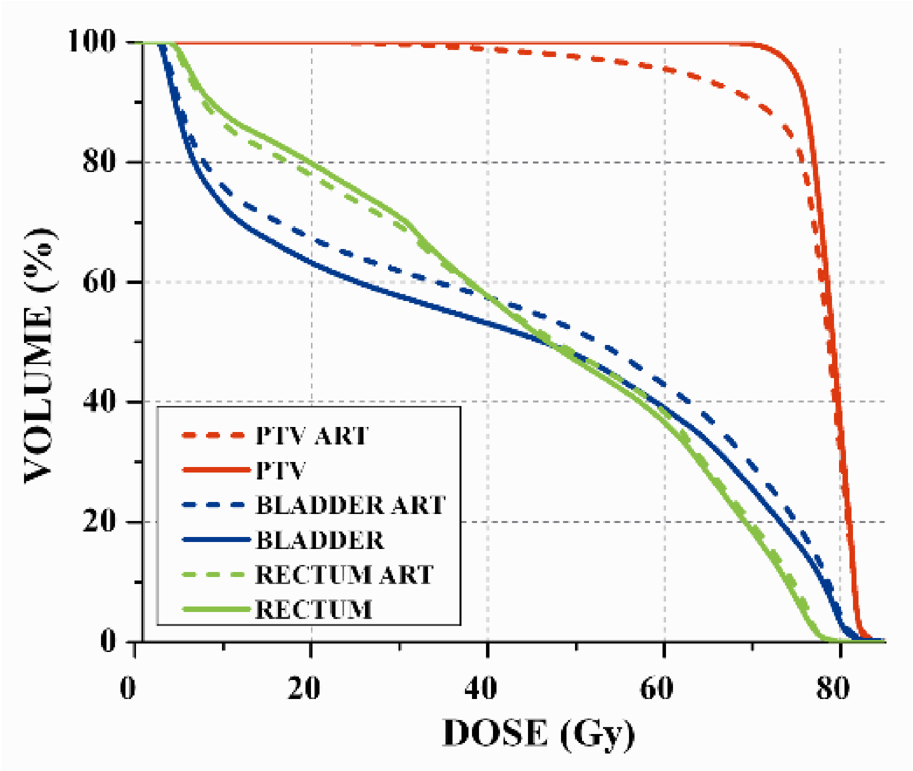
Metal in patient: Dental filling, surgical clips, hip prosthesis, rods, etc.
Leads to: Beam hardening, scatter, noise, absence of information (photon starvation)

Metal Artifact Reduction = Delineation Differences



ORIGINAL

ARTIFACT CORRECTED



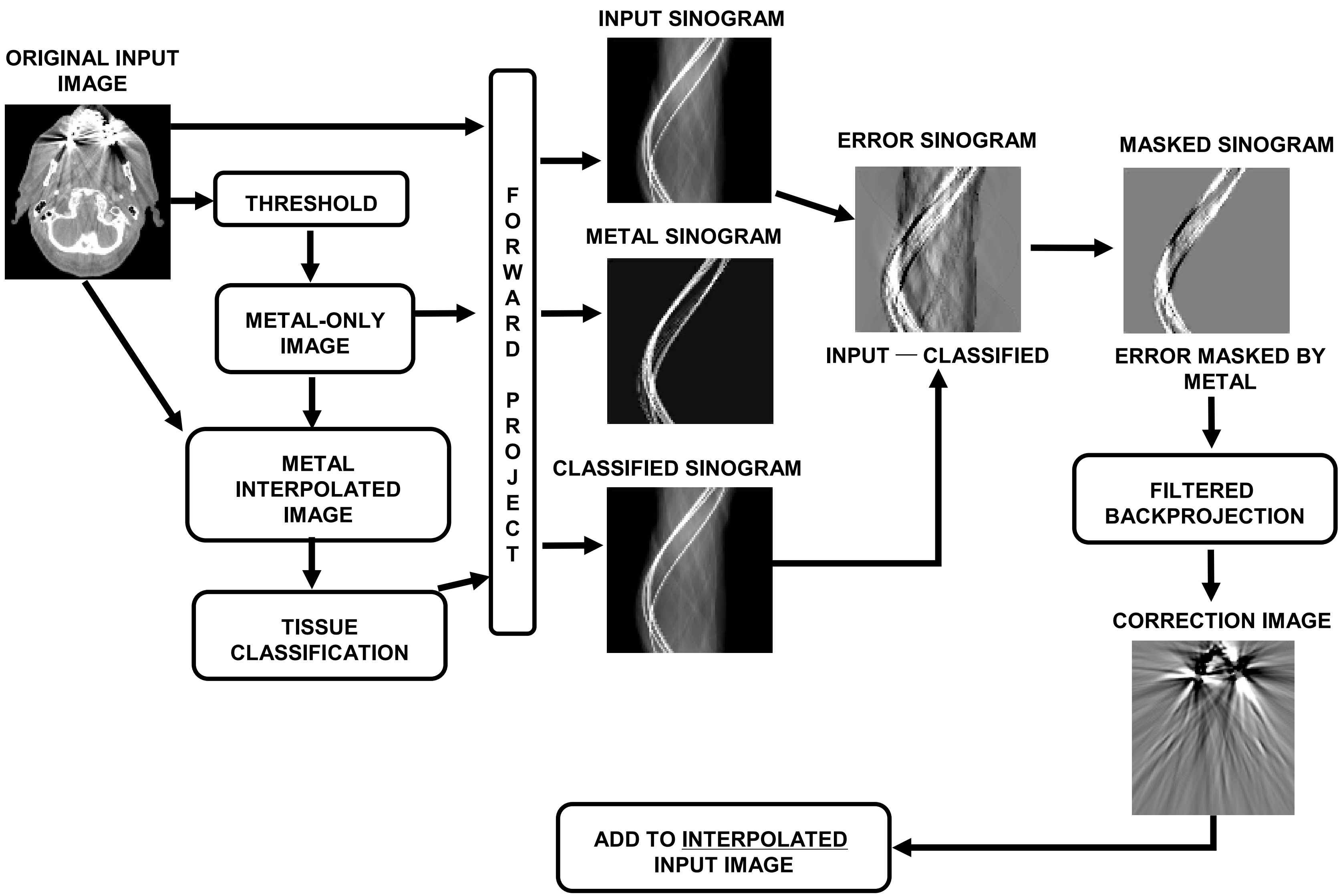
PURPOSE

- To systematically evaluate the dosimetric impact of metal artifact reduction (MAR) algorithm both in phantom and patient using four clinically commissioned treatment planning algorithms:
  - AAA and Pencil Beam Convolution (PBC) in Eclipse
  - Monte Carlo (MC, Dmed, Dwater) and PBC in Brainlab
  - With and without heterogeneity correction (HC)

Materials

- CIRS Model 002LFC IMRT Thorax Phantom with lung, soft tissue, bone and **metal** insertions
- Philips Big Bore Scanner
- Extended Brilliance Workspace (EBW) **3.5** with research interface (Philips Healthcare, Cleveland, OH)
- MAR applied to reconstructed images using compiled Matlab program (v7.8) integrated into EBW platform
- Eclipse External Beam Treatment Planning System (v8.6)
- Brainlab iplannet Treatment Planning System (RT Dose 4.1.2, RT Image 4.1.2 and PatXfer RT)
- ImageJ 1.43u with DICOM importer/exporter
- Auxiliary dose value-preserve program for ImageJ

MAR Algorithm



Simplified Work Flow

Apply MAR to CT images

↓

Generate treatment plan in Brainlab's Iplan (PBC-BL, MC)

↓

DICOM export of doses/plans to Eclipse

↓

Recalculate plans with same setup/MLCs/MUs (AAA, PBC-Eclipse)

↓

Export dose matrices & DVHs for all plans

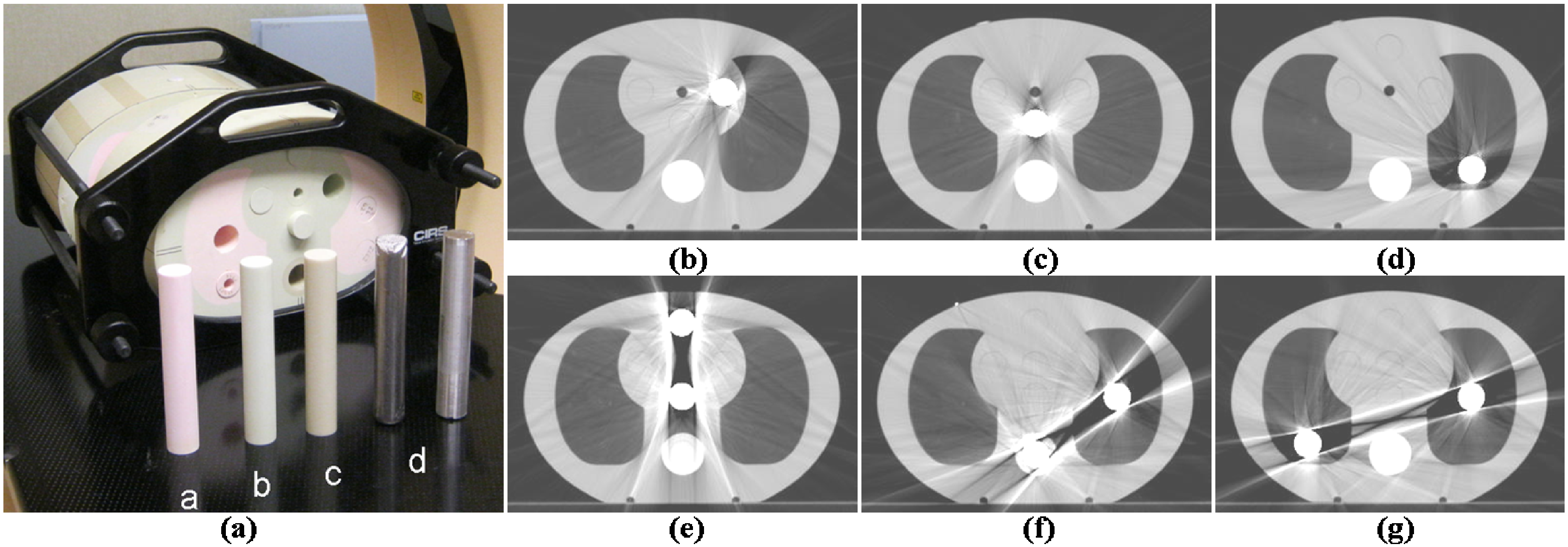
↓

Process and compare dose matrices with Image J

Treatment Planning Considerations

- 6 MV photon beam (Novalis)
- Same treatment plan for all algorithms in each case
- Same PTV and other structures for corrected and uncorrected cases
- Same Dose Matrix dimension
- Same Region of Interest (ROI) for statistics by developing a Macro in ImageJ
- Dose matrix alignment between Eclipse & Brainlab addressed

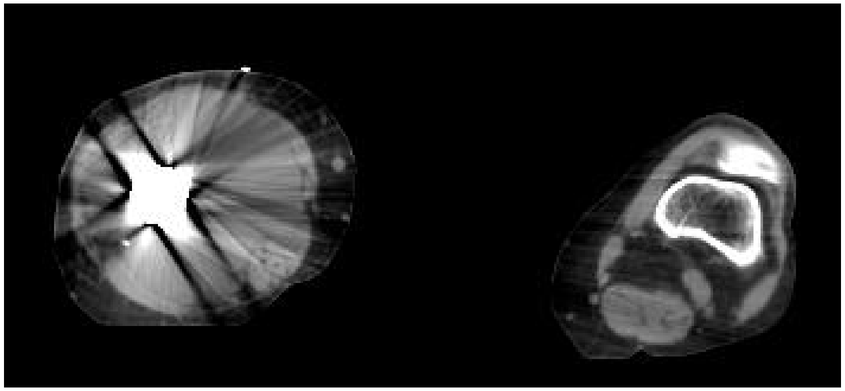
Phantom CT Data Acquisition and Configurations



Insertions: a. Lung; b. Soft Tissue; c. Bone; d. Metal (Cerrobend)

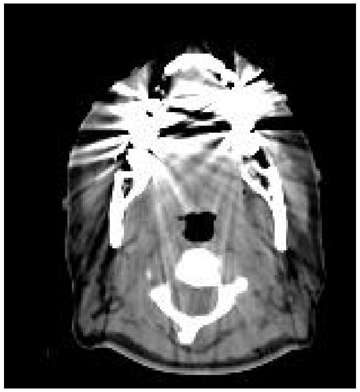
- Single Metal Rod cases: (b), (c), (d). Single 9.8 x 9.8 beam set up.
- Double Metal Rod cases: (e), (f), (g). Two opposed 9.8 x 9.8 beam set up.
- Prescribed dose: 2Gy to PTV (metal)

Patient Data

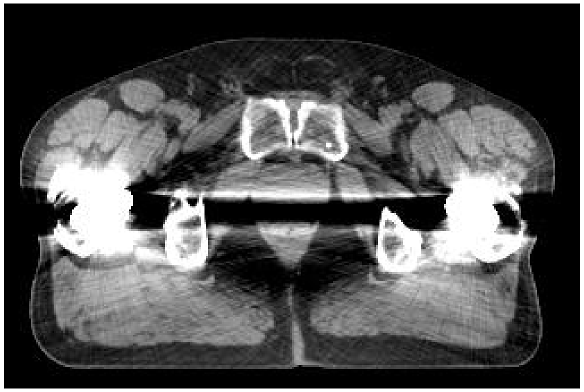


Femur: Two 3D conformal beam plan. Prescribed dose 2.0 Gy/fraction, 11 fractions

Humerus: Two 3D conformal beam plan. Prescribed dose 2.5 Gy/fraction, 7 fractions

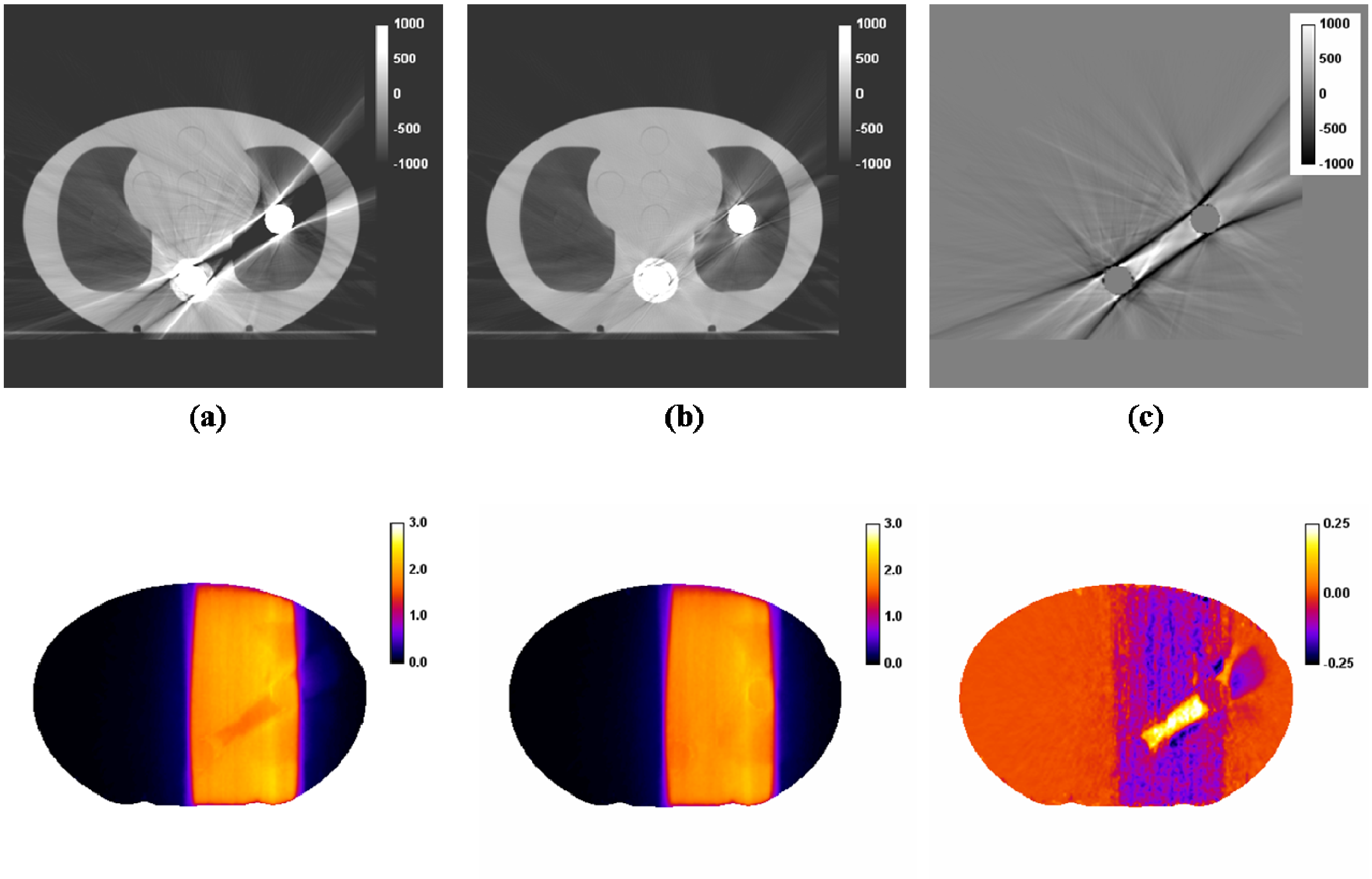


Head & Neck: Seven beam IMRT plan. Prescribed dose 2.0 Gy/fraction, 25 fractions



Prostate: Nine beam IMRTplan. Prescribed dose 1.8 Gy/fraction, 30 fractions

Results: Recovered CT Number and Dose, Phantom

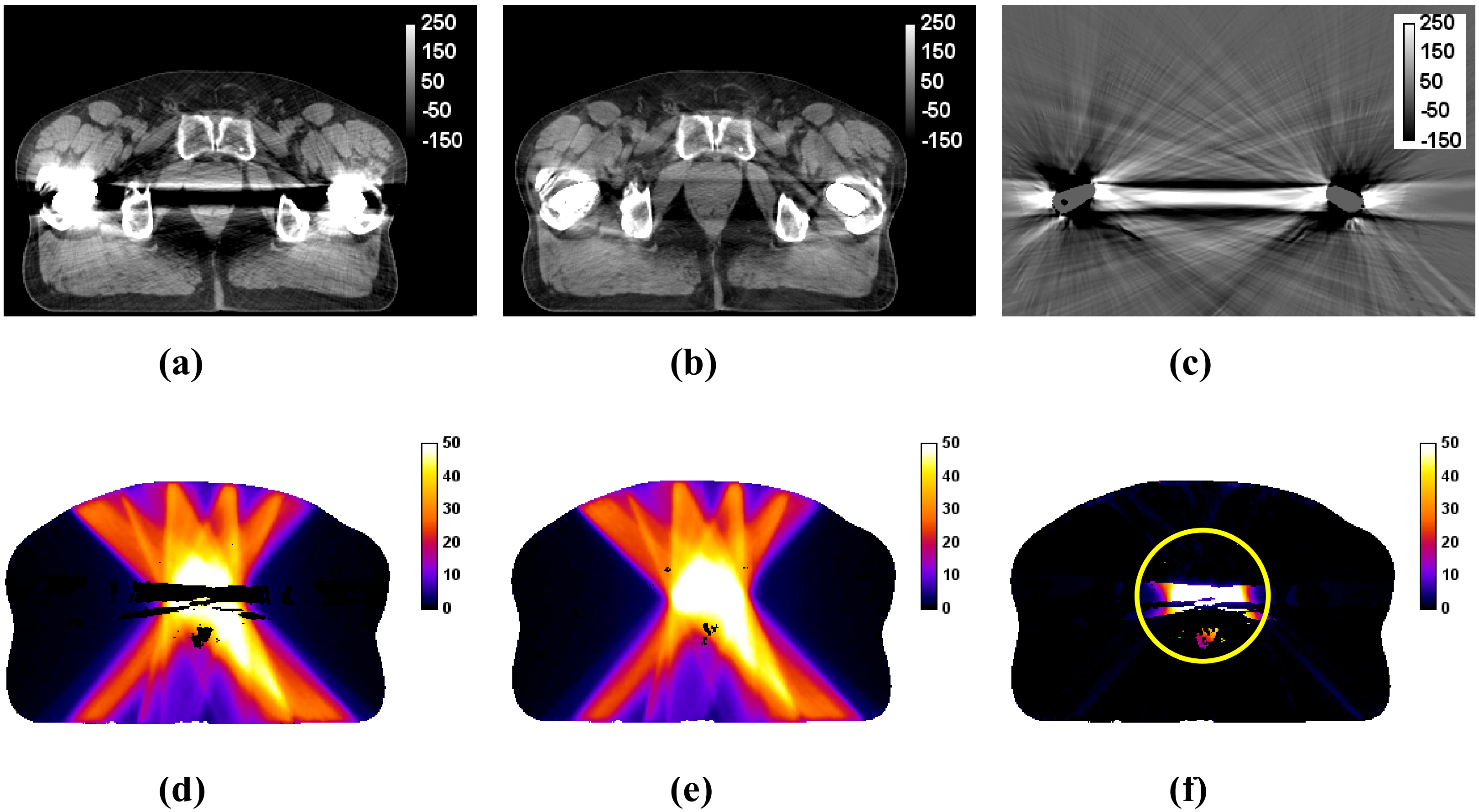


(a) (b) (c)

(d) (e) (f)

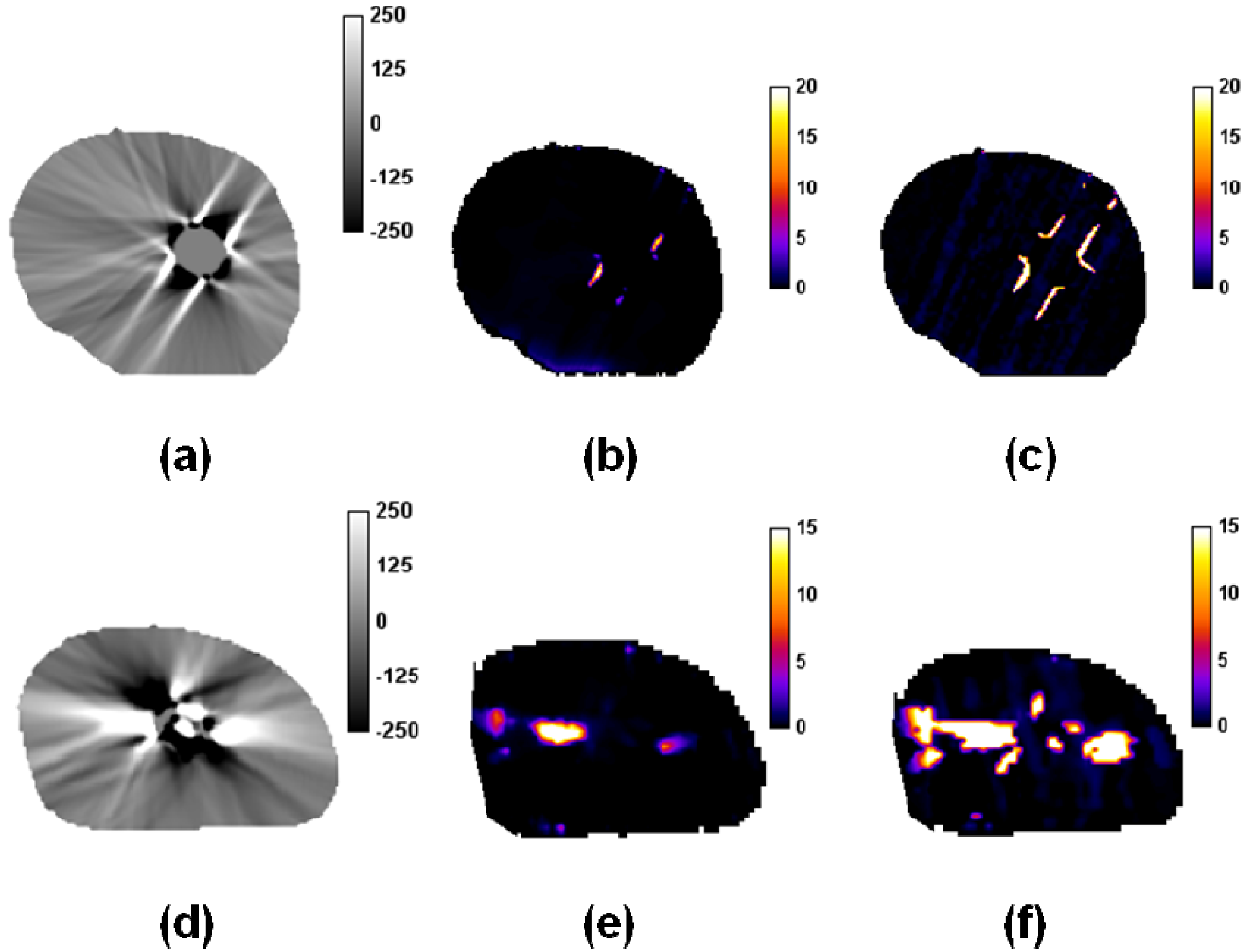
Results of algorithm MC_HC, statistics from (f) was considered to be “truth” and compared with results of other algorithms. Legends indicated CT number and dose in Gy for the top and bottom, respectively.

Results: Recovered CT Number and Dose, Patient



Results of algorithm MC_HC, prostate case, IMRT plan, statistics from circled area of (f) were compared with results of other algorithms. Legends indicated CT number and dose in Gy for the top and bottom, respectively.

Results: Recovered CT Number and Dose, Patient



Results of algorithms AAA (b, e) and MC_HC (c, f), Femur and Humerus cases, 3D conformal plan. Legends indicated CT number and dose in Gy for the left and right, respectively.

Phantom Results: Single Metal Rod

%dose discrepancy = (Mean MAR dose - mean uncorrected) / RX dose

Algorithms (HC on)	AAA Mean ± Stdev (cGy) Range (cGy)	PBC_Eclipse Mean ± Stdev (cGy) Range (cGy)	PBC_Brainlab Mean ± Stdev (cGy) Range (cGy)	MC_Dmed Mean ± Stdev (cGy) Range (cGy)
Tissue, Metal, Lung	-0.8 ± 1.7 (-0.4%) -4.5 to 3.9	-0.5 ± 0.7 (-0.25%) -2.5 to 1.5	0.2 ± 0.2 (0.1%) -3.5 to 3.4	1.4 ± 3.8 (0.7%) -10.7 to 13.8
Tissue, Metal, Bone	1.8 ± 2.2 (0.9%) -7.7 to 6.9	-2.1 ± 1.5 (-1.05%) -5.3 to 0.3	-3.6 ± 2.6 (-1.8%) -10.4 to 1.4	-1.5 ± 4.7 (-0.75%) -14.7 to 8.4
Lung, Metal	3.1 ± 2.0 (1.05%) -2.9 to 8.3	2.9 ± 2.0 (1.45%) -2.2 to 6.6	3.0 ± 2.4 (1.5%) -3.1 to 7.6	-0.3 ± 3.6 (0.15%) -11.1 to 12.2

Phantom Results: Double Metal Rod

%dose discrepancy = (Mean MAR dose - mean uncorrected) / RX dose

Algorithms (HC on)	AAA Mean ± Stdev (cGy) Range (cGy)	PBC_Eclipse Mean ± Stdev (cGy) Range (cGy)	PBC_Brainlab Mean ± Stdev (cGy) Range (cGy)	MC_Dmed Mean ± Stdev (cGy) Range (cGy)	MC_Dwater Mean ± Stdev (cGy) Range (cGy)
Tissue, Metal, Bone (Fig. 1e)	-12.3 ± 5.7 (-6.15%) -23.4 to 4.0	-1.4 ± 2.3 (-0.7%) -9.2 to 2.9	0.5 ± 3.1 (0.25%) -9.0 to 6.8	-5.1 ± 4.5 (-2.55%) -19.9 to 5.4	-10.8 ± 5.7 (-5.4%) -28.2 to 6.2
Lung, Metal, Bone (Fig. 1f)	-5.7 ± 3.5 (-2.85%) -12.8 to 5.2	-0.8 ± 1.1 (-0.4%) -3.0 to 1.6	0 ± 1.5 (0%) -2.8 to 3.5	-9.1 ± 4.3 (-4.55%) -22.1 to 5.5	0.4 ± 4.8 (0.2%) -14.4 to 17.4
Bilateral Lung, Metal (Fig. 1g)	0 ± 4.4 (0%) -9.5 to 15.3	0 ± 4.4 (0%) -11.7 to 11.7	-24.2 ± 4.5 (-12.1%) -31.7 to -14.7	-36.2 ± 6.2 (-18.1%) -52.7 to -22.6	1.4 ± 4.8 (0.7%) -12.2 to 13.5

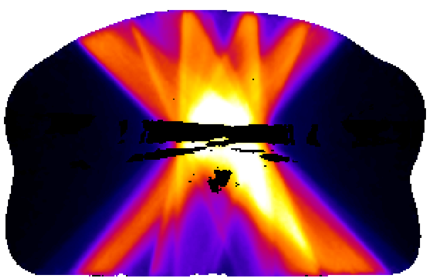
Results: Patient Data

%dose discrepancy = (Mean MAR dose - mean uncorrected) / RX dose

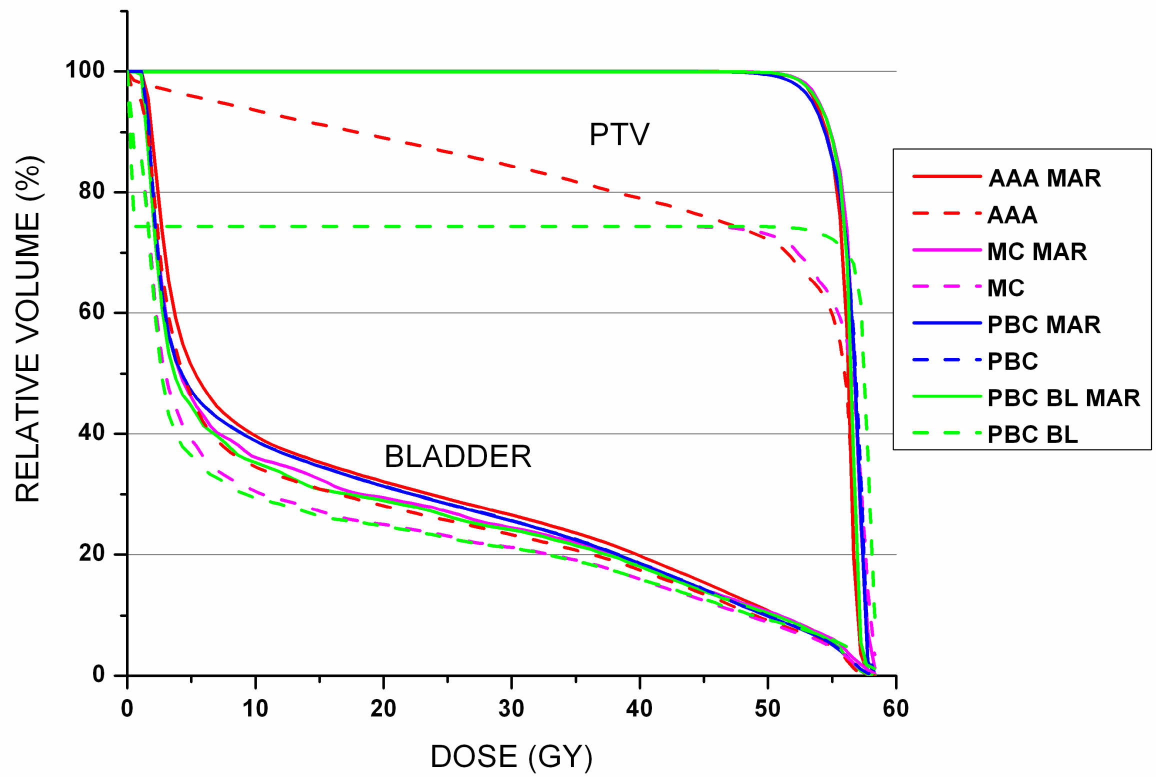
Algorithms (HC on)	AAA Mean ± Stdev (%) Range (cGy)	PBC_Eclipse Mean ± Stdev (%) Range (cGy)	PBC_Brainlab Mean ± Stdev (%) Range (cGy)	MC_Dmed Mean ± Stdev (%) Range (cGy)
Femur (3D)	-0.42±0.42 -31.2 to 12.9	0.08±0.21 -8.0 to 11.8	0.10±0.22 -5.6 to 15.6	0.70±1.35 -72.0 to 98.2
Humerus (3D)	0.34±3.41 -17.3 to 702.4	0.17±0.41 -53.7 to 36.6	7.94±23.95 -21.1 to 1803.9	6.97±24.15 -65.2 to 1804.9
Head & Neck (IMRT)	0.00±0.00 -0.2 to 0.3	0.07±0.28 -80.0 to 50.0	0.39±3.92 -96.3 to 3149.5	-0.42±4.36 -373.8 to 3141.7
Prostate (IMRT)	8.37±22.97 -79.5 to 5625.3	0.12±0.16 -39.3 to 15.8	11.01±31.21 -4698.5 to 5698.3	12.32±30.95 -4541.3 to 5725.3

Bilateral Hip Patient: DVHs

(a)



(d)



Discussion: MAR

- Dosimetric differences revealed between original and MAR corrected CT scans can be substantial.
- For double rod phantom cases in a series of configurations, the maximum dose difference observed was 52.7 cGy for 200 cGy RX (26.4% diff) for MC_Dmed.
- For the 3D planning patient cases, beams traversed directly through the metal rods, up to 8 +/- 24% mean dose differences were observed.
- For bilateral hip implant cases, significant underdosing observed between the metal implants (max difference = 106%) for MC_Dmed.
- This suggests caution should be exercised when using original CT scans to calculate dose, as significant underdosing can occur. In clinical practice, some clinics will combat this by overriding density in this region with a uniform value.
- Even if mean dose differences between MAR corrected and uncorrected cases are small, significant hot/cold spots (local regions) are observed when CT to electron density table equates MAR-affected regions to density near air.

Discussion: Algorithms

- PBC_Eclipse was the least sensitive dose calculation algorithm to the CT signal recovered with MAR, yielding dosimetric differences <1% for all cases studied.

- Brainlab algorithms (PBC and MC_Dmed) yielded largest dose discrepancies for all cases, and appeared most sensitive to MAR correction

- When HC is disabled (results not shown), negligible dose differences were observed. This suggests that clinical solutions that disable HC for metal implants may not directly benefit from MAR unless their clinical practices change.

- Compared with AAA, PBC in Brainlab was more sensitive. This may be attributed to to adaptive grid size for small heterogeneity in the PBC-Brainlab algorithm.

Conclusions

- Variety of material configurations (minor to very severe metal artifacts), interface effects, and the impact of different materials on the surrounding dose distribution were evaluated
- Systematic evaluation of 4 different dose calculation algorithms in 2 TPS
- These results can be used to facilitate the implementation of MAR corrected images in treatment planning

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