Deep learning-driven scatter-free virtual monochromatic CBCT imaging for metal artifact reduction: A feasibility study

Hoyeon Lee[1,2]
[1]Department of Diagnostic Radiology, LKS Faculty of Medicine, University of Hong Kong
[2]Centre of Cancer Medicine, LKS Faculty of Medicine, University of Hong Kong

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香 港 大 學
THE UNIVERSITY OF HONG KONG
HKU Med School of Clinical Medicine Department of Diagnostic Radiology 香港大學放射診斷學系
HKU Med School of Clinical Medicine Centre of Cancer Medicine 香港大學癌症醫學中心

INTRODUCTION

- Cone-beam CT (CBCT) is widely used in dental imaging.
- However, metal artifacts introduced by high-density objects severely degrade image quality.
- The metal artifacts degrade image quality, affecting the diagnostic reliability of and the robustness of surgical planning.
- Recently, deep learning (DL)-based metal artifact reduction (MAR) approaches have been widely investigated.
- Most existing methods identify metal traces in the sinograms and inpaint the corrupted regions [1, 2].
- However, MAR performance depends heavily on accurate metal segmentation.
- To improve the robustness of MAR, we propose a DL-based CBCT projection synthesis framework.
- The proposed model synthesizes scatter-free virtual monochromatic (VM) projection data, addressing 2 major sources of metal artifacts (scatter and beam hardening) without requiring metal segmentation.

MATERIALS AND METHODS

- We collected 15 diagnostic CT images of head and neck (H&N) cancer patients.
- Zirconia implants were placed in the patients' dentitions to introduce metal artifacts.
- A dental CBCT system (Planmeca ProMax 3D Mid) with MCGPU [3] following the scanning parameters summarized in **Table 1.**
- We acquired pairs of conventional CBCT projection data and scatter-free virtual monochromatic (VM) CBCT projection.
- The patients were divided into 3 groups: training (7 patients), internal validation (3 patients), and external testing (5 patients).
- We employed UNet++[4], shown in **Figure 1**, to synthesize the scatter-free VM projection data from the conventional projection data.
- UNet++ uses nested dense connections to transfer the information from the encoder to the decoder.
- The CBCT images were reconstructed using the FDK algorithm.
- For the quantitative comparison, we calculated the mean-absolute error (MAE) and peak signal-to-ratio (PSNR).

Table 1. CBCT scanning parameters

Parameters	Conventional	Monochromatic
Source-to-detector distance (mm)	889.0	
Source-to-isocenter distance (mm)	599.44	
Detector size (mm²)	146x146	
Angular sampling	0.8-degree interval / 450 views	
X-ray energy	90 kVp	60 keV

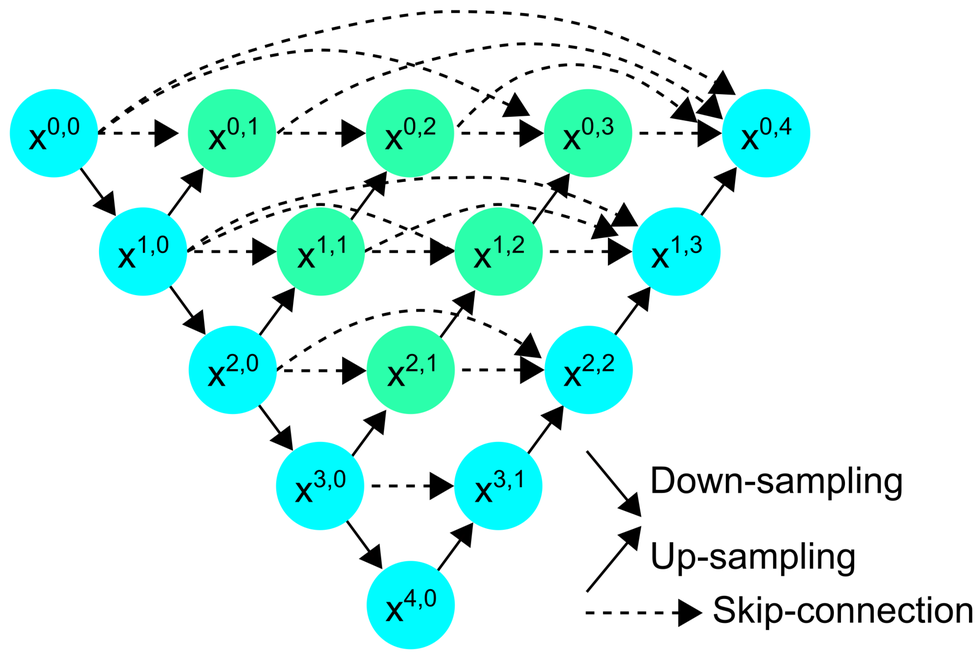

Figure 1. Architecture of UNet++

Table 2. Quantitative comparison results

	MAE	PSNR
Conventional	95.25 ± 17.80	25.04 ± 1.42
Proposed	20.58 ± 6.99	36.79 ± 2.93

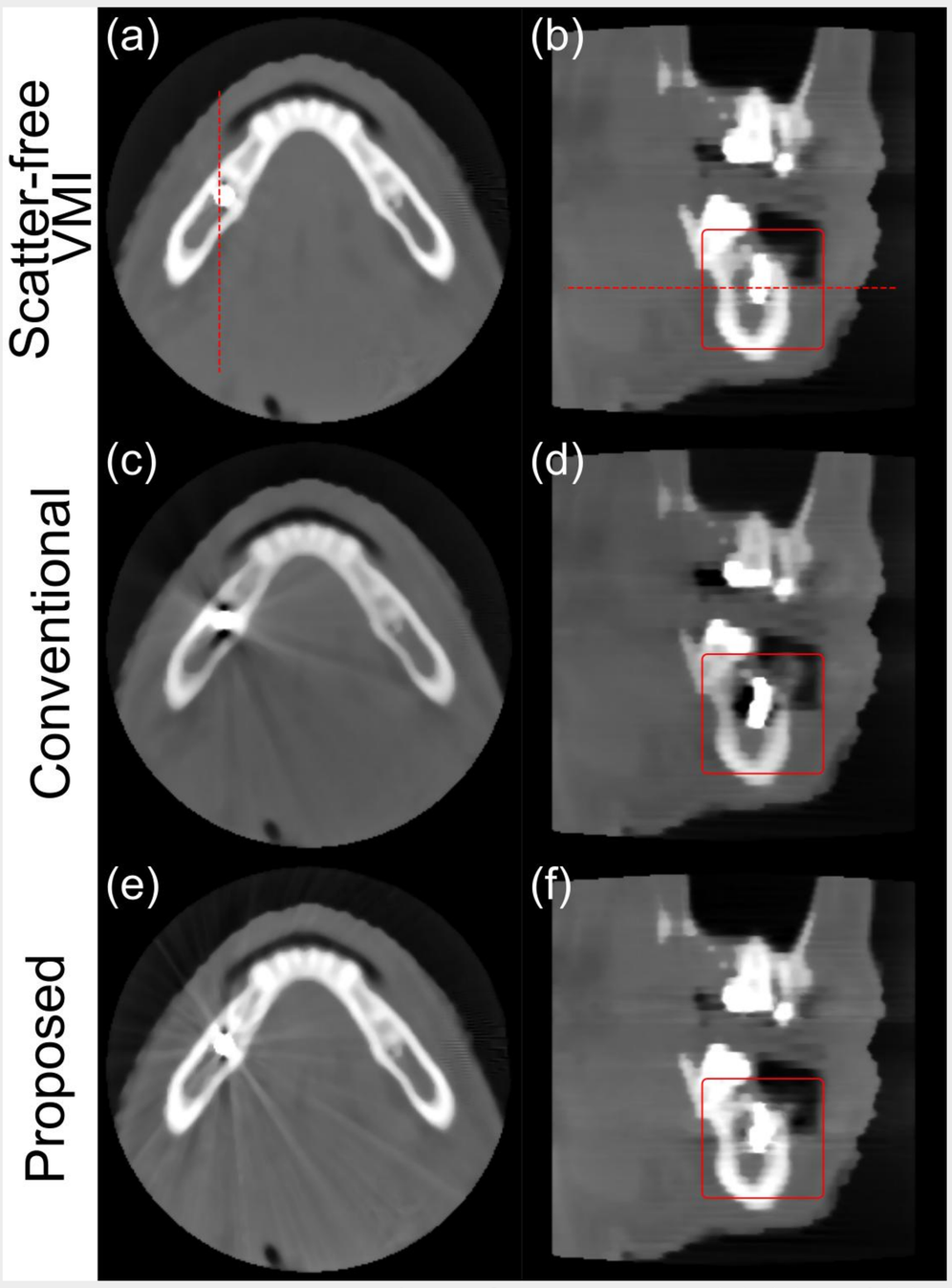

Figure 2. Representative slices of a testing case. (a), (c), and (e) are axial slices of scatter-free VMI, a conventional CBCT image, and our results, respectively. Sagittal slices including the implant are shown in (b), (d), and (f).

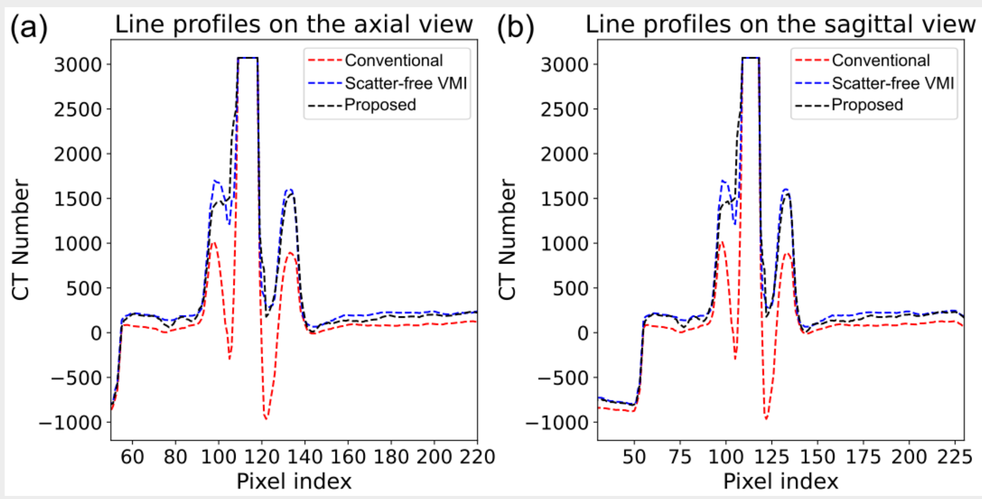

Figure 3. Line profiles of the (a) axial slices and (b) sagittal slices.

RESULTS

- The quantitative comparison results of the conventional imaging and the proposed methods are summarized in **Table 2**.
- **Figure 2** shows representative axial and sagittal slices of a test case.
- As illustrated in **Figure 2**, the proposed method successfully synthesized scatter-free VM CBCT projection data.
- This led to reduced metal artifacts in the images.
- As demonstrated by the sagittal slices in **Figure 2 (b), (d), and (f)**, the proposed method improved visualization of anatomical details adjacent to the metallic implant (red boxes).
- While these details are obscured by artifacts in the conventional imaging method.
- Figure 3 shows the line profiles depicted by red dashed lines.
- These profiles also support improved anatomical details.

CONCLUSIONS

- This study demonstrated the feasibility of a DL-based scatter-free VMI framework for MAR in dental CBCT.
- The proposed model successfully synthesized scatter-free VM projection data from scatter-contaminated polychromatic projection data.
- The synthesized results improved the visualization of anatomical structures neighboring high-density metallic implants.
- In our future study, we will:
  - ❑Employ diffusion models to improve the fidelity of the synthesis results,
  - ❑Expand the diversity of the training dataset to enhance generalizability.
  - ❑Conduct a clinical validation to evaluate the clinical contribution.

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CONTACT

Hoyeon Lee (hlee01@hku.hk)

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