The first investigation of spot size and its impact on treatment planning quality for spot scanning proton arc therapy

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Purpose

Spot scanning proton arc (SPArc) therapy, delivering dose through continuous gantry rotation with pencil beam scanning, has attracted intensive attention due to its superior dose conformity, organs-at-risk (OAR) sparing and treatment efficiency compared to intensity-modulated proton therapy (IMPT). The resulting dose distribution depends on the underlying beam model, particularly lateral spot size. To facilitate the clinic implementation of SPArc, we conducted a systematic study on SPArc plan quality across multiple disease sites using a standardized composite scoring rubric.

Methods

- Three beam models with different lateral spot size from 70MeV to 227.7MeV (Gaussian σ): small(1.7–4mm), medium(3.4–8mm), and large(6.8–16mm) were used in this study.
- Four patient datasets were retrospectively selected from the publicly available ProKnow database. Planning CT images and associated structure sets were downloaded from the database and used for proton arc treatment planning.
- SPArc plans were generated using each of the three beam models through employing proton spot scanning over a sequence of gantry control points distributed along an arc trajectory, and the plans were optimized by keeping only one energy layer at one control point. To ensure a fair comparison among beam models, the optimization objectives and clinical dose constraints were kept consistent across all plans for a given patient.

Results

1. TPS simulations showed increased spot sizes at the Bragg peak compared with those in air due to multiple Coulomb scattering in water. The in-air spot sizes represent the intrinsic beam characteristics used for TPS commissioning, whereas the in-water spot sizes provide a clinically relevant assessment of beam behavior.

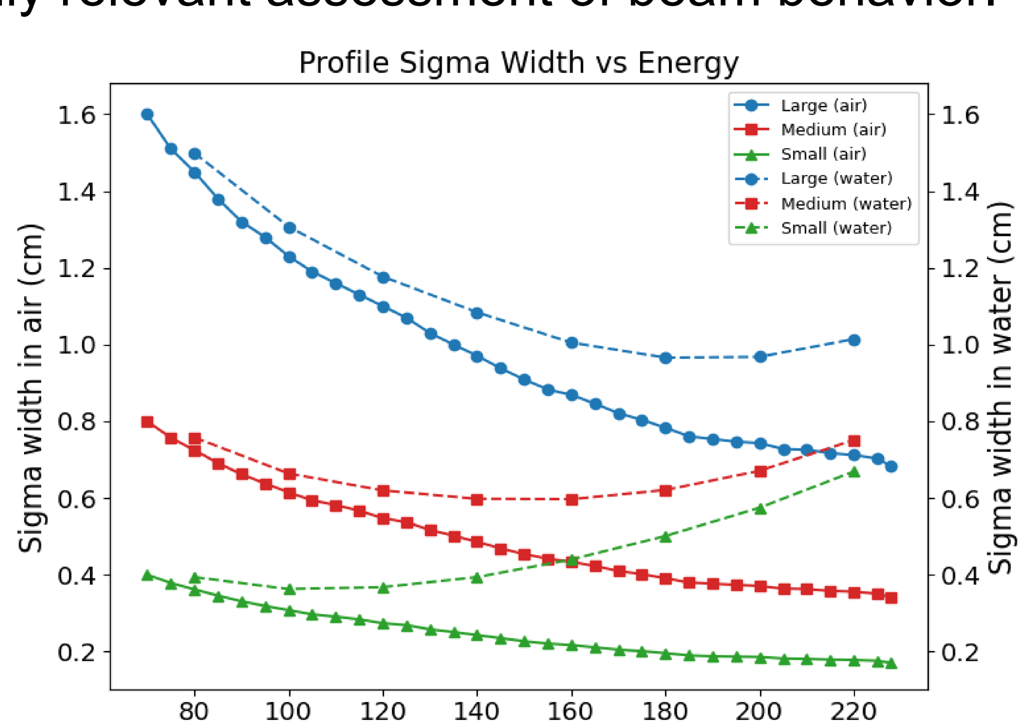

Figure 1 Lateral spot size at Bragg peak changes with beam energy in air and water. Spot sizes in air were obtained from commissioning data, with additional small and large models generated by scaling the measured values by 0.5 and 2.0, respectively.

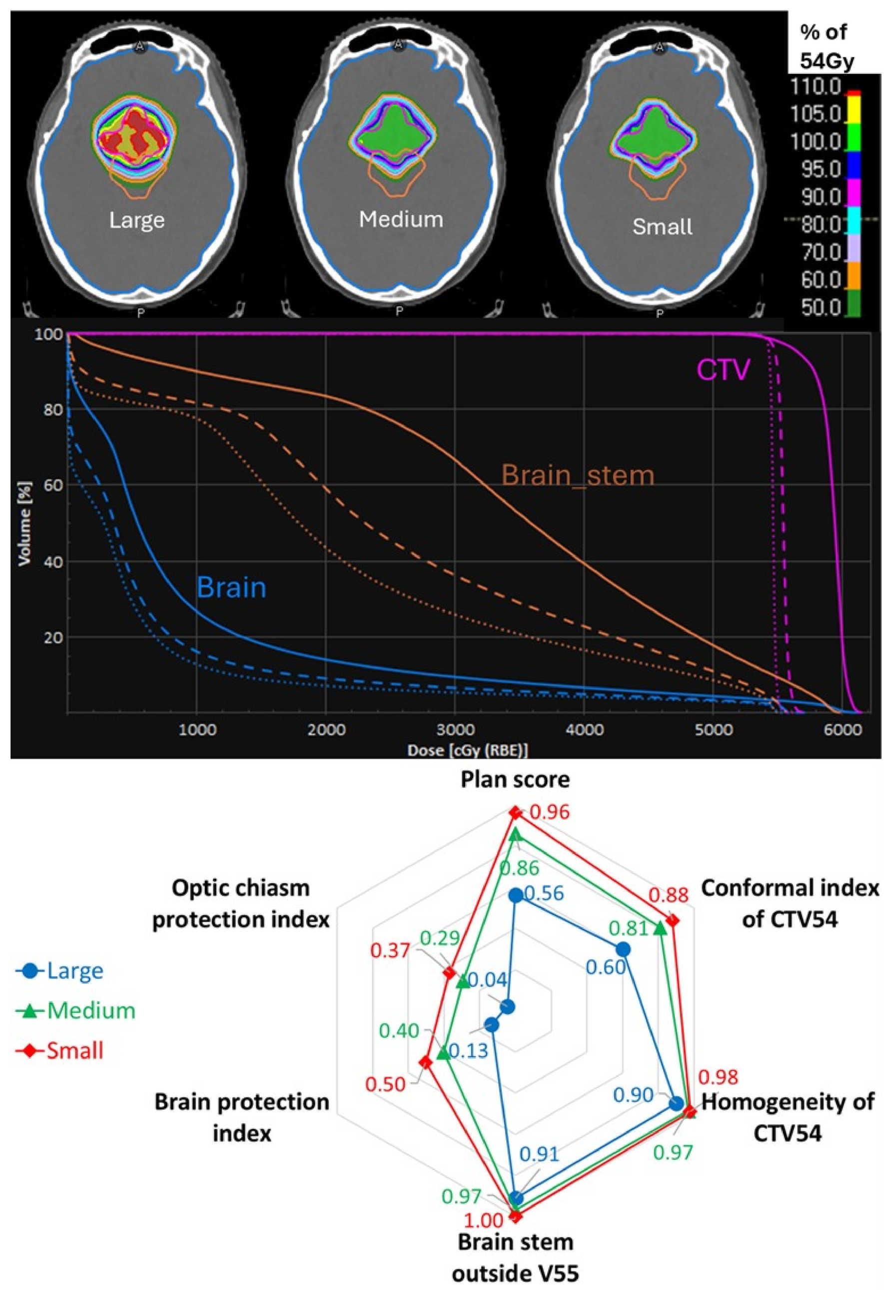

Figure 2 Plan comparison for craniopharyngioma. All plans were scaled to 54Gy covering 99% of CTV. The plan score is normalized by dividing full score 150.

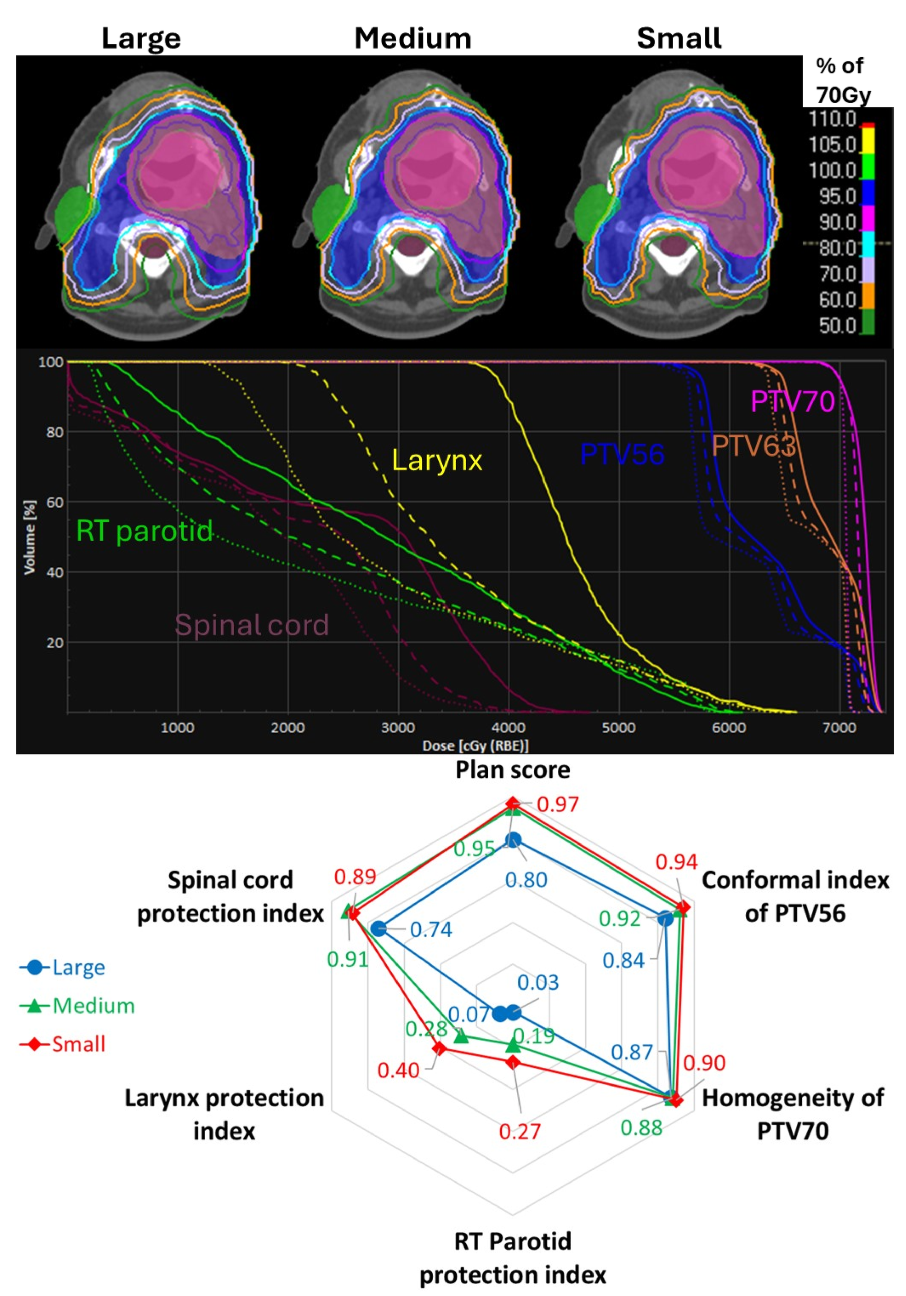

Figure 3 Plan comparison for head and neck. All plans were scaled to 70Gy covering 95% of PTV70.

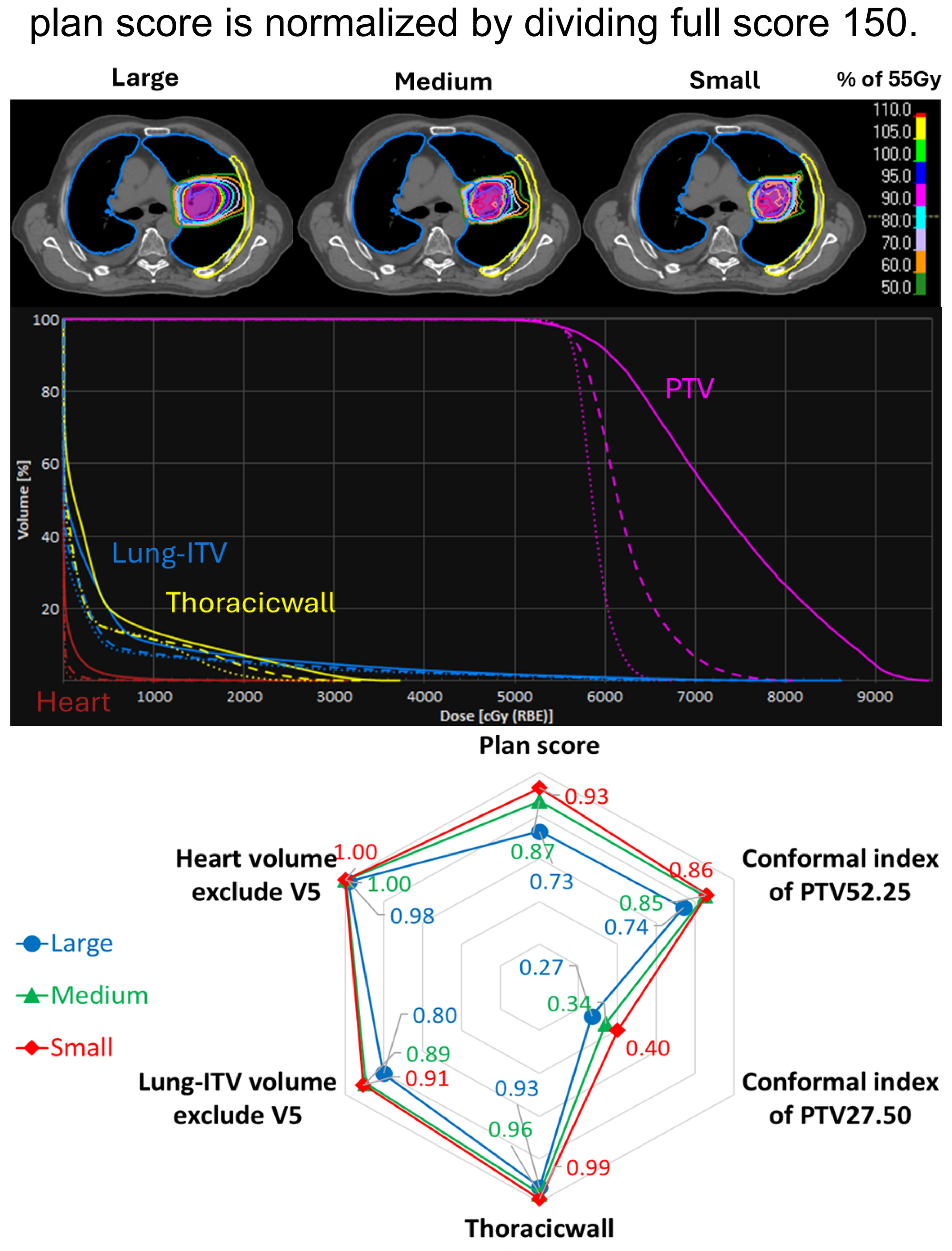

Figure 4 Plan comparison for lung site. All plans were scaled to 52.25Gy covering 98% of PTV.

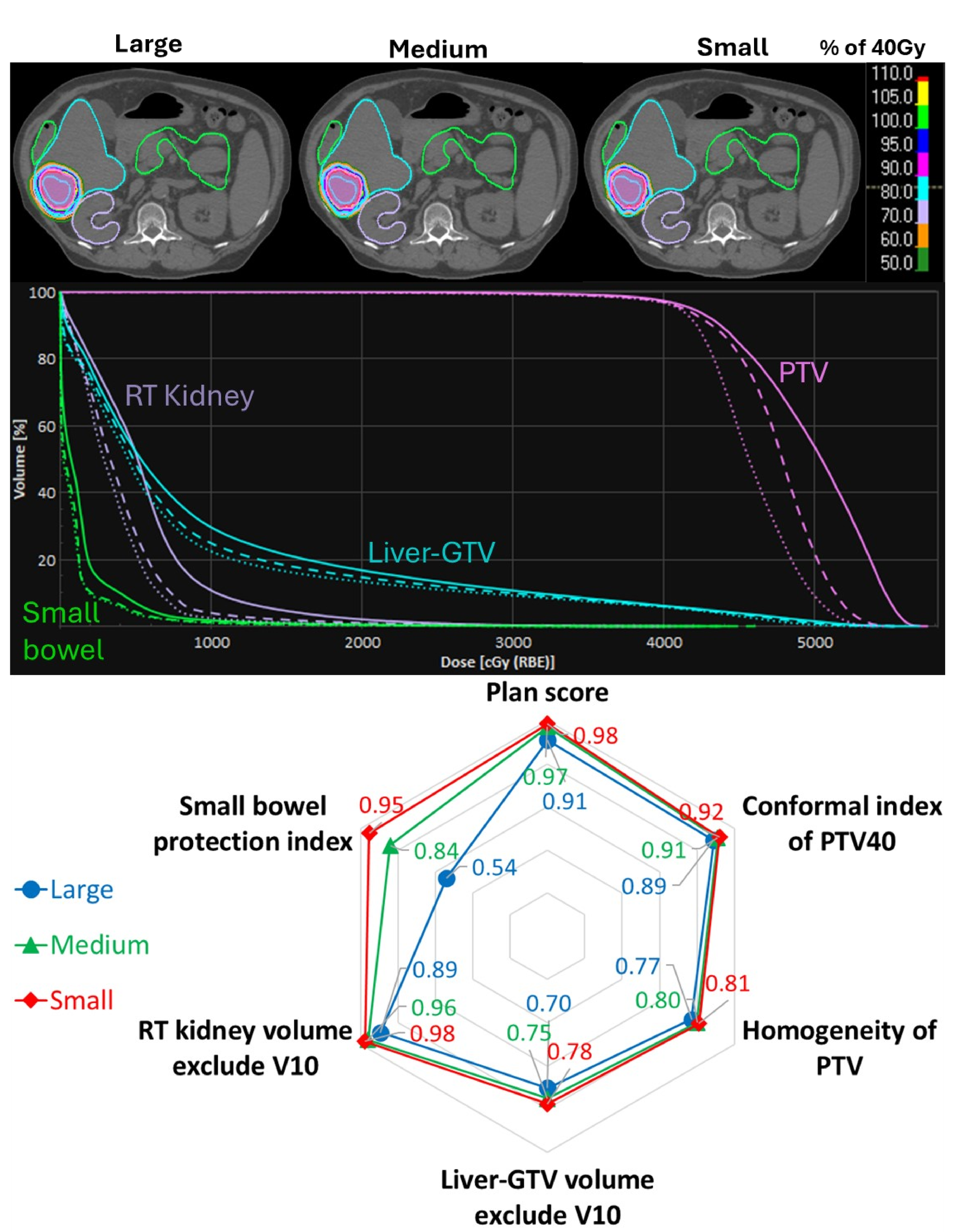

Figure 5 Plan comparison for liver site. All plans were scaled to 40Gy covering 95% of PTV.

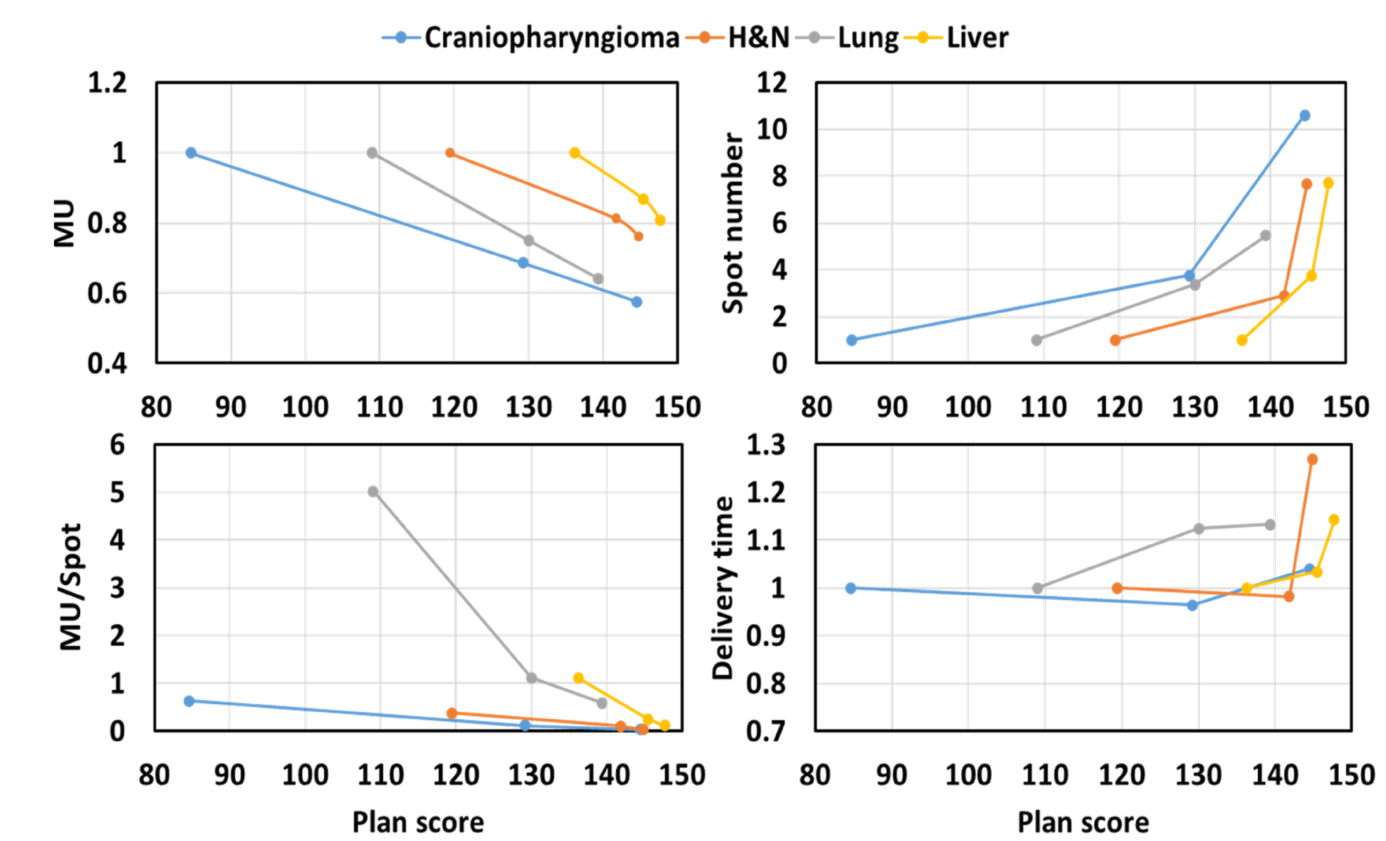

Figure 6 The comparison results of monitor units, total spots, average monitor unit per spot, and estimated delivery time.

Results

2. Across all four sites, the highest plan score were generated with small spot model, reflecting improved target coverage and OAR sparing within the scoring rubric compared to medium and large spot models.

3. Plan complexity varied with the spot size model. The large spot size model consistently yielded the highest total MU and the lowest spot number, while the small spot size model produced the lowest MU and the highest spot number. The greatest difference was observed for the craniopharyngioma case, where the small spot size model reduced total MU by up to 42% and increased the spot number by up to 10.6 times relative to the large spot size model.

4. Despite these differences, delivery times were largely unchanged across spot size models, except for the H&N case, where the substantially higher spot number caused by the large target volume increased delivery time by 27%.

Conclusions

We used three distinct spot-size beam models to quantify how spot-size modeling directly impacts SPArc plan performance using a standardized composite plan-quality scoring rubric rather than isolated DVH metrics. We expect this study to provide guidance on the trade-off between spot size and plan quality for proton arc therapy at existing spot-scanning proton therapy centers and future systems.

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