Analysis of results from an anthropomorphic stereotactic radiosurgery phantom

Carrie F. Amador, Andrea Molineu, Susan A. Smith, Nadia Hernandez, David Followill and Marilyn Stovall

Department of Radiation Physics

The University of Texas, M.D. Anderson Cancer Center, Houston, Texas

Introduction:

This study analyzed 634 irradiations of the stereotactic radiosurgery (SRS) anthropomorphic phantom from a population of 321 institutions. These results are a combination of irradiations from institutions that irradiated the phantom for their own quality assurance (QA) through the Radiation Dosimetry Services (RDS) and for NCI funded clinical trials through the Radiological Physics Center (RPC). Many institutions have used and continue to use this phantom regularly (at least annually) to ensure delivery quality.

Methods and Materials:

The anthropomorphic SRS head phantom consists of a water-fillable head shaped plastic shell that has been altered to accept imaging and dosimetry inserts. This phantom works with fixed and re-locatable localization systems, with CT and MRI imaging, and with linac and Gamma Knife treatment machines. The water-fillable imaging insert houses a 1.9 cm diameter nylon sphere as the target. The dosimetry insert houses two TLD capsules and radiochromic film in coronal and sagittal planes, corresponding to planes through the center of the target. The dosimetric precision of the TLD is ±3%, and the spatial precision of the film and densitometer system is ±1 mm.

Institutions imaged the phantom, developed a treatment plan and irradiated the phantom according to the plan. Institutions were instructed to create treatment plans delivering 30 Gy to the center of the target. The target was covered by an isodose line typically between 50% and 85%. The dose measured by the TLD was compared to the planned dose and the film results were used to determine target coverage. Fastplan, Radionics, BrainLab, MultiPlan and GammaPlan systems were represented in this work.

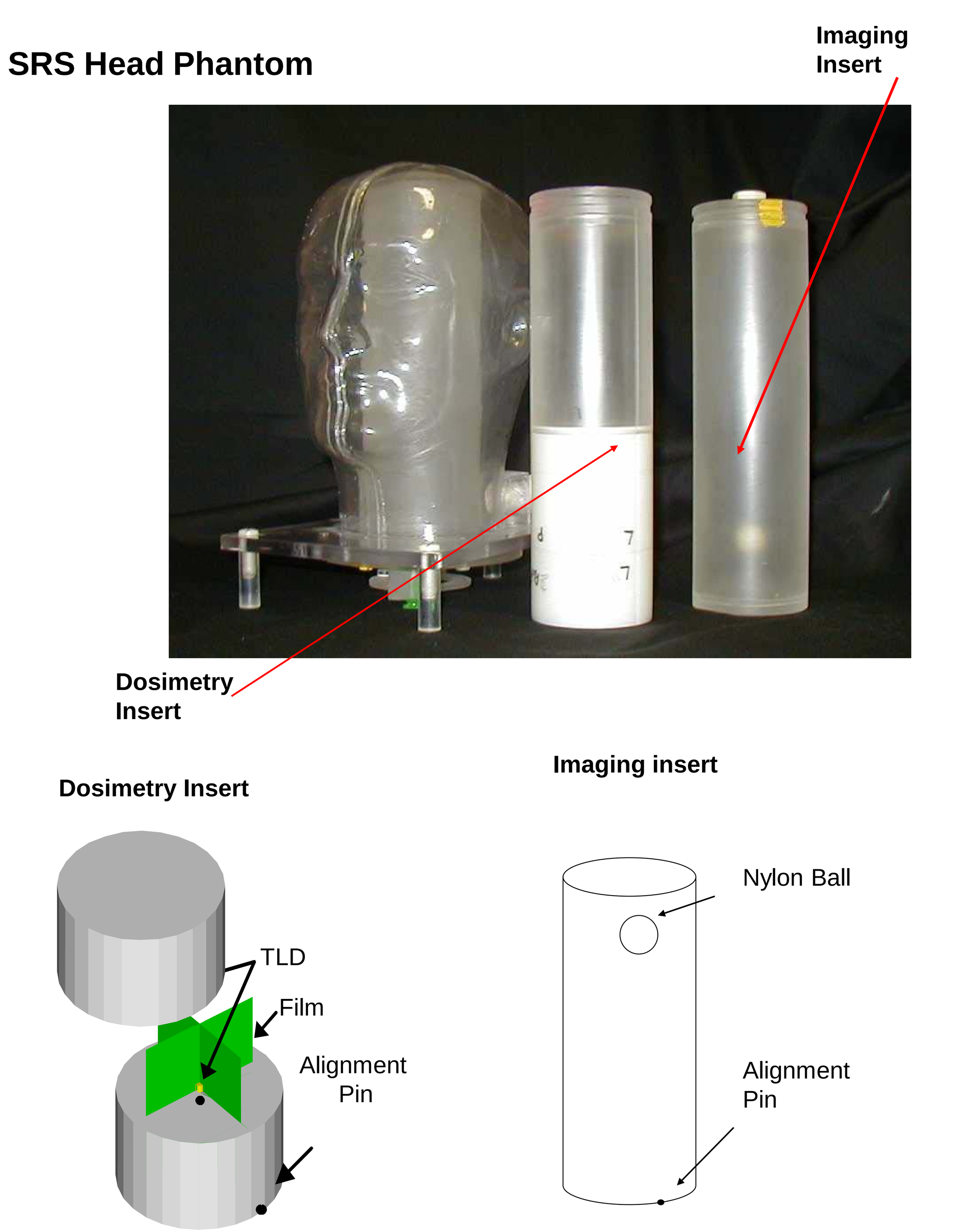

Figure 1. The imaging insert is water-filled and holds the 1.9 cm diameter spherical target. The dosimetry insert contains radiochromic film in coronal and sagittal planes. The film placement corresponds to planes through the center of the target. The dosimetry insert also contains 2 TLD in locations adjacent to the film.

Methods and Materials continued:

The following guidelines are used to analyze the phantom results:

- Dose to the center of the target (Measured/Inst): 1.00 ± 0.05
- Treated volume ratio (Measured/Inst): 0.75 – 1.25
- Minimum dose to target (min.dose/rx dose): ≥0.90
- Treated volume to target volume ratio: 1.00 – 2.00

The dose to the center of the target is reported as a ratio of the TLD dose versus the institution's calculated dose. The treated volume is an ellipsoid with diameters determined from the location of the prescription dose on the orthogonal film profiles. The planned volume is an ellipsoid defined by the dimensions of the prescription line provided by the institution. The treated volume ratio is the ratio of the treated volume to the planned volume. The target volume is a 1.9 cm diameter sphere. The minimum dose covering the target is taken from three orthogonal profiles and compared to the planned prescription line for tumor coverage. The guidelines that were used to analyze these phantoms are adapted from the Radiation Therapy Oncology Group: Radiosurgery Quality Assurance Guidelines published by Shaw *et al*.

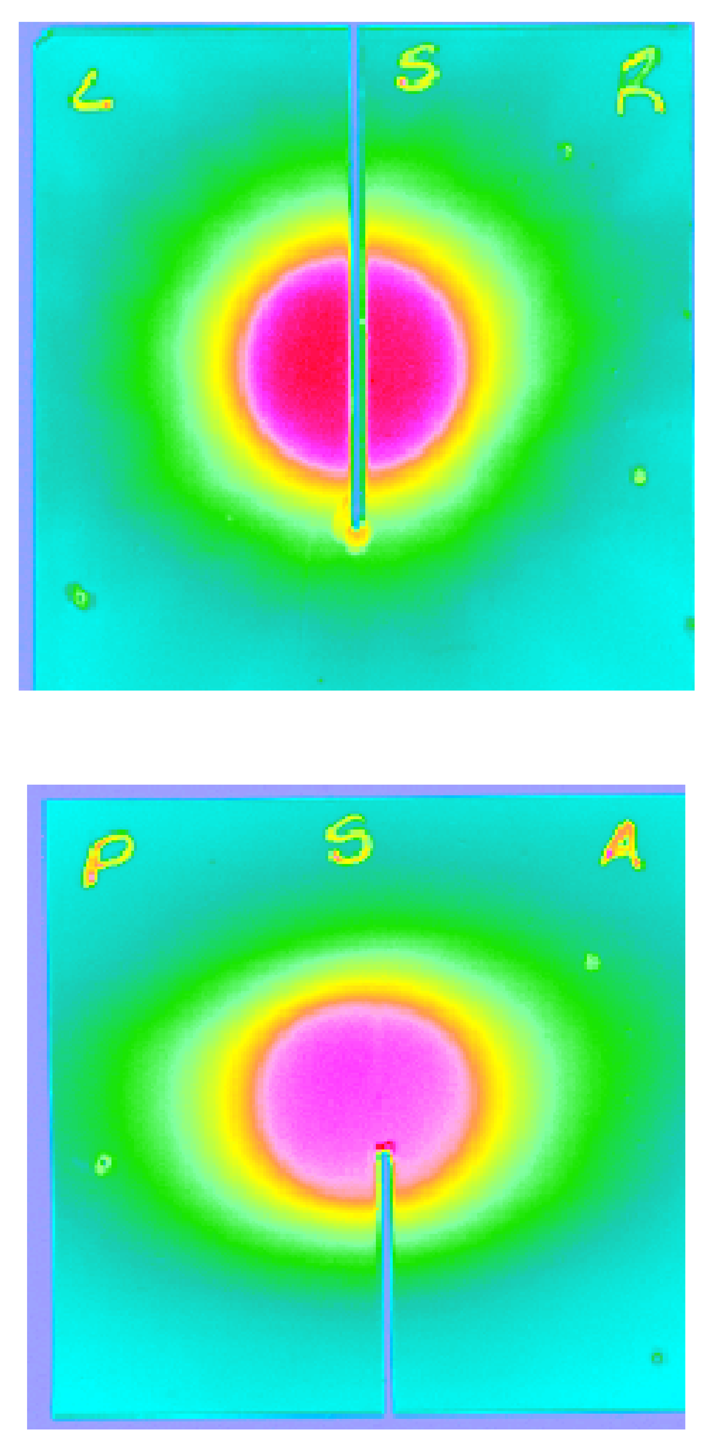

Figure 2. Radiochromic film image from an SRS phantom.

Results:

Between 2000 and December 2010, SRS phantoms were irradiated by 321 institutions for a total of 634 irradiations. 125 of the irradiations were performed with Gamma Knife and 509 were performed with linear accelerators. The percent of institutions meeting all four guidelines was 54% for accelerators and 39% for Gamma Knife units. The minimum dose to the target is the one guideline institutions most often failed to achieve. When that guideline is excluded from the analysis, the percentage of institutions meeting the guidelines increases to 84% for accelerators and 90% for Gamma Knife units. See Tables 1 and 2 for the overall results as well as the linear accelerator results stratified by treatment planning system.

Results continued:

	Average ± std. dev.	Min.	Max.	% that met the guideline
Linac:				
TLD (Measured/Inst)	1.00 ± 0.03	0.69	1.14	93
Treated volume ratio	1.04 ± 0.15	0.45	1.62	90
Min. dose to target	0.97± 0.13	0.11	1.62	80
Measured Treated volume to Target volume	1.56 ± 0.51	0.51	4.96	92
Gamma Knife:				
TLD (Measured/Inst)	0.98 ± 0.03	0.82	1.07	91
Treated volume ratio	1.09 ± 0.11	0.75	1.44	98
Min. dose to target	0.88 ± 0.30	0.15	1.44	49
Measured Treated volume to Target volume	1.71 ± 0.33	0.87	2.51	88

Table 1. Results from linear accelerators and Gamma Knife

TPS	TLD (Measured/ Inst)	Treated volume ratio	Minimum dose to target	Measured Treated volume to Target volume
FastPlan	0.99 ± 0.03	0.98 ± 0.11	0.96 ± 0.13	1.31 ± 0.32
Radionics	0.99 ± 0.02	1.07 ± 0.16	1.01 ± 0.17	1.64 ± 0.54
BrainLab	1.00 ± 0.03	1.05 ± 0.16	0.98 ± 0.13	1.69 ± 0.53
MultiPlan	1.00 ± 0.03	1.01 ± 0.11	0.94 ± 0.11	1.33 ± 0.28

Table 2. Results (average ± std. dev.) from different treatment planning systems used with linear accelerators.

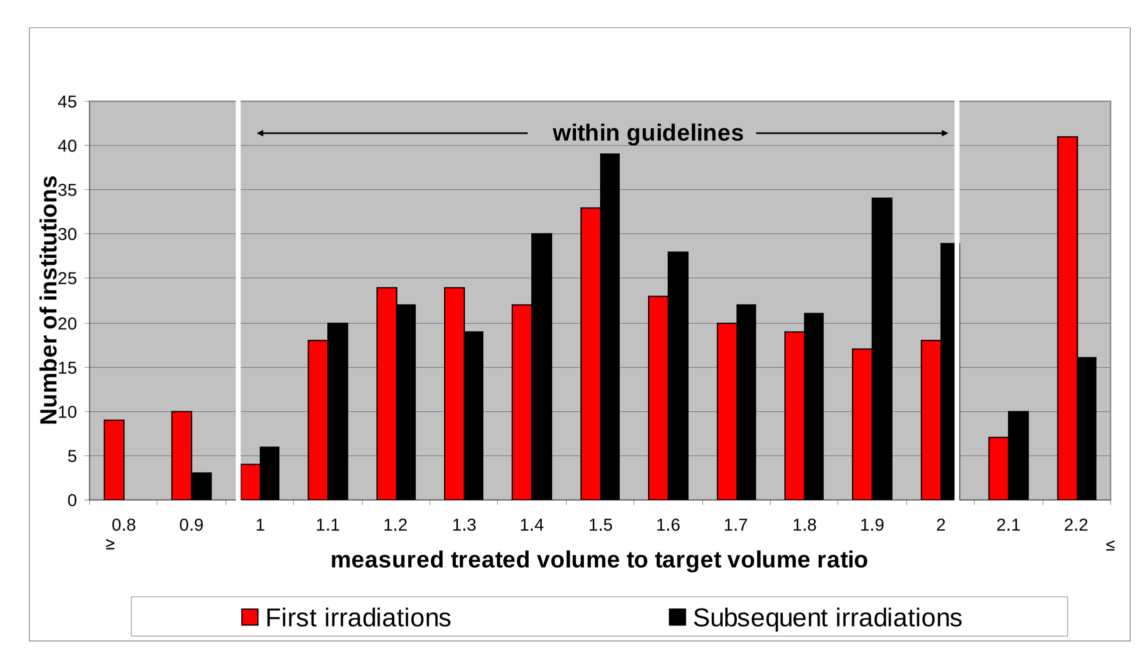

Figure 3: Results of the measured treated volume to target volume ratio.

Figure 3 illustrates the measured treated volume to target volume ratio for the first irradiation at each facility (in red) and the subsequent irradiations (in black). The average pass rate for this guideline increased from 77% to 90%. There was improvement shown for subsequent irradiations for the other three guidelines; however it was less dramatic, with pass rates improving by only four and six percentage points. The white lines indicate which results fall inside the guideline.

Results continued:

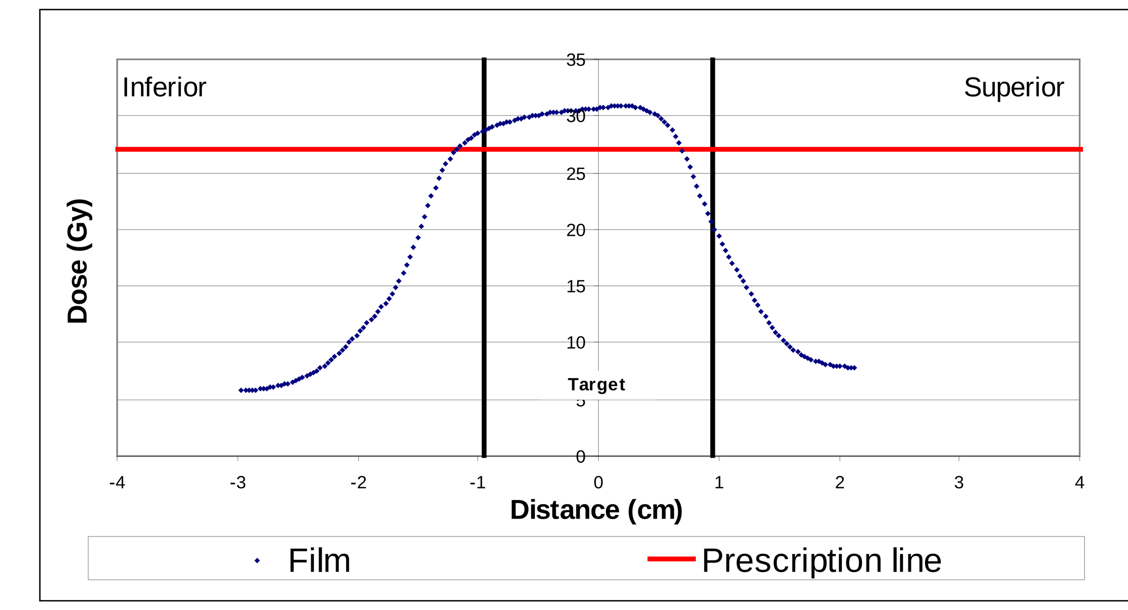

Figure 4. Superior-Inferior of film profile.

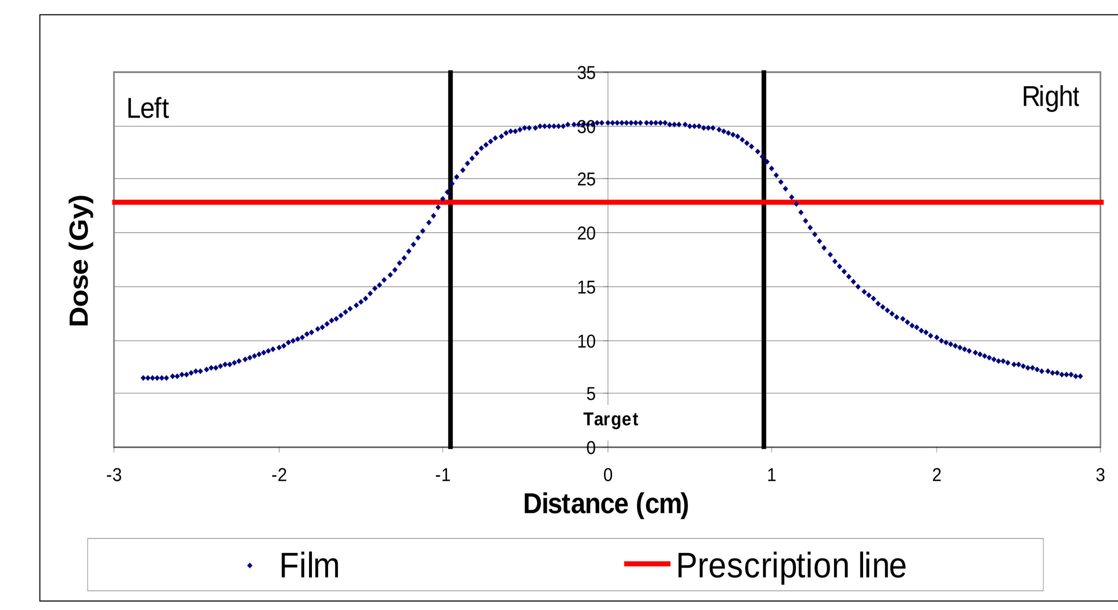

Figure 5. Right-Left of film profile.

Figures 4 and 5 illustrate film profiles taken in the superior-inferior and anterior-posterior respectively for two different phantom irradiations. In both cases the prescription dose is indicated by a red line. Figure 4 illustrates an instance where the institution failed to cover the target with the prescription dose. Figure 5 is a typical example of full target coverage.

Discussion:

The results for both linear accelerators and Gamma Knife units show that both delivery systems have similar results for three of the four evaluation guidelines. However, the minimum dose to the target guideline was achieved less often using Gamma Knife units than with linear accelerators. This difference is likely due to the Gamma Knife's limitation in cone size where the largest available cone is 16 or 18 mm in diameter, depending on model. The cone size is 1-3 mm smaller than the phantom target size. In order to ensure uniform dose to the TLD in the center of the target, institutions were historically asked to irradiate the phantom with only one isocenter. We now have the ability to ask for doses to the actual TLD location so the single isocenter limitation is not always enforced. The SRS linear accelerator systems do not have this limitation.

The four SRS linear accelerator treatment planning systems showed no significant differences in their abilities to meet the guidelines.

Conclusions:

Institutions are capable of meeting the SRS phantom guidelines for all available machines and treatment planning systems studied. For SRS, institutions are able to deliver dose to the central plateau with the same level of uncertainty as conventional external beam treatments. An improvement in the overall irradiation pass rate between first and subsequent irradiations suggests an improvement in SRS treatment delivery as institutions correct discrepancies found during the first irradiation.

Reference:

Shaw, E.; Kline, R.; Gillin, M.; Souhami, L.; Hirschfeld, A.; Dinapoli, R.; Martin, L. Radiation Therapy Oncology Group: Radiosurgery Quality Assurance Guidelines. Int. J. Radiat. Oncol. Biol. Phys. 27:1231-1239; 1993

Support:

The investigation was supported by PHS grants CA10953, CA81647 and CA21661 awarded by the NCI, DHHS.