

Multi-Head Attention Enhanced Recurrent Mamba Network for Efficient High-Resolution IMRT Dose Generation

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Objective:

Monte Carlo (MC) simulation is the gold standard for dose calculation in radiation therapy, as it can accurately reproduce the interaction processes between photons and human tissues in intensity-modulated radiation therapy (IMRT) and generate high-precision dose distributions. However, it suffers from technical limitations of low computational efficiency and long runtime. In the clinical design of radiation therapy plans, the conventional default setting for the dose calculation grid is 3 mm; if a refined calculation grid such as 1 mm is adopted to improve the accuracy of dose simulation, the simulation time will increase exponentially. Deep learning models can effectively resolve this technical contradiction. To meet the dual requirements of high-precision dose simulation and computational efficiency, this study will construct and train a deep learning-based dose calculation model to achieve the high-precision and high-efficiency generation of dose distributions.

Methods:

This study we proposes a high-precision dose generation strategy based on a multi-head attention enhanced recurrent Mamba network. This strategy seamlessly integrates the gamma pass rate loss function into the network training framework, enabling the efficient and accurate conversion of dose simulation results from a 3 mm grid (meeting the minimum clinical requirements) into high-resolution and high-precision dose distributions.

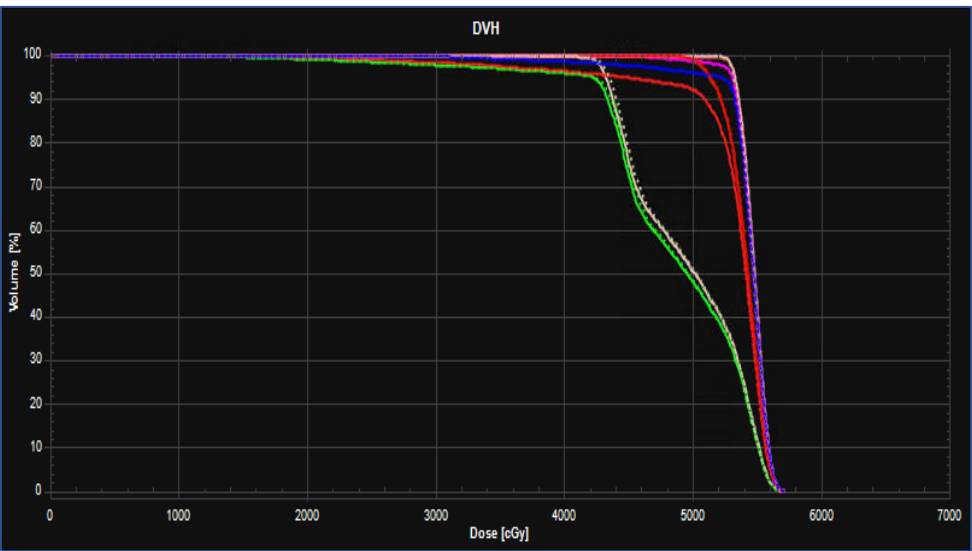


FIGURE 1. Dose volume histogram of the prediction and ground truth

Results:

This method can super-resolve the dose distribution from a 3 mm grid to the precision of a 1 mm grid within 30 seconds. Validated by gamma analysis with a dose threshold of 10%, the pass rates of this method reached $99.11\% \pm 0.71\%$, $97.52\% \pm 0.61\%$ and $96.31\% \pm 1.03\%$ under the gamma evaluation criteria of 3 mm/3%, 2 mm/2% and 1 mm/1%, respectively.

Conclusion:

Our method resolves the MC-IMRT dose calculation accuracy-efficiency dilemma, achieving 3 mm-to-1 mm dose super-resolution in 30 s (gamma pass rates >95%) and offering an efficient clinical high-precision dose calculation solution with great application potential

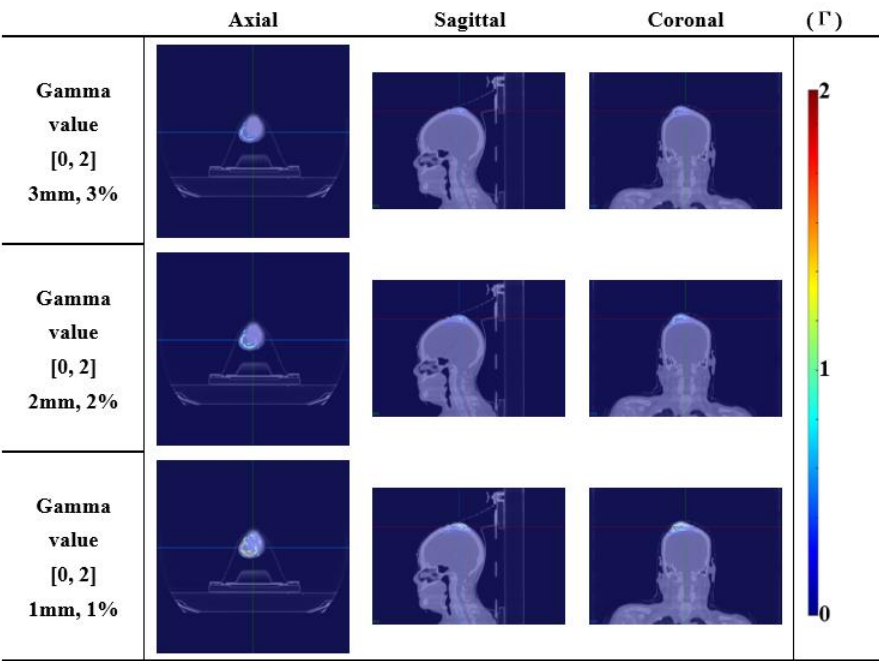


FIGURE 2. Gamma maps (under 3mm 3%, 2mm 2%, and 1mm 1% criteria)

1. Thummerer, A., Schmidt, L., Hofmaier, J., Corradini, S., Belka, C., Landry, G., & Kurz, C. (2025). Deep learning based super-resolution for CBCT dose reduction in radiotherapy. *Medical Physics*, *52*(3), 1629–1642. <https://doi.org/10.1002/mp.17557>

2. Wang, Y., Liu, Y., Bai, Y., Zhou, Q., Xu, S., & Pang, X. (2024). A generalization performance study on the boosting radiotherapy dose calculation engine based on super-resolution. *Zeitschrift für Medizinische Physik*, *34*(2), 208–217. <https://doi.org/10.1016/j.zemedi.2022.10.003>