Deep Learning-Based Auto-Segmentation of Spinal Cord and Thecal Sac in Stereotactic Body Radiotherapy for Spinal Metastases

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INTRODUCTION

- **Stereotactic Body Radiotherapy for Spinal Metastases (Spine SBRT)**
  Spine SBRT is an effective treatment for spinal metastases, which are often located adjacent to **critical serial organs** (Figure 1).
- **Delineation of the Spinal Cord and Thecal Sac**
  Accurate **spinal cord and thecal sac contouring is essential to maximize efficacy and minimize toxicity**, but inter-observer variability remains significant despite existing guidelines[1].
- **Automatic Contouring Model**
  Deep learning-based segmentation may improve efficiency and consistency, but evidence in spine SBRT remains limited.
- **Purpose**
  Development and evaluation of a deep learning-based automatic contouring model for the spinal cord and thecal sac in spine SBRT.

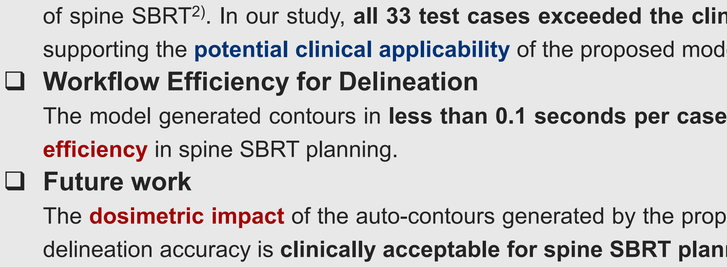

Figure 1. Contours and dose distribution in spine SBRT

METHODS AND MATERIALS

- **Study Design and Dataset**
  Single-institution retrospective study of 288 patients (163 spinal cord, 125 thecal sac contours).
- **Model Development (Figure 2,3)**
  - ✓ Three input image set into 3D U-Net : T1WI alone, T2WI alone, and combined T1WI+T2WI.
  - ✓ Split into training, validation, and test sets at a 7:1:2 ratio
- **Segmentation accuracy metrics**
  - ✓ Dice Similarity Coefficient (DSC)
  - ✓ 95% Hausdorff Distance (HD95)
- **Statistical Analysis**
  Two-sided Wilcoxon signed-rank tests (< 0.05)

Table 1. Patient information

Index	Spinal cord (n=163)	Thecal sac (n=125)
Age, median (range)	66 (30-84)	64 (23-84)
Gender, F/M	54/109	47/78
Target Vertebral Levels		
1 level	89 (54.6%)	63 (50.4%)
2 levels	49 (30.1%)	20 (16.0%)
≥3 levels	25 (15.3%)	42 (33.6%)

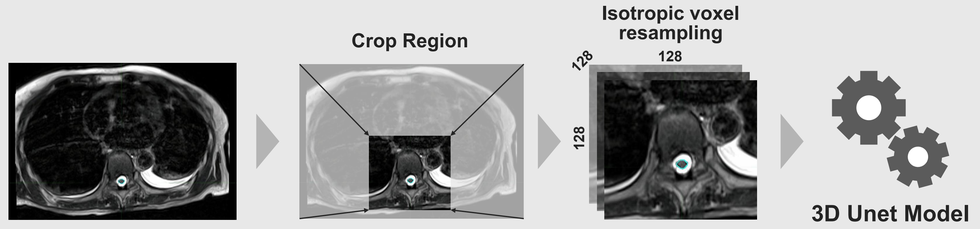

Figure 2. Image Preprocessing

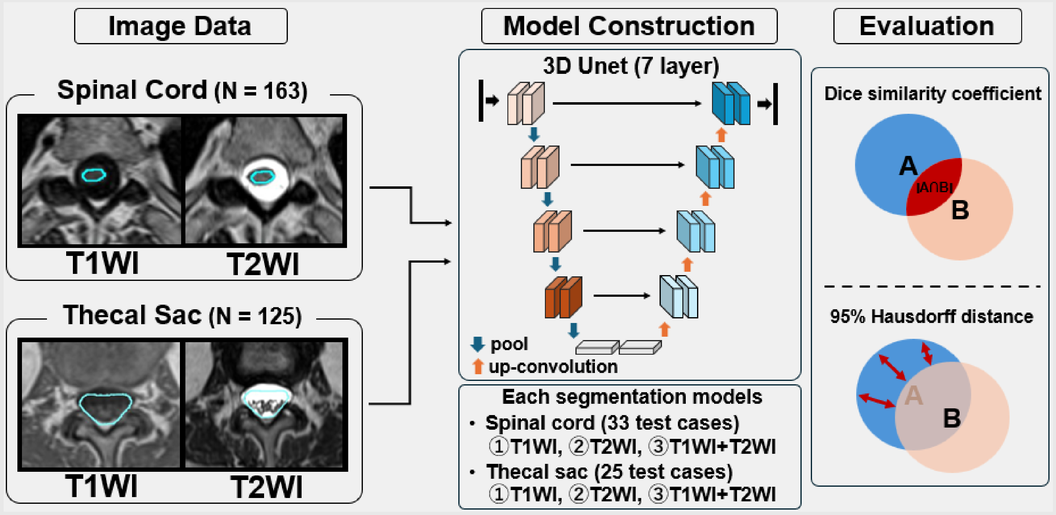

Figure 3. Flowchart of this study

RESULTS

- **Overall Segmentation Performance**
  All models achieved a **mean DSC ≥ 0.82** for the spinal cord and **≥ 0.84** for the thecal sac.
- **Best-Performing Model: Combined T1WI+T2WI Model**
  - ✓ **Spinal cord**: **All 33 test cases** achieved a **DSC ≥ 0.70**
  - ✓ **Thecal sac**: **All 25 test cases** achieved a **DSC ≥ 0.78**
  - ✓ **Less than 0.1 seconds** per case in generated contours

Table 2. Segmentation accuracy of the models

ROI	Model	DSC (mean ± 1 SD)	HD95 (mean ± 1 SD) [mm]
Spinal cord	T1WI	0.82 ± 0.07	1.72 ± 1.91
	T2WI	0.82 ± 0.06	2.00 ± 3.45
	T1WI+T2WI	**0.84 ± 0.06**	**1.39 ± 0.61**
Thecal sac	T1WI	0.84 ± 0.07	2.73 ± 1.83
	T2WI	0.85 ± 0.06	2.54 ± 1.35
	T1WI+T2WI	**0.87 ± 0.05**	**2.28 ± 1.35**

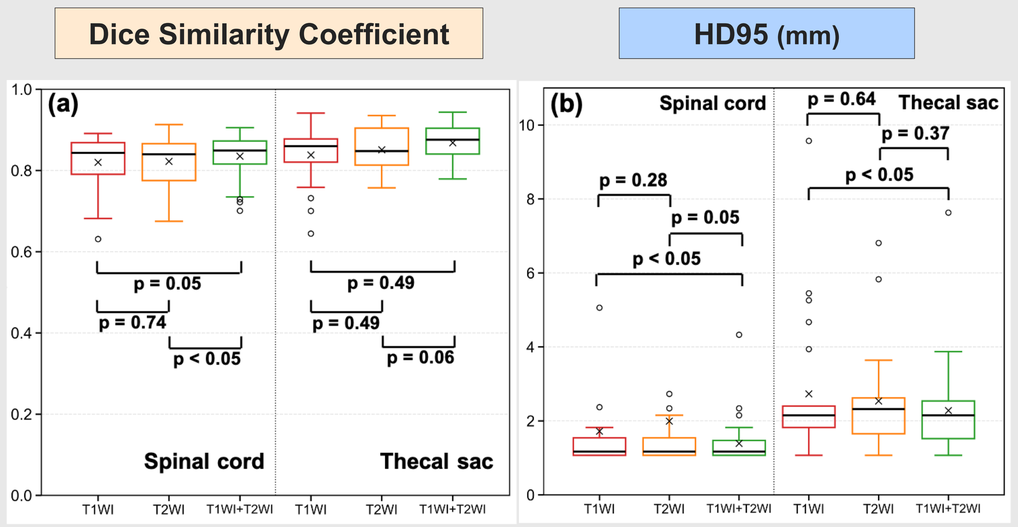

Figure 4. Boxplots of (a) Dice similarity coefficient. (b) 95th Hausdorff distance (HD95) between the spinal cord and thecal sac for each model. The horizontal line is the median value, the cross (×) is the mean value.

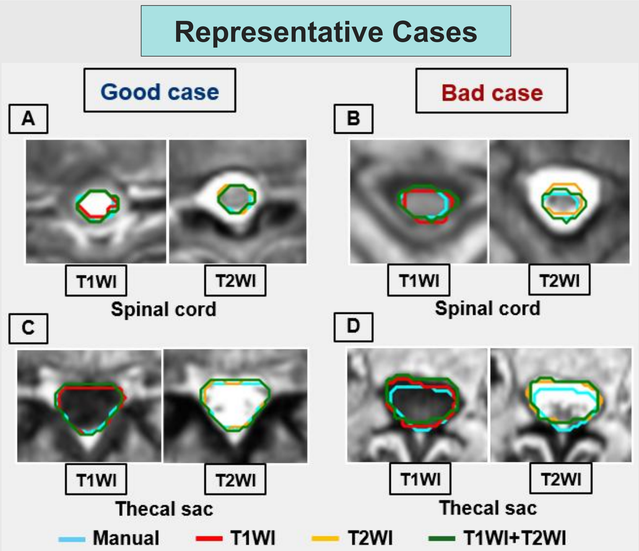

Figure 5. Manual contours (cyan line) and model-predicted contours from the T1WI model (red line), T2WI model (orange line), and the combined T1WI+T2WI model (green line).

DISCUSSION

- **Summary of the Present Study**
  This is the first study to develop a **deep learning–based automatic contouring model** for both the spinal cord and thecal sac in spine SBRT. The **combined T1WI+T2WI** model showed the best segmentation performance (mean DSC ± 1SD of 0.84 ± 0.06 for the spinal cord and 0.87 ± 0.05 for the thecal sac).
- **Segmentation Accuracy of the Automatic Contouring Model**
  Ito et al. defined a DSC ≥ 0.70 as clinically acceptable spinal cord delineation accuracy in a multi-institutional dummy-run study of spine SBRT[2]. In our study, **all 33 test cases exceeded the clinical acceptability threshold for spinal cord delineation**, supporting the **potential clinical applicability** of the proposed model in spine SBRT.
- **Workflow Efficiency for Delineation**
  The model generated contours in **less than 0.1 seconds per case**. These findings suggest its potential to **improve workflow efficiency** in spine SBRT planning.
- **Future work**
  The **dosimetric impact** of the auto-contours generated by the proposed model should be assessed to determine whether their delineation accuracy is **clinically acceptable for spine SBRT planning**.

CONCLUSIONS

The proposed deep learning models **achieved clinically acceptable spinal cord segmentation and consistently high thecal sac accuracy**. Deep learning–based automatic segmentation may support spinal cord and thecal sac delineation in spine SBRT by **improving efficiency and standardization**.

REFERENCES

1) Toussaint A, et al. Variability in spine radiosurgery treatment planning: results of an international multi-institutional study. Radiat Oncol. 2016;11:57.
2) Ito K, et al. Contouring compliance and variability of targets and organs at risk in spine SBRT: a 34-institution study. Radiother Oncol. 2025;207:110877.

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