# Evaluation of the dosimetric impact of rotational setup errors on target and organs at risk in spine SBRT

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## INTRODUCTION

- **Stereotactic body radiotherapy (SBRT)** for spinal metastases provides improved local control and pain relief due to its higher dose concentration and central dose delivery compared to conventional radiotherapy(1).
- Creating a steep dose distribution using **VMAT** can reduce the dose to the spinal cord, but this also increases the impact of setup errors (Fig. 1).
- In our previous study, we investigated the dosimetric impact of **translational setup errors** in spine SBRT. Therefore, the present study focused on the effects of **rotational setup errors**.

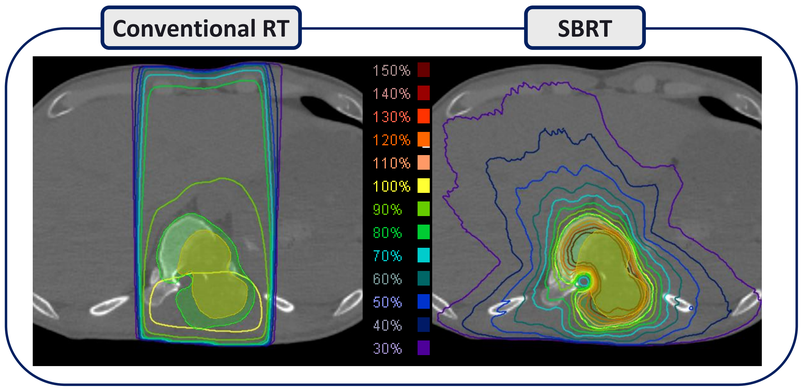



**Fig. 1. Dose distributions of conventional RT (left) and SBRT (right) for spinal metastases**

## AIM

We quantitatively evaluated the dosimetric effects of rotational errors in the three axes (**Pitch, Yaw, and Roll**) during spine SBRT on the target and OARs.

## METHODS

**Patient Background**

- This retrospective study included **15 patients** with spinal metastases (2 in the cervical spine, 5 in the thoracic spine, and 8 in the lumbar spine).

**Treatment Plan**

- **A 2-arc VMAT plan** was created with a prescribed dose of **24 Gy in 2 fractions**, applying a 2 mm margin to both the clinical target volume (CTV) and spinal cord. Most plans met the dose constraints (Table 1).

**Setup error simulation**

- Setup errors were added in **0.5 degrees** increments between **0.5 degrees** and **3.0 degrees** in the pitch, yaw, and roll directions, respectively (Fig. 2). The center of rotation was set to the isocenter, which is the center of mass of the PTV. The CT images and structure set were rotated using Python (version 3.12) , and the calculations were performed again.

**Analysis Metrics**

- The dose metrics ：**CTV $D_{95\%}$, GTV $D_{95\%}$, the spinal cord $D_{0.03cc}$** and **thecal sac $D_{0.03cc}$**.
- The threshold for rotational error resulting in a **dose change of 5%** or more was analyzed.

**Table 1. Dose constraints for treatment planning. (24 Gy/2 fr)**

| Structure | Metric | Requirement |
|---|---|---|
| PTV | $D_{95\% \text{ or } 90\%}$ | = 24.0 Gy (100%) |
| | $D_{2\%}$ | ≦ 38.4 Gy (160%) |
| GTV | **$D_{min}$** | **≧ 24.0 Gy (100%)*** |
| | **$D_{98\%}$** | **≧ 33.6 Gy (140%)*** |
| PRVcord, Thecal sac | $D_{0.035cc}$ | ≦ 17.0 Gy |
| Esophagus | $D_{0.035cc}$ | ≦ 24.0 Gy |
| | $D_{2.5cc}$ | ≦ 19.0 Gy |
| Larynx | $D_{1cc}$ | ≦ 20.0 Gy |

*Bold requirement, as high as possible.

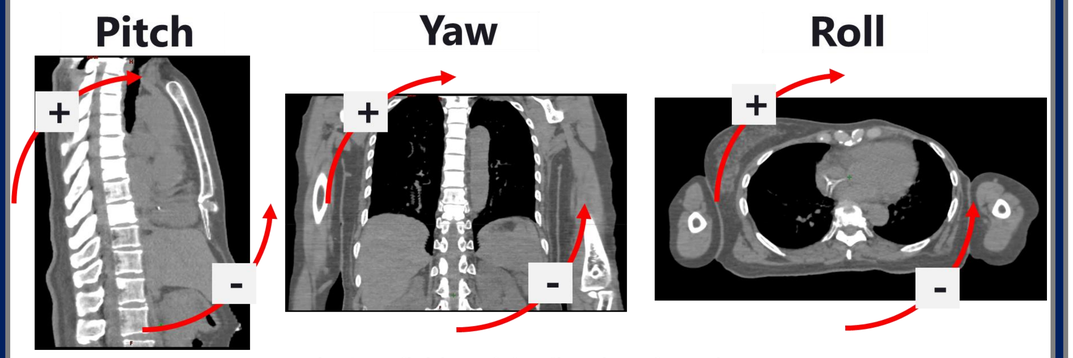
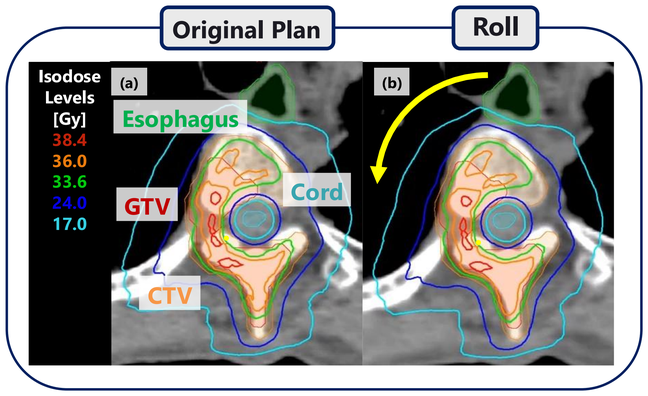



**Fig. 2. Definition of the direction of rotation**

## RESULTS

### (1) A typical example of changes in dose distribution due to rotational error

- We present a case involving the addition of a **roll-axis rotational error**, which results in significant dose variation in the spinal cord among the three axes of rotational error (Fig. 3) .
- There was **negligible change** in the dose distribution after rotational error compared to the reference plan. Since the spinal cord is located near the isocenter, which is the center of rotation, no effect on the dose distribution was observed.



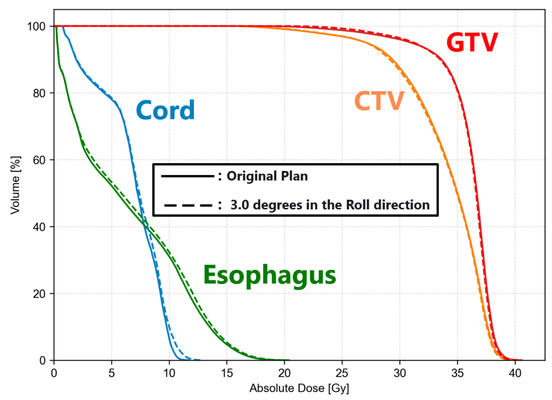




**Fig. 3. Changes in Dose Distribution and DVH Due to Rotational Error in Representative Cases**
**(a): Original Plan, (b): 3.0 degrees in the Roll direction**
**The yellow dots in the figure indicate the isocenter positions.**

### (2) Changes in dose due to rotational error

- As shown in CTV $D_{95\%}$ and GTV $D_{95\%}$, there was virtually no change in dose even when rotational error was introduced. The change in dose was **less than 1.5%**, indicating that the effect of rotational error is negligible. For the target, **dose constraints were met in all plans even when rotation was applied**.
- The dose constraint of 17 Gy for the spinal cord $D_{0.03cc}$ was satisfied even when a rotation error of **3.0 degrees** was added.
- The dose constraint of 17 Gy for the thecal sac $D_{0.03cc}$ was not met at the mean value even with a rotation of 0.5 degrees in directions other than the roll axis.

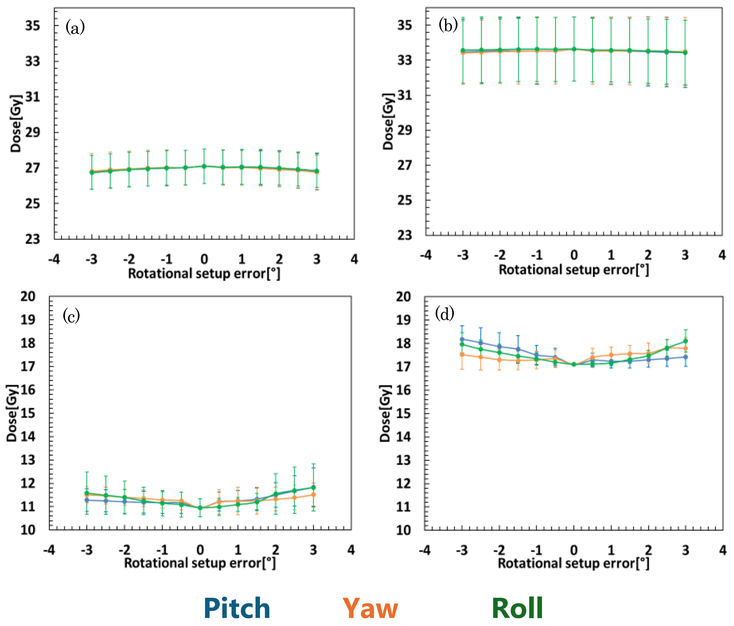



**Fig. 4. Changes in dose due to rotational error for each dose indicator**
**(a): CTV $D_{95\%}$, (b): GTV $D_{95\%}$, (c): Spinal cord $D_{0.03cc}$, (d): Thecal sac $D_{0.03cc}$**
**Furthermore, the 95% confidence interval is shown as the error range for each dose metric.**

### (3) Changes in dose due to rotational error

- Even with **3.0 degrees**, no doses exceeding 5% were observed for CTV $D_{95\%}$ or GTV $D_{95\%}$.
- The reason the dosimetric impact of rotational setup error was small is that, since the angular changes are centered on the isocenter, it is believed that the positional relationships of the entire target can be maintained relatively easily.

**Table 2. Threshold for rotational setup errors resulting in a dose change of 5% or more**

| Targets・OARs | Pitch | Yaw | Roll |
|---|---|---|---|
| **CTV $D_{95\%}$** | **>3.0** | **>3.0** | **>3.0** |
| **GTV $D_{95\%}$** | **>3.0** | **>3.0** | **>3.0** |
| **Spinal cord $D_{0.03cc}$** | **3.0** | **2.0** | **2.5** |
| **Thecal sac $D_{0.03cc}$** | **2.5** | **3.0** | **2.0** |

## CONCLUSIONS

- Even when a 3.0 degrees rotational error occurred in the spinal cord, **the dose constraints were met in all cases**.
- In spine SBRT, target coverage remained robust against rotational errors of up to **3.0 degrees** (variation rate < **1.5%**).
- In contrast, for the OARs the spinal cord and the thecal sac a rotational error of **2.0 degrees** resulted in a dose variation of **5%** or more.
- Although dose constraints were met, the high sensitivity of the OARs underscores the need for rigorous rotational setup correction.

## REFERENCES

1) A. Sahgal et al. Stereotactic body radiotherapy versus conventional external beam radiotherapy in patients with painful spinal metastases: an open-label, multicentre, randomised, controlled, phase 2/3 trial. The Lancet Oncol 2021; 22: 1023-33

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