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Metal Artifact Reduction for Radiotherapy CBCT By MV-to-kV and kV/MV-to-kV Image Conversion

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INTRODUCTION

- Cone beam CTs at typical kV energies exhibit metal artifacts in IGRT patients with metal prosthetics.
- MV-CBCT, available on some linacs, reduces metal artifacts, particularly with recent multi-layer x-ray detectors, which improve photon collection efficiency.
- Despite these advances, MV-CBCT still suffers from poorer soft tissue contrast-to-noise (CNR), as compared to standard kV-CBCT.
- As a novel remedy, we design a deep network (denoted MV-kV) to convert a given, low-artifact MV-CBCT to synthetic kV-CBCT, thereby restoring standard kV-CBCT image quality (minus artifacts).
- Additionally, for linacs equipped with both kV- and MV-CBCT, we test a variant network (denoted kV/MV-kV) that synthesizes a superior kV-CBCT from a combination of MV-CBCT and artifacted kV-CBCT input slices (Fig 1(b)).

METHODS AND MATERIALS

- Input/output slice pairs for network training/testing were collected using Truebeam kV-CBCTs (140 kVp, 37 mGy) and MV-CBCTs (2.5 MV, 45 mGy) of a custom pelvis phantom with 2.5" spherical femoral head sockets.
- MV-CBCT was implemented with a prototype 4-layer, high-efficiency x-ray detector. The femoral sockets allowed simulated hip implants in several uni/bilateral configurations to be interchanged.
- Scans of four implant configurations and materials were acquired: uni- and bi-lateral titanium, bi-lateral aluminum, and a no-metal, natural anatomy baseline.
- The data was augmented by rotating the reconstructed volumes out-of-plane (up to 24º) in non-standard 3D poses before extracting in-plane slices.
- The training set included the titanium and metal-free configurations in non-standard poses only. The test set included all implant configurations, including bi-lateral aluminum, in a standard non-rotated pose.

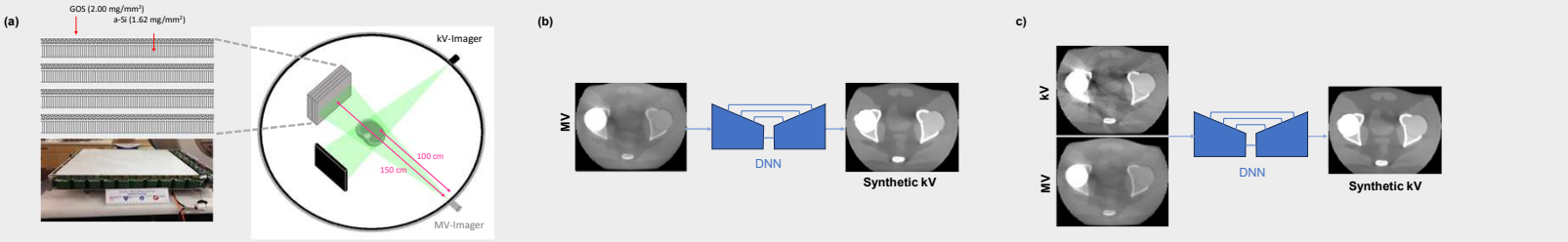
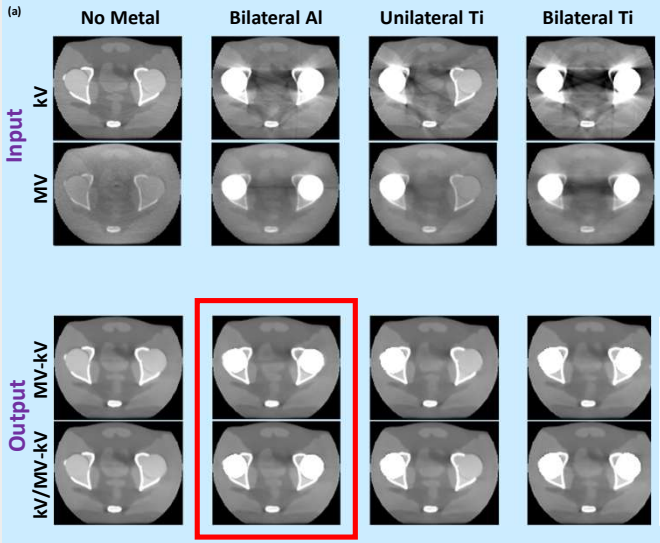


Figure 1: (a) System configuration and 4-layer MV-imager. Source-Detector Distance was 150 cm and Source-Patient distance was 100 cm for both imagers. **(b)** Variant DNN for MV-to-kV synthesis **(c)** Variant DNN for kV/MV-to-kV synthesis.

RESULTS

- Both Unet variants substantially reduce artifacts.
- SSIM relative to metal-free kV-CBCT improved by >2x in scans with a unilateral titanium hip implant and >4x with bilateral aluminum and titanium.
- CNR exceeded the given MV-CBCT by >2.7x in all cases.
- The kV/MV-kV converter matched the CNR of the reference metal-free kV-CBCT in all cases as well, and improved visualization of the prostate as compared to MV-kV only.



(b) SSIM

	No Metal	Bilateral Al	Unilateral Ti	Bilateral Ti
kV	1.00	0.17	0.43	-0.05
MV	N/A	N/A	N/A	N/A
MV-kV	0.97	0.91	0.95	0.95
kV/MV-kV	0.97	0.97	0.97	0.95

(c) CNR

	No Metal	Bilateral Al	Unilateral Ti	Bilateral Ti
kV	4.3	0.0	1.6	0.1
MV	1.2	1.2	0.3	0.3
MV-kV	6.4	3.3	5.5	5.0
kV/MV-kV	6.2	6.8	5.1	6.5

Figure 3: (a) Axial slices from the given kV- and MV-CBCT reconstructions together with the synthetic kV-CBCT slices derived by the MV-kV and kV/MV-kV converter networks. **(b)** Artifact reduction measured in terms of structural similarity (SSIM) **(c)** Contrast-to-noise ratio (CNR) between adipose and muscle regions of interest (ROIs).

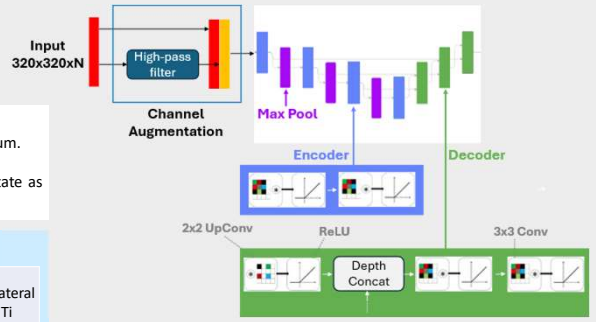


Figure 2. Deep Neural Network (DNN) architecture and pre-feature extraction

CONCLUSIONS

- AI-based MV-to-kV conversion promises to reduce CBCT metal-artifacts without the sacrifices in CNR normally afflicting MV-CBCT.
- When available, an additional channel of input from an artifacted kV-CBCT appears to further improve and stabilize the method.
- Both DNN variants substantially restored structured similarity and CNR, but the kV/MV-to-kV method generalized from the training data set better

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