

Automated Segmentation of Target Volumes for Craniospinal Irradiation in Proton Therapy

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INTRODUCTION

Background

- Craniospinal irradiation (CSI) requires a uniform dose delivery to cerebrospinal fluid (CSF) pathways, including the whole brain and spinal cord.
- The target volume of CSI, therefore, extends significantly along the superior-inferior axis, which consequently makes the manual contouring of target volume highly time-consuming.

Objective

- To address this, we developed an automated segmentation model for CSI target volume in proton therapy using a deep learning-based approach.
- This study aims to significantly reduce the workload for target contouring while minimizing interobserver variation, ultimately enhancing the overall plan quality of CSI treatment.

MATERIALS AND METHODS

Patient Data

- Total 50 pediatric patients treated CSI proton therapy at National Cancer Center Korea (NCKK).
- 40 cases for training and 10 cases for evaluation.
- Patient ages ranged from 3 to 18 years (median 9 years).

Target Volume

- Clinical Target Volume (CTV) was selected as it serves as the basis for defining planning target volume (PTV) in the NCKK CSI target definition.

- (1) Brain CTV: From whole brain to C4.
- (2) Spine CTV: From C1 to S2.

Deep Learning Model

- Framework: nnU-Netv2 (default 2D configuration)
- Library: PyTorch 2.6.0.
- Hardware: NVIDIA RTX 4070 GPU.
- Training: Epochs 1,000 and Batch size 12.
- Optimizer: Stochastic Gradient Descent (SGD) with learning rate 0.01, momentum 0.99, and weight decay 3e-5.
- Loss function: Dice + Cross-Entropy.

Evaluation

- Evaluation Metrics
 - Dice Similarity Coefficient (DSC)
 - Intersection over Union (IoU)
 - 95th percentile Hausdorff Distance (HD95)
 - Average Symmetric Surface Distance (ASSD).
- Clinical Acceptability
 - 5-point Likert scale

RESULTS

Automated Contouring

- Figure 1 demonstrates the comparison between automatically generated CTVs (green and blue) and manually delineated reference CTVs (red and orange).
- High concordance was observed for both brain and spine regions, indicating accurate performance of the automated segmentation model relative to the ground truth.

Evaluation Metrics

- Figure 2 displays the distribution of evaluation metrics. The blue reference line indicates ideal (perfect) segmentation performance.
- The CTV contours for both the brain and spine showed high agreement with the reference, clustering closely around the reference line. Notably, brain CTVs consistently outperformed spine CTVs across all metrics, suggesting more robust and consistent performance in the brain region.

Clinical Acceptability

- Figure 3 summarizes the results of a 5-point Likert scale survey evaluating the clinical acceptability of the automatically generated CTVs. Two medical physicists involved in CSI planning participated in the assessment.
- They rated 25% as neutral, 60% as agree, and 15% as strongly agree, indicating a high level of clinical acceptability.

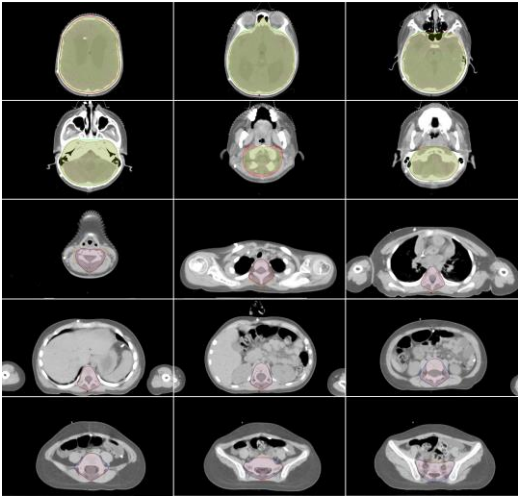


Figure 1. Comparison between automatically segmented CTVs (green and blue) and manually delineated reference CTVs (red and orange).

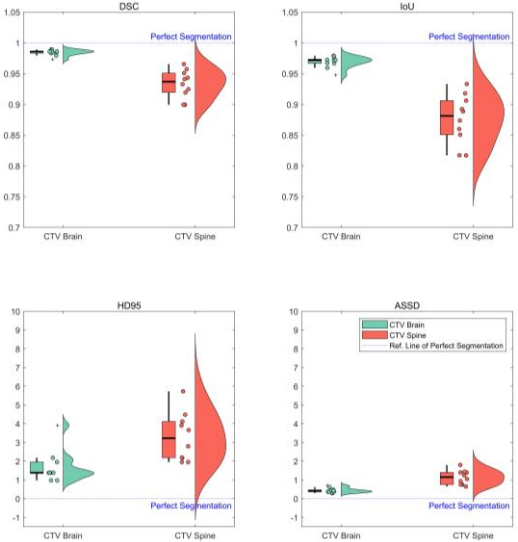


Figure 2. Distribution of evaluation metrics. The blue reference line indicates ideal (perfect) segmentation performance.

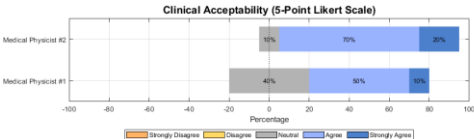


Figure 3. Results of 5-point Likert scale survey evaluating the clinical acceptability of the automatically delineated CTVs.

CONCLUSION

- ◆ In this study, an automated segmentation model for target volumes in pediatric CSI proton therapy was developed.
- ◆ The model demonstrated promising performance based on the comparison of automated and reference segmentations, quantitative evaluation metrics, and clinical acceptability.
- ◆ This approach has the potential to reduce the clinical workload and minimize interobserver variability in CSI proton treatment planning.