THE SURFACE AREA EFFECT:
The Dependence of Intermediate Dose Spill on PTV Surface Area

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AIM

The purpose of this **phantom model research** was to **investigate two characteristics of the** Planning Target Volume (**PTV**) that have a marked effect on the intermediate dose spill in cranial Stereotactic Radiosurgery (SRS) as measured by R50%: **Mean Dose deposited within the PTV (D_{av})** and **Surface Area of the PTV (SA_{PTV})**.

INTRODUCTION

SRS refers to the highly conformal delivery of a very high dose, with very high spatial precision, in a single fraction, to a target typically in the cranium. One objective of SRS, regardless of delivery equipment or technique, is to minimize the non-target brain dose. There are many metrics for quantifying the intermediate dose spill and thus, the non-target brain dose; we use R50%.

$$R50\% = \frac{\text{IDC50\% Volume}}{\text{PTV Volume}} \quad \text{where IDC50\% = 50\% IsoDose Cloud}$$

R50% is a common metric in lung SBRT but is less commonly used in SRS. Yet, R50% conveniently scales with the prescription dose, and since all isodose lines are concentric nested shells, R50% is a reasonable surrogate for any intermediate isodose level. PTV Volume is abbreviated as V_{PTV}.

METHOD

A 3D Phantom model was obtained from a high-resolution CT scan (1.25 mm slices) of the IROC SRS Head Phantom®. Planning was conducted using the Eclipse® Treatment Planning system. Final doses were calculated using the AAA algorithm (v15.6) on a 1 mm calculation grid. A prescription (Rx) dose of 18 Gy delivered in a single fraction was used in all cases. Four PTV shapes were created as high-resolution structures using standard Eclipse contouring tools and included spheres, ellipsoids, cylinders, and "jacks." A "jack" is a 3D solid composed of three orthogonal ellipsoids sharing a common center. The "jack" has a high surface area to volume ratio and serves as an extreme case. The PTV volumes were centered within the skull. All treatment plans utilized the same beam geometry consisting of 5 non-coplanar hemi-arcs and were planned using VMAT (RapidArc®) delivery using a TrueBeam STx HD MLC. Optimizations utilized the Eclipse PO (v15.6) algorithm. The D99% condition (99% of the PTV receives at least the Rx dose) was used as a constraint on all optimizations. Eclipse NTO was used to limit the dose spill. An additional constraint was used to control the mean PTV dose by starting D_{max} at "unlimited" and then decreasing from 140% to 100% of the Rx dose in increments of 5%.

The following scenarios were considered: **same SA_{PTV}, differing V_{PTV}** for spheres and cylinders (Fig. 1); **same V_{PTV}, differing SA_{PTV}** also for spheres and cylinders (Fig. 2); and **all PTV shapes/sizes and their dependence on SA_{PTV}** (Fig. 3) **and V_{PTV}** (Fig. 4).

RESULTS

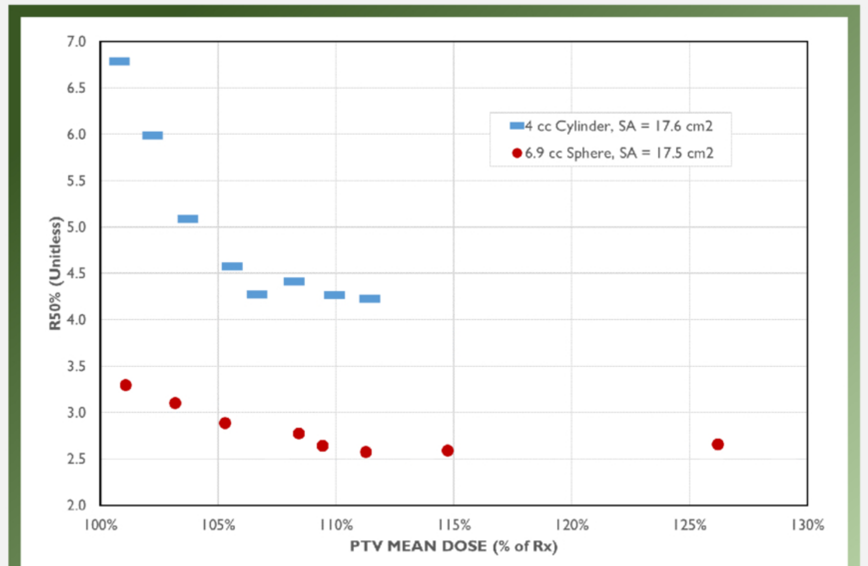

Fig. 1. **R50% vs PTV Mean Dose (Same SA_{PTV}, Differing V_{PTV}).** For the same surface area, the smaller V_{PTV} has the larger R50%. As the dose becomes more homogeneous (D_{av} approaches D_{Rx}), R50% increases. For D_{av} > 110% D_{Rx}, R50% again increases. There is a "sweet spot" at D_{av} ≈ 110%, which is more pronounced for larger volume tumors.[1]

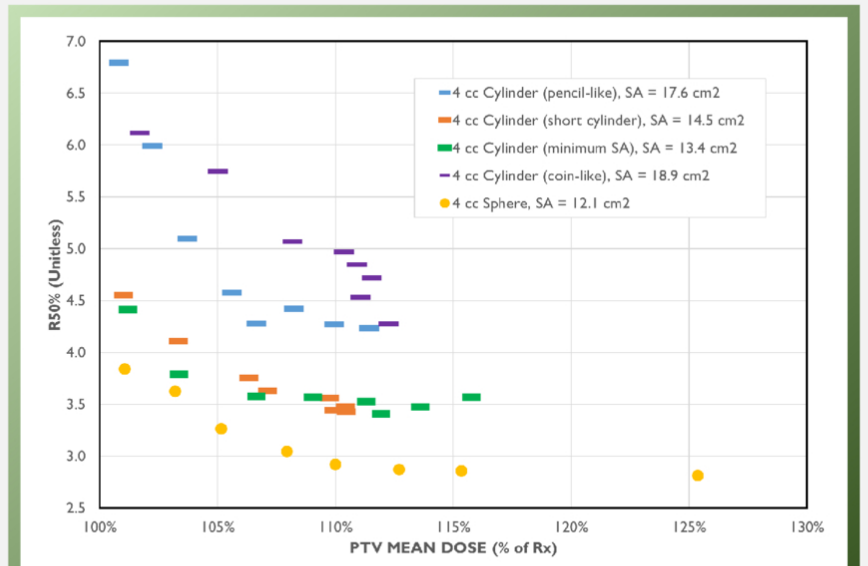

Fig. 2. **R50% vs PTV Mean Dose (Same V_{PTV}, Differing SA_{PTV}).** For the same volume, the larger SA_{PTV} has the larger R50%. The sphere is always the smallest SA_{PTV} for any given volume and always has the smallest R50%. The cylinders have larger SA_{PTV} and, thus, larger R50%. There is a progression in the cylinders from pencil-like to coin-like.

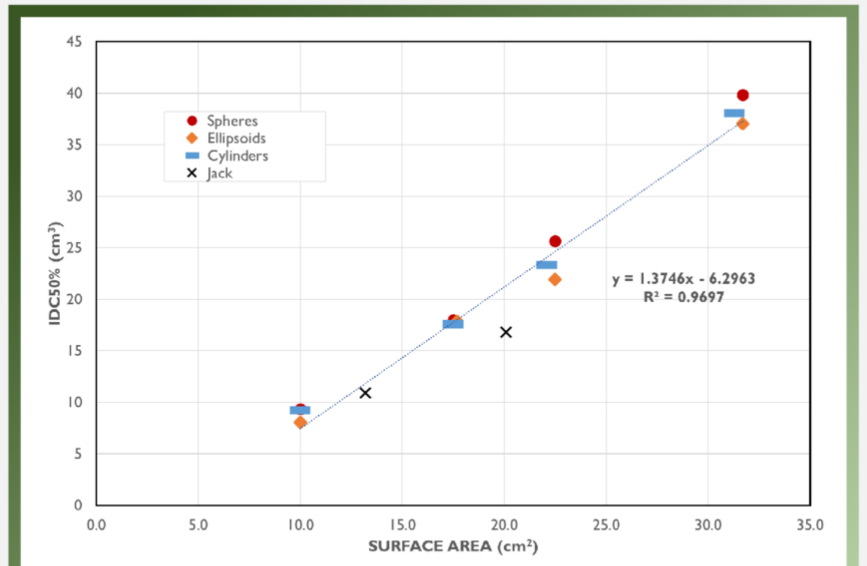

Fig. 3. **IDC50% vs PTV Surface Area, 4 PTV Shapes.** IDC50% is unified function of SA for all PTVs regardless of shape. The spheres, ellipsoids, cylinders, and jacks all fall on one unified line with a very high correlation.

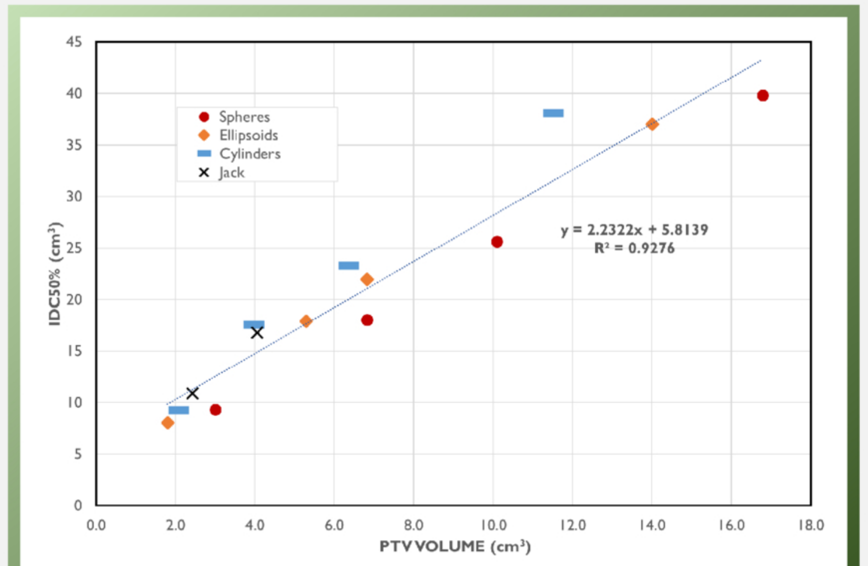

Fig. 4. **ICD50% vs PTV Volume, 4 PTV Shapes.** IDC50% is a less robust linear function of V_{PTV} than SA_{PTV} (Fig. 3). The spheres are a different line than the curve of cylinders, and the jacks may be another line all together.

CONCLUSIONS

PTV D_{av} Effect: The mean dose in the PTV has a clear effect on the R50%. As the D_{av} approaches the D_{Rx} (with D99% Rx), the R50% increases (Fig. 1). A minor increase in R50% is also seen when D_{av} is higher than 110% D_{Rx}. This dose "sweet spot" is more pronounced in larger PTVs studied in lung phantom.[1]

PTV Surface Area Effect: For the same volume, the higher the SA_{PTV}, the higher the R50% (Fig. 2). For the cylinders, there is a progression in cylinder aspect ratio that goes from a pencil-like shape to a coin-like shape (both high SA objects with high R50%) through a minimum SA cylinder. The minimum SA cylinder (diameter = height) is closest to the sphere, which is always the smallest SA object for any given volume. Surface area was hypothesized to be a factor in R50% by other authors;[2] Fig. 2 clearly demonstrates this.

IDC50% is a very strongly linear function of SA_{PTV} (Fig. 3): In addition, the correlation of IDC50% is stronger to SA_{PTV} than to V_{PTV} (Fig. 4). Thus, by extension, **R50% is highly dependant on SA_{PTV}** (of course, R50% is dependant on V_{PTV} by definition).

All these concepts are explored in depth in recently published work.[1]

REFERENCES

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2. Goldbaum D, Hurley J, Hamilton R. A simple knowledge-based tool for stereotactic radiosurgery pre-planning. J Appl Clin Med Phys. 2019;20(12):97-108. doi:10.1002/acm2.12770.

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