2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Optimization of Patient-Specific QA Metrics for Detecting Spinal Cord Dmax Delivery Deviations in Spine Stereotactic Body Radiotherapy

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ABSTRACT

Purpose
This study aimed to optimize patient-specific quality assurance (PSQA) gamma criteria for detecting spinal cord maximum dose (Dmax) deviations in spine stereotactic body radiotherapy (SBRT) using myQA SRS and electronic portal imaging device (EPID)-based dosimetry.

Methods
Three spine metastasis cases treated with volumetric modulated arc therapy-based spine SBRT were analyzed. Three baseline plans and 39 error plans were generated in RayStation v10A by introducing multileaf collimator (MLC) opening/closing errors, MLC positional shifts, and monitor unit scaling errors. Plans were delivered on a TrueBeam linear accelerator and evaluated using myQA SRS at 0° and 90° detector-plane orientations and EPID with PerFRACTION. Two-dimensional global gamma analysis was performed using 3%/2 mm, 2%/2 mm, 3%/1 mm, 2%/1 mm, and 1%/1 mm criteria with a 10% dose threshold. Receiver operating characteristic (ROC) analysis was performed for each criterion, with positive cases defined as |ΔDmax| ≥2%.

Results
For EPID, the highest AUC was obtained with the 3%/2 mm criterion (AUC, 0.63; 95% confidence interval [CI], 0.44–0.81; cutoff, 91.6%). For myQA SRS at 0° , the 2%/2 mm criterion showed the highest AUC (AUC, 0.84; 95% CI, 0.70–0.95; cutoff, 91.9%). At 90° , the selected 3%/1 mm criterion showed favorable discrimination (AUC, 0.79; 95% CI, 0.63–0.93; cutoff, 87.4%).

Conclusions
ROC analysis identified detector- and orientation-specific gamma criteria associated with spinal cord Dmax deviations. The optimal criterion differed among EPID and myQA SRS measurements at 0° and 90° . These findings support the use of ROC-optimized gamma criteria for clinically relevant PSQA evaluation in spine SBRT.

INTRODUCTION

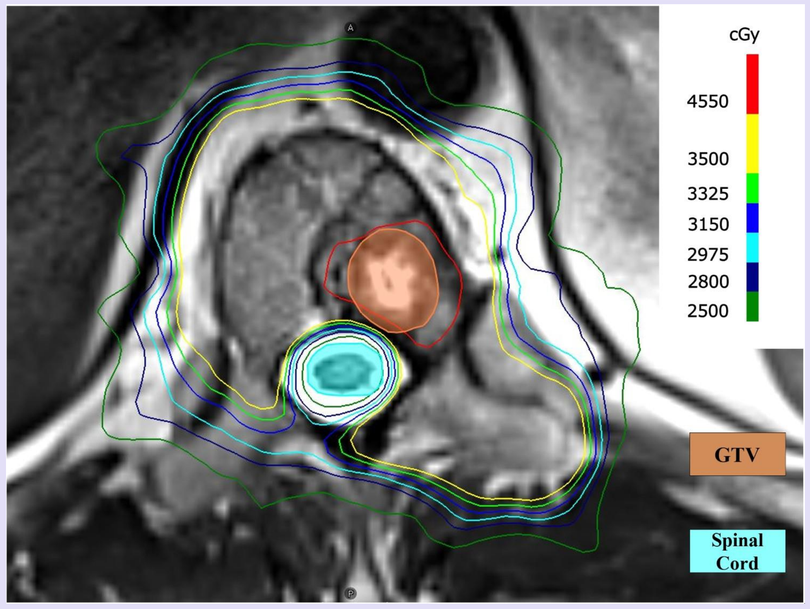
- Spine stereotactic body radiotherapy (SBRT) creates steep dose gradients near the spinal cord [1].
- Even millimeter-scale positional errors can compromise target coverage or increase the spinal cord dose [2].
- High-resolution detectors and stringent gamma criteria are recommended for SBRT patient-specific quality assurance (PSQA) [2].
- myQA SRS and electronic portal imaging device (EPID)-based dosimetry are practical PSQA approaches[3]; however, optimal gamma criteria for detecting spinal cord Dmax deviations remain unclear.

Purpose

To propose optimal PSQA gamma criteria for detecting spinal cord maximum dose (Dmax) deviations caused by multileaf collimator (MLC)-related errors in spine SBRT.

METHODS AND MATERIALS

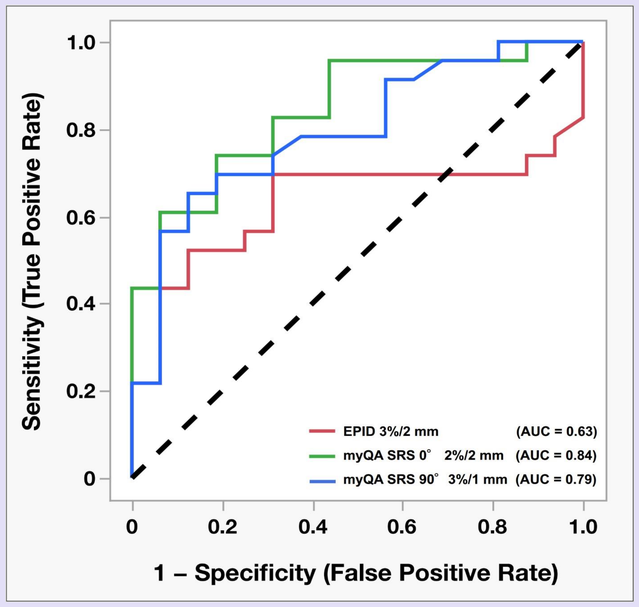
- **Treatment planning**
  RayStation v10A (RaySearch Laboratories)
  TrueBeam with Millennium 120 MLC (Varian Medical Systems)
  10 MV flattening filter-free, 2–3 volumetric modulated arc therapy arcs
  Dose gradient: approximately 10-15%/mm around the spinal cord
  Collapsed Cone algorithm, 1-mm dose grid
  Spinal cord Dmax constraint: ≤25 Gy



- **Delivery error**
  Baseline plans (n = 3) were generated without intentional errors.
  Thirty-nine error plans were created using an in-house Python script in RayStation.
  Simulated errors included MLC opening/closing errors of 1–2 mm, MLC positional shifts of ±1 and ±2 mm, and monitor unit (MU) scaling errors of ±1% and ±2%.
- **Quality assurance evaluation**
  myQA SRS (IBA Dosimetry): measurements at 0° coronal and 90° sagittal detector-plane orientations
  EPID: a-Si 1200 with PerFRACTION (Sun Nuclear)
  Gamma criteria: 3%/2 mm, 2%/2 mm, 3%/1 mm, 2%/1 mm, and 1%/1 mm; 10% dose threshold
- **Receiver operating characteristic (ROC) analysis**
  Spinal cord Dmax deviations were calculated from baseline; positives were defined as |ΔDmax| ≥2%.
  ROC analysis was performed for each gamma criterion using JMP® Student Edition 19.0.1 (SAS Institute Inc.).
  Optimal criteria were selected based on AUC, Youden index, and practical cutoff values.

RESULTS

ROC curve comparison



Optimal Gamma Criteria Based on ROC Analysis

Metric	Criterion	AUC	95% CI* lower	95% CI upper	Optimal cutoff (%)	Youden index
myQA SRS 0° (Coronal)	2%/2 mm	0.84	0.70	0.95	91.90	0.55
	2%/1 mm	0.83	0.68	0.94	86.80	0.54
	3%/2 mm	0.82	0.67	0.94	97.10	0.56
myQA SRS 90° (Sagittal)	1%/1 mm	0.81	0.66	0.93	62.40	0.55
	3%/1 mm	0.79	0.63	0.93	87.40	0.53
	2%/1 mm	0.79	0.63	0.92	78.30	0.57
EPID	3%/2 mm	0.63	0.44	0.81	91.60	0.40
	2%/2 mm	0.63	0.44	0.81	87.80	0.34
	3%/1 mm	0.62	0.43	0.80	77.00	0.34

* CI: confidence interval

KEY FINDINGS

- AUC point estimates differed between myQA SRS and EPID and across measurement orientations.
- The highest AUC was observed with myQA SRS at 0° using the 2%/2 mm criterion (AUC = 0.84).
- The 3%/1 mm criterion at 90° showed favorable discrimination (AUC = 0.79).
- ROC analysis identified detector- and orientation-specific gamma criteria for spine SBRT PSQA.

DISCUSSION / CONCLUSIONS

➢ ROC analysis showed that gamma passing rate–based detection of spinal cord Dmax deviations depended on the detector system, measurement orientation, and gamma criterion. TG-218 recommends stricter criteria for SBRT without specifying a universal criterion [4].Although the 0° coronal orientation of myQA SRS showed the highest AUC, the 90° sagittal orientation is clinically relevant for evaluating the steep dose-gradient region between the target and spinal cord. Its selected criterion of 3%/1 mm is consistent with the stricter SBRT PSQA criterion recommended in MPPG 9.b [2].EPID-based PSQA showed lower AUC point estimates than myQA SRS in this dataset, consistent with recommendations favoring high-resolution detectors for SBRT [2,3]. These findings support the use of ROC-optimized, detector-specific, and orientation-specific gamma criteria for detecting MLC-related spinal cord Dmax deviations in spine SBRT.

REFERENCES

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