Synthetic CT validation for MR-only head-and-neck radiotherapy

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Introduction

MRI provides advantages for tumor and critical structure delineation for patients undergoing head-and-neck (H&N) radiotherapy. However, H&N MR-only workflows remain challenging due to the large field-of-view and susceptibility artifacts arising from the sinuses, dental hardware, and immobilization devices. The purpose of this work is to generate and assess synthetic CTs (sCTs) to facilitate MR-only H&N radiotherapy workflows.

The innovation of this study is to demonstrate the clinical feasibility and validation of **a 3D deep-learning, MRI-based head-and-neck (H&N) sCT generation method** for MR-only treatment planning. The H&N region remains a clinically demanding site for sCT generation with heterogeneous anatomy (bone, air cavities, and soft tissue), devices such as dental hardware and bite blocks present for immobilization, large field-of-view requirements, and steep dose gradients near critical structures.

This study has direct clinical impact because the model is evaluated using planning CT, MRI, and IMRT dosimetric data used clinically from treated patients in our department, enabling performance to be assessed using clinically relevant data.

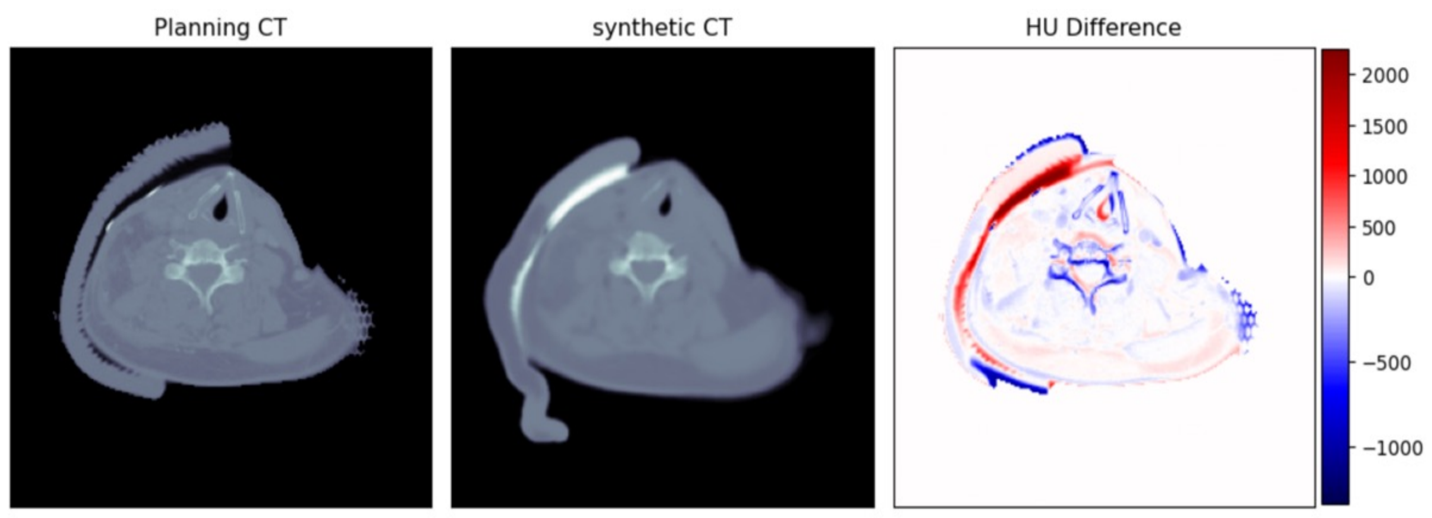

Figure 1: Difference map computed within the intersection of the pCT and sCT body contours. The difference map shows the evaluation mask used for calculating the MAE. Left: planning CT (pCT). Middle: synthetic CT (sCT). Right: difference map (sCT – pCT). The diverging colormap is zero-centered (white = 0 HU), with red indicating positive HU error (sCT > pCT) and blue indicating negative HU error (sCT < pCT).

Methods

Twenty patients with H&N tumors undergoing IMRT (minimum twenty fractions) were included:

Task:

- Generate sCTs (in-plane resolution 1.0x1.0mm^2, 2mm slice thickness) from MRIs using a 3D convolutional neural network-based prototype (Siemens Healthineers).

Data processing:

- sCTs were rigidly co-registered to pCTs and resampled to a uniform matrix.
- Clinical IMRT plans were forward-calculated onto the sCT and compared using gamma analysis and dose-volume-histograms.

Treatment sites:

- Tongue
- Nasopharynx
- Thyroid
- Oropharynx

Immobilization Devices:

- Thermoplastic masks
- Bite blocks

Imaging Modalities:

- 120kVp CT (pCTs)
- 3D T1-weighted gradient-recalled-echo (GRE) Dixon MRI (repetition time /echo time =5.5 / 2.46ms, slices=80-90).

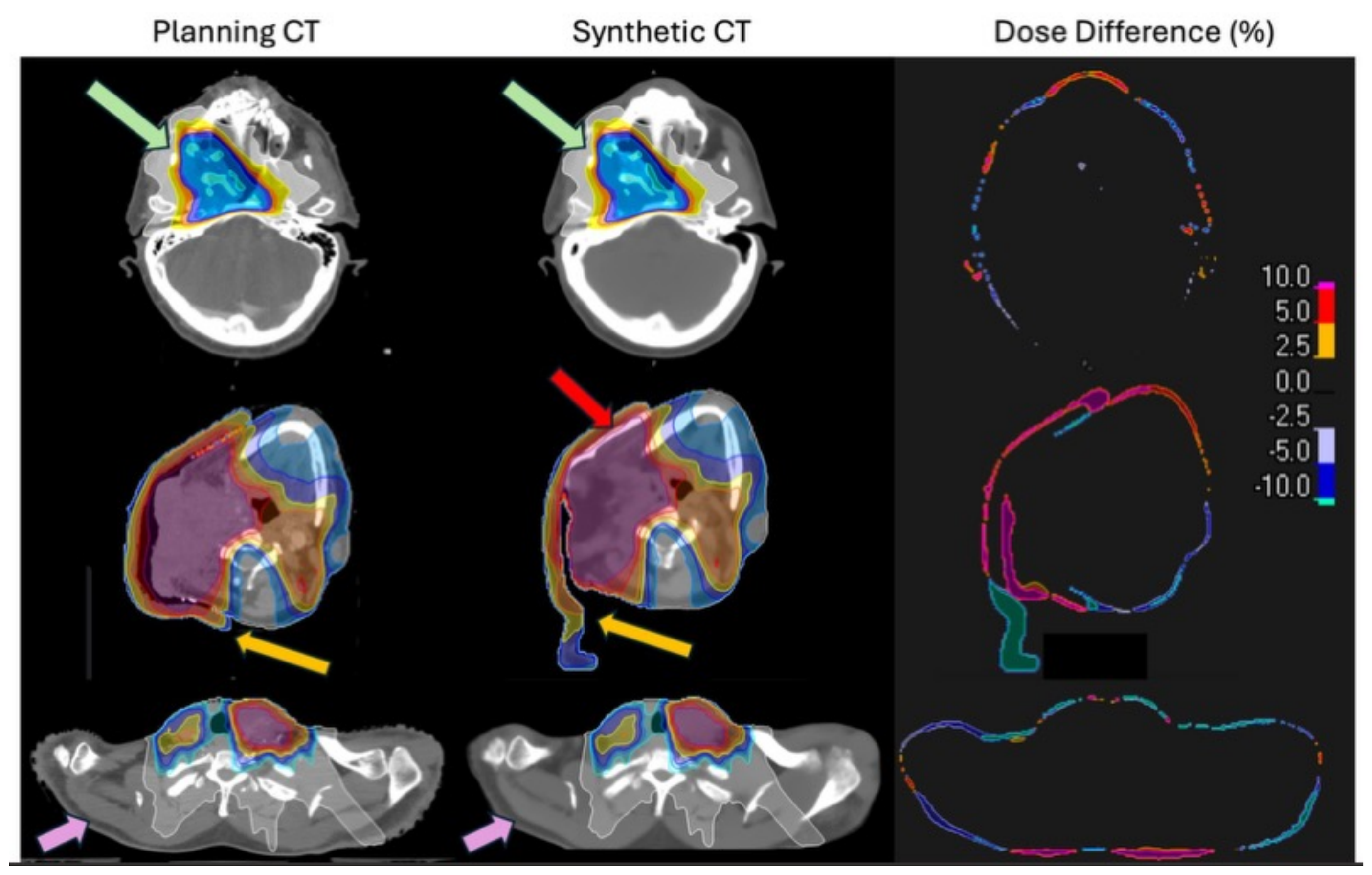

Figure 2: Example dose distributions for three slices of a test patient included in the test dataset.

Key Results

sCTs achieved a mean absolute error of 134.56±15.88 HU within the body-contour intersection to ensure voxel-wise comparisons were restricted to anatomical regions present in both images (Figure 1). This avoids bias from differences in FOV or non-anatomical structures (e.g., immobilization devices/couch), which would otherwise artificially inflate or deflate error metrics.

High dose agreement between pCT- and sCT-based plans was observed (gamma passing rates: 97.83±3.88% at 3%/3 mm, 96.14±5.20% at 2%/2 mm, and 91.25±7.89% at 1%/1 mm). Target coverage was preserved, with dose to 95% to the PTV agreeing within 0.15±1.39%. These results suggest **high performance of the sCT model even in the presence of challenging anatomy and devices/hardware causing susceptibility artifacts in MRI** (Figure 2). The quantitative measurements are in good agreement with the findings from prior studies [1].

sCTs were accurately reconstructed even for bulky tumors and atypical bone anatomy (e.g. missing maxilla). Failure modes included false high-density material abutting bolus (n=1) and underestimation of bone in the nasal sinus (n=5) and oral hardware (n=2) but yielded negligible dosimetric impact.

Figure 2 *(continued)*: The left column shows the planning CT, middle column shows synthetic CT, and right column shows the difference in dose distributions. Despite susceptibility differences in the sinuses, dose distributions in this region were comparable between sCTs and CTs (green arrows).

As expected, dosimetric disagreements were seen when bolus placement differed between CT and MRI (orange arrow). In general, bolus placement was accurately captured by sCT, though 1 instance of false insertion of high-density material was seen in one case (red arrow). Large FOVs in the MRI allowed for accurate reconstruction of shoulders (pink arrows).

Conclusion

This work demonstrates clinical feasibility of sCTs for MR-only H&N radiotherapy. sCTs demonstrated strong agreement with pCTs in terms of image fidelity and dose calculation. Residual errors were primarily associated with challenging patient-specific conditions such as bolus material, hardware, and bone/air cavities. Future work will focus on improving generalization through optimized preprocessing and artifact-aware modeling, including patients with a wider range of immobilization devices.

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References

[1] Singhrao et al., Evaluating the Hounsfield unit assignment and dose differences between CT-based standard and deep learning-based synthetic CT images for MRI-only radiation therapy of the head and neck, J. Med. Phys., November 2023