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Single-Iso-Multiple-Targets (SIMT) Radiosurgery Plan Quality Control via a Novel Deep Neural Network with Spherical Convolutions

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Abstract
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Abstract

Objectives:

To develop a spherical coordinate-defined deep learning model to predict normal brain dosimetric quality for single-isocenter multiple target (SIMT) stereotactic radiosurgery (SRS) treatment plans. The objective of this model is to assist clinical decision-making in prescription dose determination and to provide a quality control tool to improve SIMT dosimetric quality consistency.

Methods:

The developed model interpreted each SIMT case's anatomy by fitting the patient's brain to a sphere that envelopes the entire skull. Based on the geometric center of the fitted sphere, all PTVs were projected onto a spherical surface via ray tracing. The volumetric information on PTV distribution within the brain was thus transformed into a patient-specific feature representative defined by two variables in a spherical coordinate system (i.e., azimuthal angle and polar angle). Based on this derived feature, a deep spherical convolutional neural network mimicking the encoding branch of the U-Net was trained to predict a specific dose-volume evaluator for the brain. Being equivalent to the classical neural network architectures for image processing within the Cartesian coordinate, the developed network implemented convolutional operations on the derived spherical surface with rotation equivariance.
The proposed model was applied to 106 SIMT cases (total PTVs per case: 2-43, total PTV volume per case: 0.22-19.93 (cc)) from our institution. Three models were trained independently to predict brain V50% (cc), V60% (cc), and V66.7% (cc) as dosimetric quality metrics, respectively. The training process followed an 8:2 train/test split ratio, and 5-fold cross-validation was employed within the training dataset. The model's performance was studied by comparing the prediction results with the ground truth values of 21 test cases. The mean absolute error (MAE) in volume (cc) and the coefficient of fitting determination (R2) were quantitatively evaluated.

Results:

In the 21 test cases, the mean brain V50%, V60%, and V66.7% ground truth values were 14.28 (cc), 10.45 (cc), and 8.73 (cc), respectively, and the MAEs achieved by the developed models were 1.97±0.27 cc, 1.31±0.19 cc, and 1.23±0.12 cc, respectively. Higher errors were observed for cases with larger numbers of discrete PTVs, but not necessarily for cases with larger total PTV volumes. The R2 results of the three models were 0.89±0.03, 0.93±0.01, and 0.90±0.01, respectively, suggesting an effective non-linear correlation between patient anatomy and the studied dosimetric evaluators modelled by the deep neural networks.

Conclusion(s):

A novel deep neural network based on spherical convolutions was successfully developed and implemented to predict brain dosimetric evaluators (brain V50%, V60%, and V66.7%) for SIMT SRS treatment. The spherical transform design used in this model enabled effective data dimension reduction for deep learning implementation while preserving volumetric anatomy information. These findings present a novel opportunity to guide prescription dose and fractionation, and to provide planners with achievable SRS planning goals in order to improve consistency in treatment planning quality. Future prospective studies are warranted to evaluate the clinical impact of this model on treatment planning and patient outcomes.