Data-Augmented Deep Learning for Anatomical Completion and Dose-Accurate MR-Only Radiotherapy Planning

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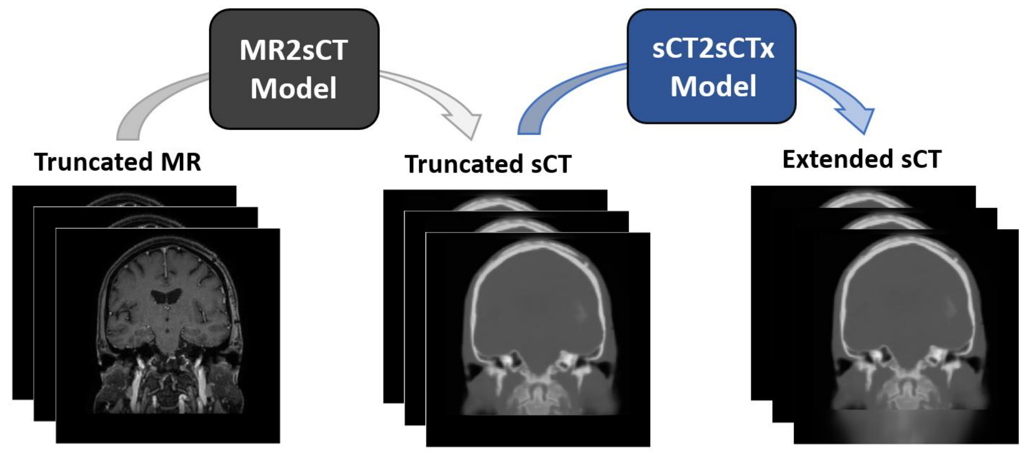
INTRODUCTION

In MR-only radiotherapy planning (MROP), limited field-of-view (LFOV) acquisition and imaging artifacts can introduce truncated anatomy and density inaccuracies, reducing the reliability of dose calculation and preventing comprehensive plan evaluation due to incomplete visualization of OAR. This work develops and evaluates a data augmentation-driven (DAD) deep learning framework for recovering planning-appropriate images from truncated or corrupted inputs.

METHODS



- **Clinical motivation**: In MROP, LFOV acquisition and image artifacts frequently result in truncated anatomy, which can lead to inaccurate tissue density representation and dose calculation errors. This limitation is particularly relevant for brain and head-and-neck treatments, where long treatment fields are commonly required to cover lymphatic regions extending into the neck and upper thorax. While MR-to-synthetic CT (MR2sCT[1] in Fig. 1) techniques enable MR-only workflows, truncated MR images often propagate truncation into sCT, limiting their suitability for accurate dose calculation.

Figure 1. Overview of the extended synthetic CT generation workflow for MR-only treatment planning. Truncated MR images are first converted to truncated synthetic CT (sCT) using an MR2sCT model from prior work. The proposed data augmentation–driven image recovery network is then applied to extend the truncated sCT to a full-length synthetic CT (sCTx), enabling recovery of missing inferior anatomy for accurate dose calculation.

- **Technical innovation:** To address this limitation, we introduce a data augmentation–driven image recovery framework that extends truncated anatomy without modifying network architectures. As illustrated in Fig. 2, image degradation is explicitly modeled during training via masking embedded in the data augmentation pipeline, enabling the network to learn recovery from synthetically truncated inputs using complete reference images as ground truth. Integrated into the synthetic CT generation workflow for MROP (Fig. 1), this framework serves as a second-stage module following MR2sCT, extending truncated sCT to recover missing inferior anatomy and generate extended synthetic CT (sCTx) suitable for dose calculation. This approach provides a flexible and general solution for improving the accuracy, robustness and safety of MR-only radiotherapy planning in the presence of LFOV constraints.

During inference, the trained recovery network was applied to truncated images to generate recovered images suitable for dose calculation. To demonstrate the framework for MROP, truncated brain MR images were first converted to truncated sCT using an MR2sCT model, followed by an sCT recovery step using the proposed image recovery network to generate extended sCT volumes including partial neck anatomy, making them suitable for treatment fields.

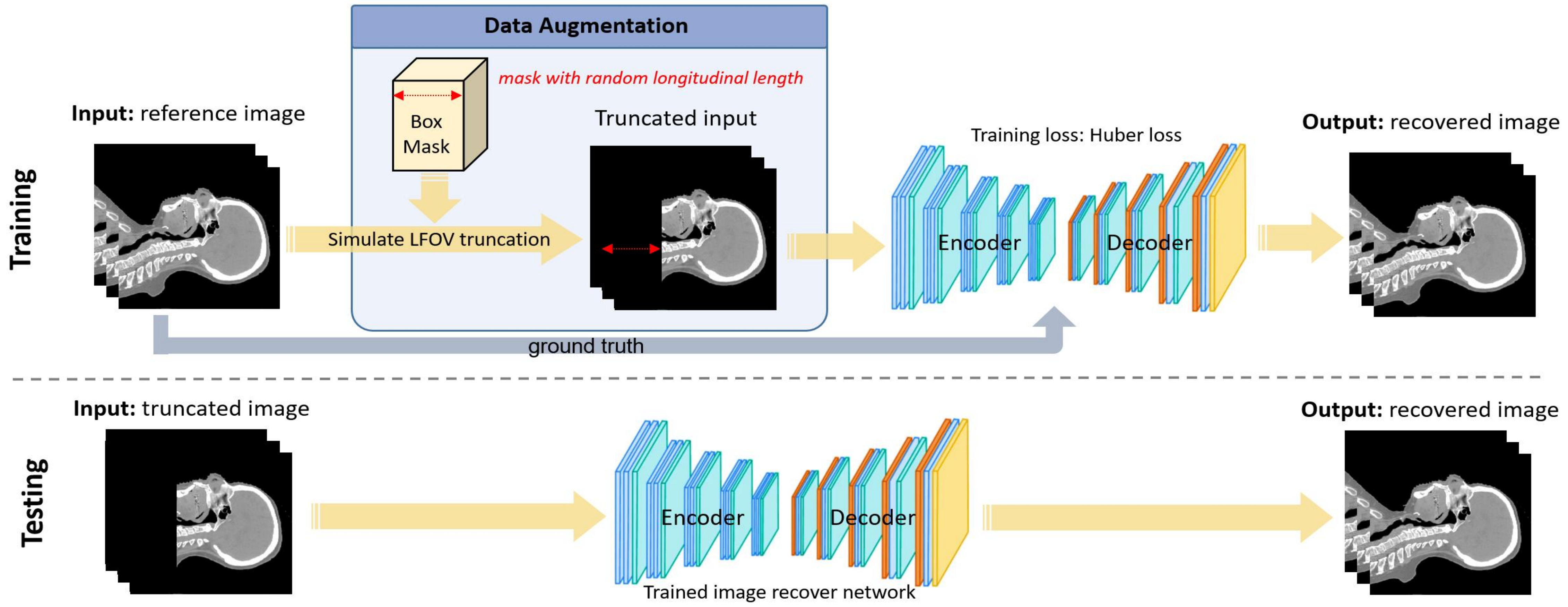


Figure 2. Overview of data augmentation–driven image recovery framework. During training, a mask with randomly sampled longitudinal lengths are applied to full-length reference images to simulate LFOV truncation. The network is trained to recover the degraded inputs back to the corresponding unmasked reference images, which serve as ground truth. During testing, the trained recovery network is applied to truncated images to generate recovered images suitable for dose calculation.

RESULTS

A brain case with the whole brain defined as the target volume was evaluated by the proposed framework. The recovered sCTx demonstrates anatomically consistent recovery of truncated regions with reasonable HU patterns, as illustrated by qualitative images and HU profiles (Fig. 3). Dose calculations performed on sCTx show high agreement with those based on the rCT (Fig. 4). These results indicate that the proposed image recovery framework enables planning-suitable image completion and supports accurate dose calculation in MROP.

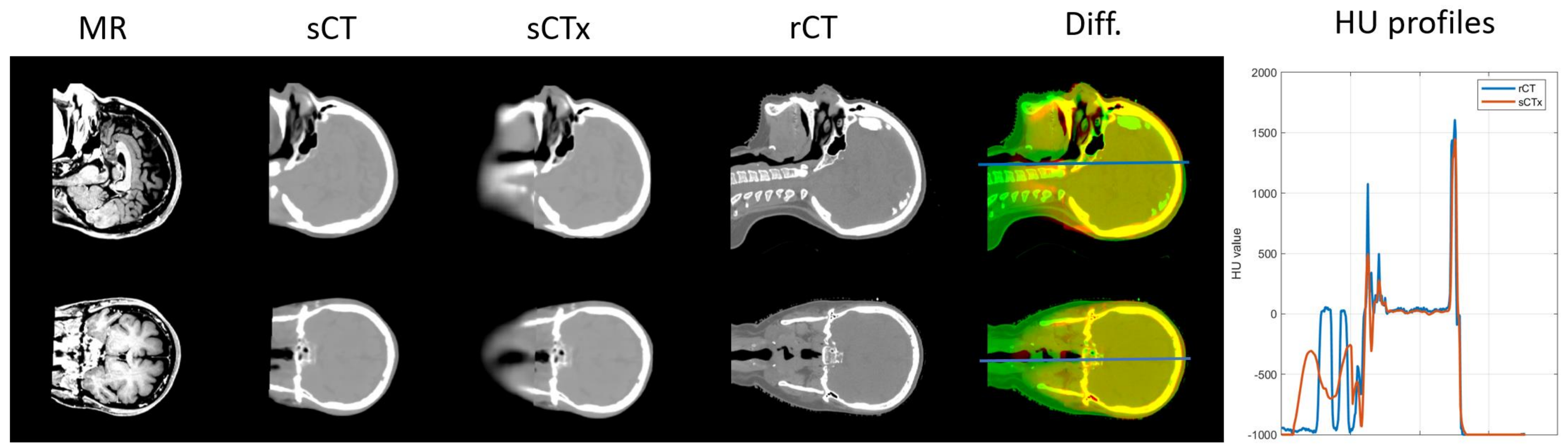


Figure 3. Qualitative image comparisons among truncated T1-weighted MR, initial synthetic CT (sCT), extended synthetic CT (sCTx), and reference CT (rCT) are shown for representative axial slices in sagittal and coronal views. Corresponding difference maps (sCTx–rCT) are provided, where colors closer to yellow indicate smaller HU differences. One-dimensional HU profiles extracted along the indicated blue line are shown to illustrate the continuity and relative consistency of HU patterns between sCTx and rCT.

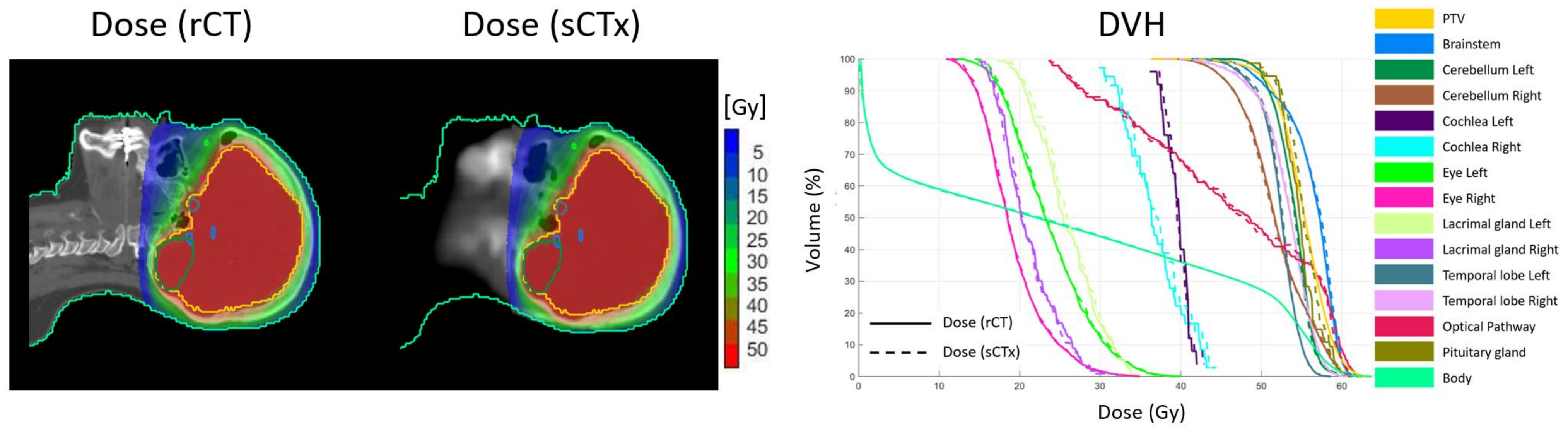


Figure 4. Dose distributions calculated on the reference CT (rCT) and extended synthetic CT (sCTx) are shown for a whole-brain treatment plan, along with DVH.

The sCTx achieved reliable anatomical compensation and tissue contrast compared with the reference CT (rCT), including truncated regions. Dose calculation performed on sCTx demonstrated high agreement with that based on the rCT, as reflected by consistent DVHs and a 98.67% gamma passing rate using 3%/3 mm criteria between the dose distributions.

CONCLUTIONS

A DAD deep learning framework was developed to recover truncated anatomy in LFOV medical images. In MROP applications, the recovered images supported accurate dose calculation and more complete plan evaluation by restoring missing anatomical regions, enhancing robustness in the presence of LFOV constraints.

REFERENCES

[1] Mingli Chen, et. al. Universal MR-to-Synthetic CT: A Streamlined Framework for MR-Only Radiotherapy Planning. 2025. AAPM 67th Annual Meeting & Exhibition.

ACKNOWLEDGMENTS

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