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Quantifying the Spatial Sensitivity of Helical Diode Arrays In SBRT Patient-Specific QA

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ABSTRACT

Purpose: To quantify Gamma Passing Rate (GPR) volatility in SBRT QA caused by the spatial coincidence of helical diode arrays (10 mm pitch) with high-gradient fields. While 3%/2mm criteria reduce alignment artifacts, more sensitive 3%/1mm criteria are recommended for SBRT. This study evaluates GPR instability driven solely by stochastic diode alignment relative to the stereotactic treatment fields.

Methods: QA was performed for one SBRT plan per site (Lung, Liver, Prostate, Spine, and Seminal Vesicles) on an Elekta Infinity (3%/1mm, 10% threshold, global normalization). To isolate sampling effects, plans were shifted longitudinally in the treatment planning system (0.0 to 17.5 mm) and physically on the couch during measurements. This isolated significant GPR changes to discrete sampling effects. GPR fluctuations were quantified with two main drivers: the Diode Inclusion Effect (change in GPR due to the number of diodes exceeding the 10% threshold) and the Local Agreement Effect (change in GPR due to agreement at specific diode coordinates as they navigate areas of low and high dose gradients).

Results: A periodic fluctuation of GPR was observed to coincide with the 10 mm detector pitch across all cases with a mean GPR range (Max–Min) of 6.1%. Volatility was inversely related to target size with lung (20.2 cc) and seminal vesicles (8.6 cc) showing the highest swings (8.8% and 7.9%, respectively) while the prostate (122.4 cc) was 3.5%. Decomposition indicated this was driven by the Local Agreement Effect as diodes shifted to more favorable regions of better agreement. Conversely, the T4 Spine case instability was masked by the Diode Inclusion Effect, where shifts "pruned" failing edge diodes from the analysis.

Conclusions: SBRT pass rates at 3%/1mm are highly dependent on the sub-millimeter spatial coincidence of the 10 mm -spaced detector grid. QA results may reflect geometric alignment rather than accurate treatment delivery.

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INTRODUCTION

- Diode arrays with 10 mm spacing have resolution limitations in SBRT but are still commonly used for Patient-Specific Quality Assurance (PSQA).
- AAPM recommends a 3%/1mm gamma evaluation criteria for stereotactic fields [1, 2].
- Stochastic alignment of discrete diodes within high-gradient fields can cause gamma pass rate (GPR) volatility, such that “passing” PSQA can be dependent on geometric luck than actual delivery accuracy.
- This study answers the question: “How dependent are SBRT PSQA passing rates on geometric placement of diodes in an SBRT field?”

METHODS AND MATERIALS

- PSQA was performed on an Elketa Infinity using 3%/1mm criteria, a 10% threshold, and global normalization for the following sites: lung, liver, prostate, spine, seminal vesicles.
- Plans were QA’s after shifting the array position in the treatment field by 2.5 mm longitudinal increments (ranging from 0.0 to 17. mm), as represented in Figure 1.
- Fluctuations in GPR were isolated into two primary drivers:
  1. Diode Inclusion Effect: When a shift in diode locations varies the number of diodes evaluated for GPR (exceeds 10% dose threshold); see Figure 1.
  2. Local Agreement Effect: GPR changes due to differences in planned vs. measured dose at specific diode coordinates when navigating low and high dose gradients.

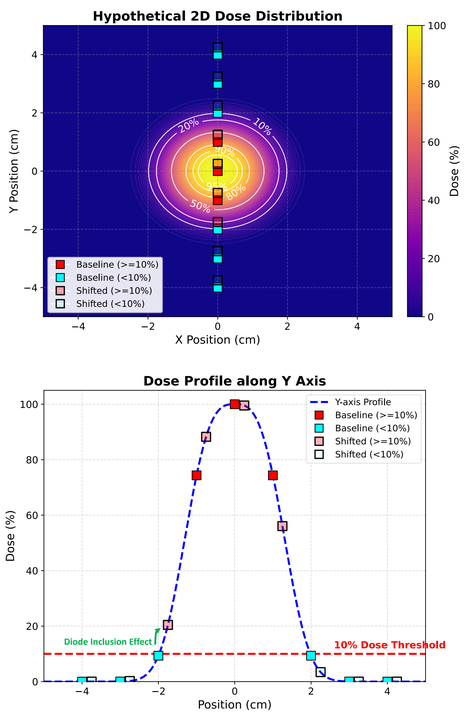

Figure 1. A hypothetical illustration of the effect of shifting a diode array within a high-gradient treatment field. (Top) Locations of diodes are depicted in a 2D dose distribution before and after a 2.5 cm shift of the array. (Bottom) The squares indicate points of diode measurement before and after the shift on a longitudinal dose profile. Red squares represent diodes that measure dose above the 10% threshold while excluded points are colored blue.

RESULTS

- GPR fluctuated periodically with 10 mm detector pitch across all evaluated cases (e.g. GPR evaluated with shifts of 2.5, 5.0, and 7.5 mm corresponded with shifts of 12.5, 15.0, and 17.0 mm), see Figure 2.
- GPR volatility inversely correlated with target size as shown in Figure 3. The overall mean GPR range (max – min) was 6.1%.
  - Smaller targets, such as the lung (20.2 cc) and seminal vesicles (8.6 cc), exhibited the highest instability with GPR swings of 8.8% and 7.9%, respectively.
  - The prostate (122.4 cc) varied by only 3.5% in GPR
- Decomposition analysis showed that the Diode Inclusion and Local Agreement effects frequently drive instability in opposite directions, see Figure 4.
- In the T4 spine case, true instability was masked because the Diode Inclusion effect “pruned” failing edge diodes from the analysis.

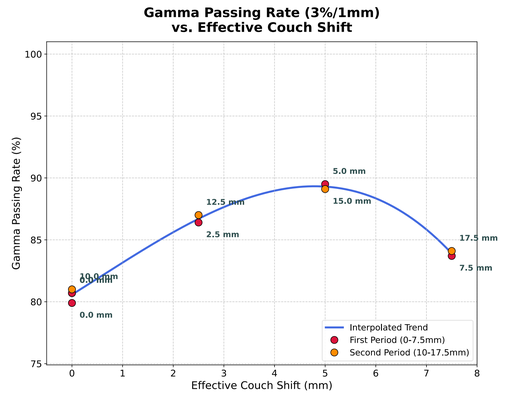

Figure 2. Gamma passing rate (3%/1mm) periodicity with effective couch shift of the lung SBRT plan.

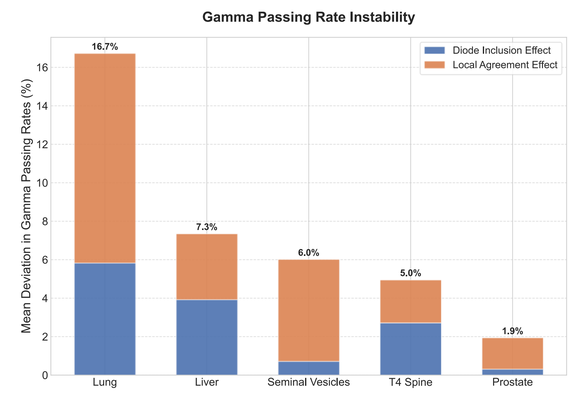

Figure 3. Mean deviation in GPR across five SBRT sites showing increased instability for smaller target volumes.

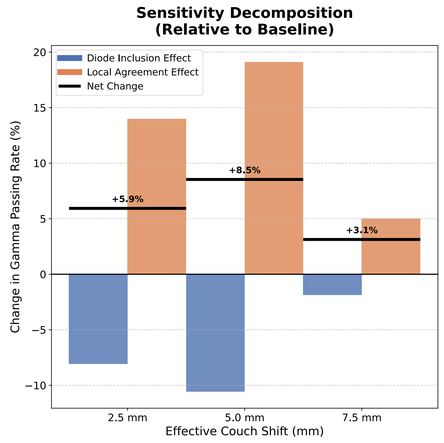

Figure 4. Net change in GPR relative to the unshifted baseline measurement, decomposed into Diode Inclusion and Local Agreement effects for the same lung plan.

Table 1. Summary of target volumes, baseline passing rates, and the observed range of GPR fluctuation for each anatomical site.

Treatment Site	Target Size (cm^3)	Baseline GPR (%)	Range of GPR (%)
Prostate	122.40	92.2	89.8 – 93.3
Liver	37.15	87.2	84.4 – 88.4
T4 Spine	31.70	86.8	84.0 – 87.3
Lung	20.16	80.7	80.7 – 89.5
Seminal Vesicles	8.58	79.4	79.4 – 87.3

DISCUSSION

- Measurement under sampling introduced substantial GPR uncertainty across all anatomical sites tested.
- Opposing effects (Diode Inclusion and Local Agreement) can potentially cancel each other out, which masks localized failures.
- SBRT pass rates evaluated at 3%/1mm are highly dependent on the sub-millimeter spatial coincidence of the 10mm-spaced grid.
- These findings highlight the magnitude of false-positive risk for these limited-resolution diode arrays for stereotactic PSQA application.
- Standard QA results using these devices may reflect geometric alignment rather than accurate treatment delivery.

CONCLUSIONS

- SBRT pass rates at 3%/1mm can be highly dependent on the sub-millimeter spatial coincidence of the 10 mm -spaced detector grid with the high gradients of the treatment field.
- Standard PSQA workflow may reflect geometric alignment rather than accurate treatment delivery.

REFERENCES

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2. Cirino E, Benedict SH, Dupre PJ, et al. AAPM-RSS Medical Physics Practice Guideline 9.b: SRS-SBRT. J Appl Clin Med Phys. 2025;26:e14624. https://doi.org/10.1002/acm2.14624