Introduction

The M.D. Anderson Cancer Center (MDACC) has developed an anthropomorphic head phantom for remote monitoring of stereotactic radiosurgery (SRS) treatments. The phantom contains a 1.9 cm imageable target as well as TLD and radiochromic film. The TLD allow us to estimate dose to the center of the target with an accuracy of ± 3%. The radiochromic film allow us to measure the location of the dose gradients (field edges) within ± 1 mm along three orthogonal axis. This phantom has been provided to the community through the Radiological Physics Center (RPC) and the Radiation Dosimetry Services (RDS) since 1995. The design of the phantom is presented as well as a summary of the data obtained through the last four years of monitoring. The data includes dose to the center of the target, alignment of isodose distributions, and comparisons of radiation treatment area with that determined by the institution's treatment planning system. We have also been able to compile data to compare dosimetry (dose and localization precision) between Gamma-Knife and Linac based stereotactic treatments. We have also collected demographic information on the modalities for localization, planning and delivering SRS treatments in our monitored population.

Materials and Methods

The remote monitoring system, shown in figure 1, consists of a water filled head shaped plastic shell (The Phantom Laboratories, Salem, NY), this shell has been fitted to accept inserts through the neck, these inserts are 7.5 cm diameter cylinders that reproducibly align to a high degree of precision (0.1 mm). One insert, the imaging insert, is used to establish a target in stereotactic space. This insert is water filled with a 1.9 cm (3/4") nylon ball suspended at a know location. This combination of nylon and water allows localization with either CT or MRI. A second insert, the dosimetry insert, locates two TLD capsules and two pieces of radiochromic film at a know location with respect to the location of the target. The film sheets are placed orthogonal to one another in the insert. The films are pierced to indicate position and orientation while in the dosimetry insert. The remote monitoring system is completed by the addition of software that utilizes alignment marks on the film to locate the dose distributions in stereotatic space with respect to the center of the target (figure 2.A, 2.b). This system has been found to work with fixed and relocatable localization systems, with CT and MRI imaging and with Linac and Gamma Knife treatment machines.

Imaging Modality	Treatment Modality	
	Gamma Knife	Linac
CT	1	24
MRI	11	2
Not Specified	1	20

Table 1: Imaging Modality vs. Treatment Modality: We did not explicitly collect this data so we have a large number of unspecified entries in this table.

Figure 1: The SRS Monitoring System: Shown in the figure is the water filled outer shell, the Imaging insert, partially inserted into the outer shell, and on the right, the dosimetry insert, with the top removed to show the radiochromic film used for localization.

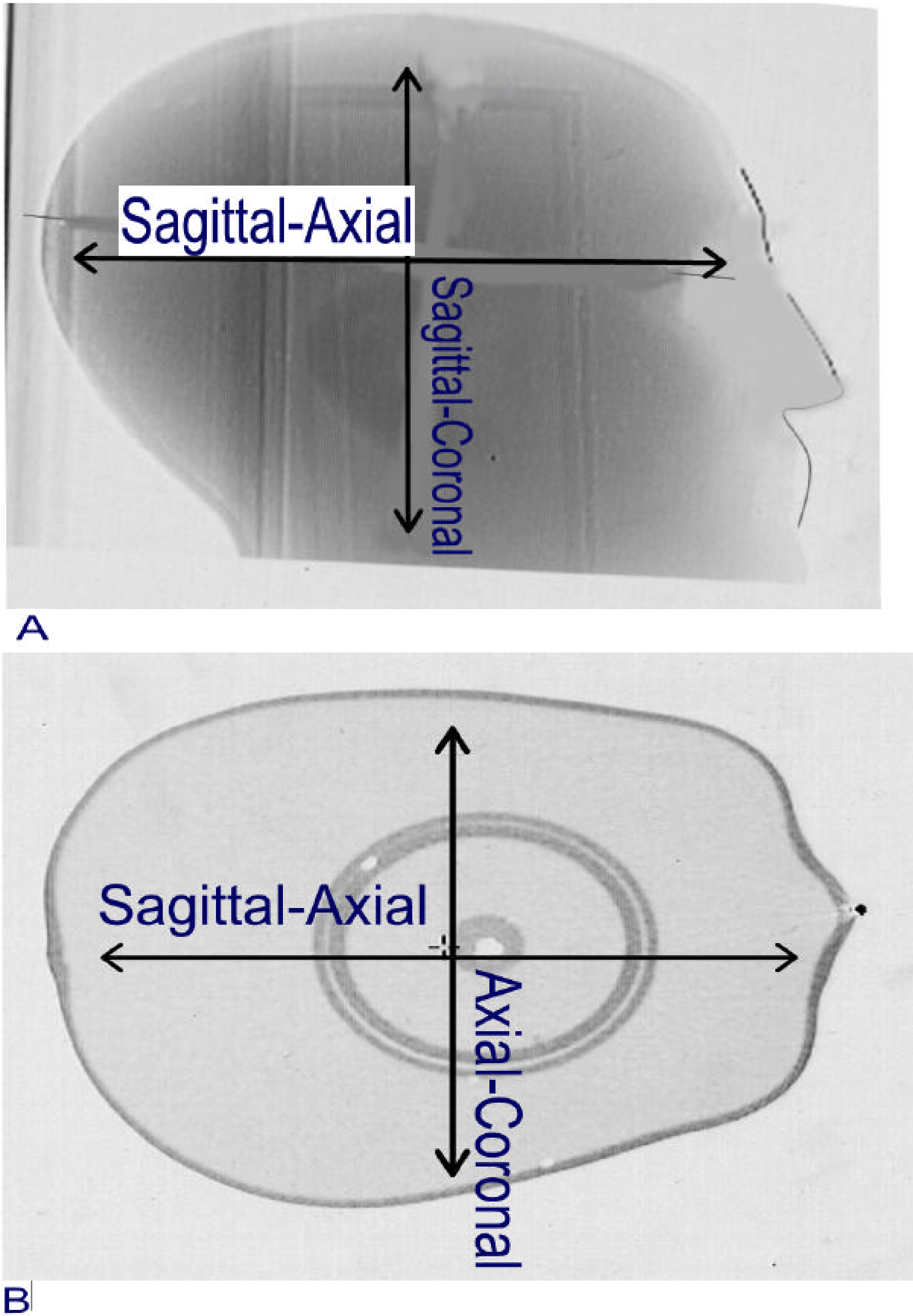
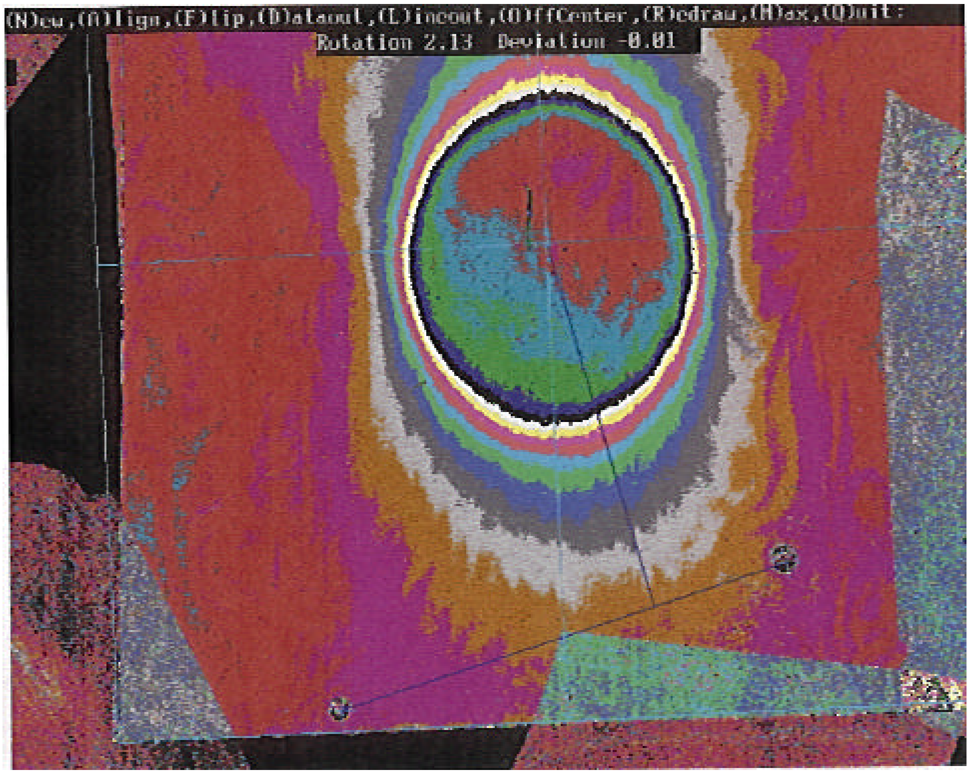


Figure 2.A, 2.B: These are radiographic images of the phantom with the imaging insert in-place, the principle axis of the phantom are labeled and these definitions are used through out this presentation. One of the pieces of photochromic film lies in the plane of figure 2.A, the other lies in the Coronal plane, which is not shown.



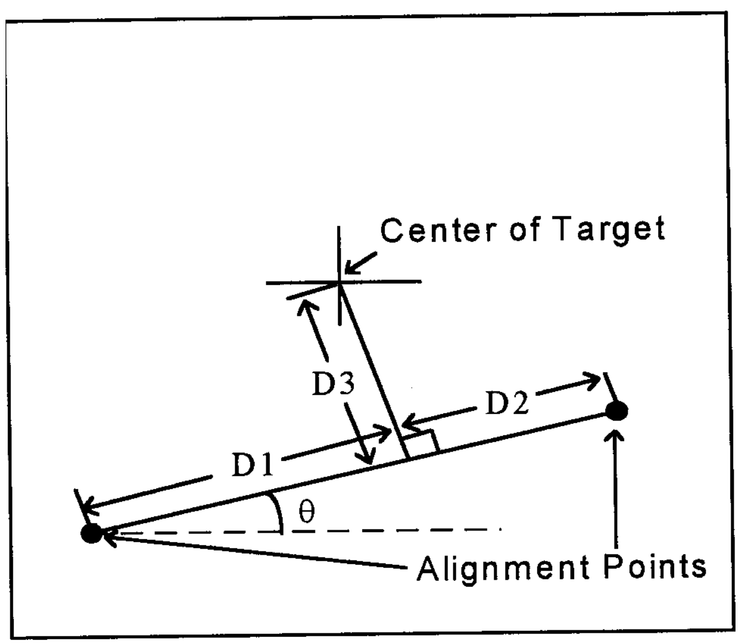


Figure 3.A: SRS Analysis Software: This is screen capture from software used to localize the dose distribution with respect to the target. Figure 3.B: Film Localization System: This demonstrates the system used to translate the two alignment marks on the films to the location of the center of the target in a rotationally invariant manner. The rotation of the film is determined separately based on the slope of the line between the points.

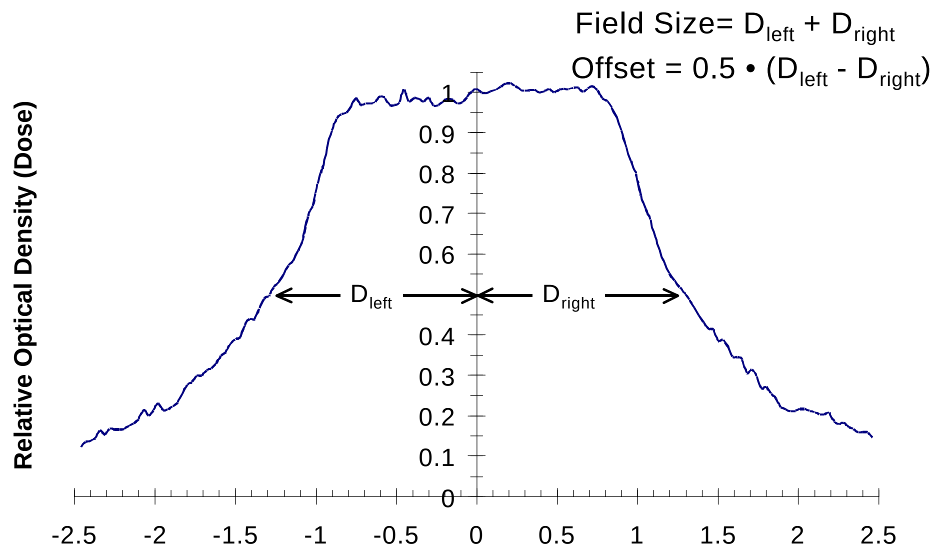


Figure 4: Typical Dose Profile: This demonstrates a dose profile along one of the principle axis of the phantom (see figure 2). The data was extracted from the digitized photochromic film with the software demonstrated in figure 3.A. This figure also presents the definitions used for field size and offset through out this presentation, these values are defined at the prescription isodose line, in this case the 50% isodose line.

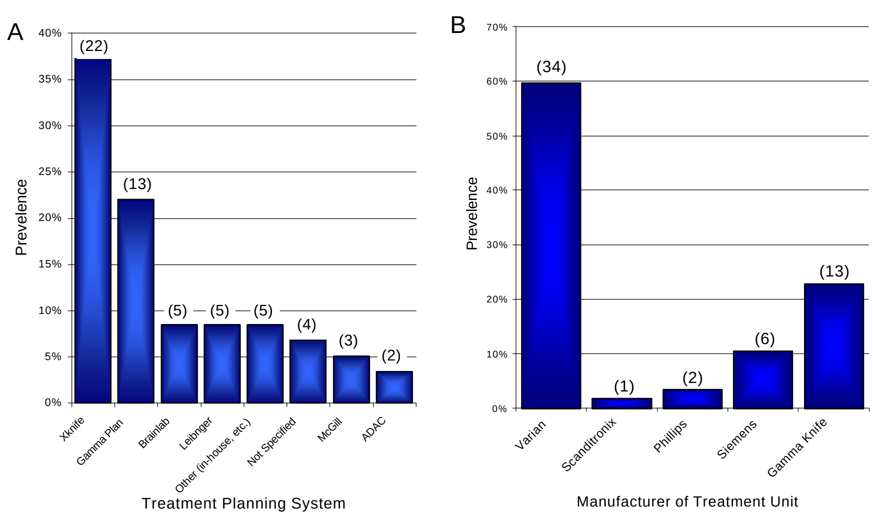


Figure 5.A . Treatment Planning Systems: The distribution of treatment planning systems used to plan the SRS treatments of the phantom (different versions of the same treatment planning system were combined). Figure 5.B: Treatment Units: The distribution of manufactures of treatment units used to irradiated the phantom. It should be noted that this reflects the demographics of accelerators in the United States.

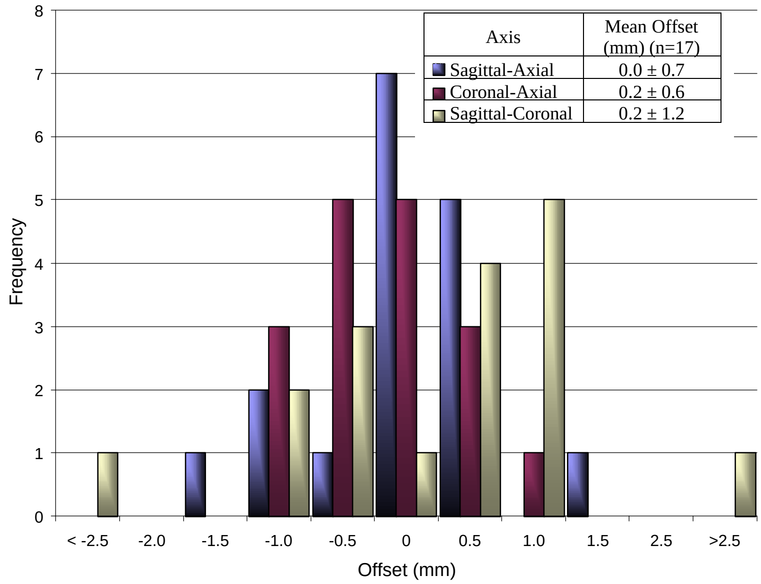


Figure 6: Measured Offsets by Axis for a Single Phantom: To ensure there is no systematic bias in each of our monitoring systems we can look at the magnitudes and directions of measured offsets (figure 4), this verifies our commissioning data. The graph above is for one of our four phantoms and there are no clear systematic alignment problems. It should be noted that the Sagittal-Coronal axis shows far more spread than the other two axes, most likely due to CT slice spacing. The table shows the mean of the measured offsets plus or minus one standard deviation. The values for each axis are consistent with the 0.5 mm accuracy we designed the SRS monitoring system to achieve.

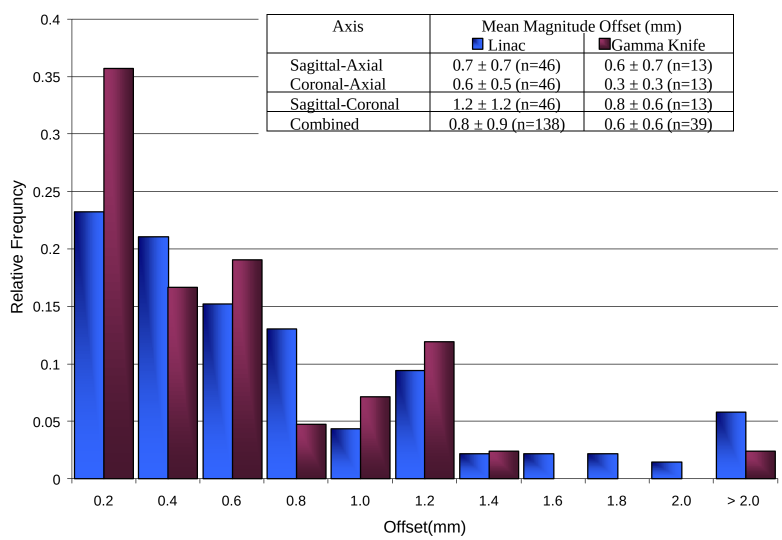


Figure 7: Magnitude of Offset by Treatment Machine (all axes): This is the magnitude of the one-dimensional offset of the center of the prescription isodose line from the center of the target (figure 4). Data from all three principle axes have been combined. This graph has been normalized by the number of data points allowing an easy comparison between linac and Gamma Knife treatments. The table presents the mean values of the magnitude of measured offset for each axis plus or minus one standard deviation. Linac and Gamma Knife data have been combined in the table.

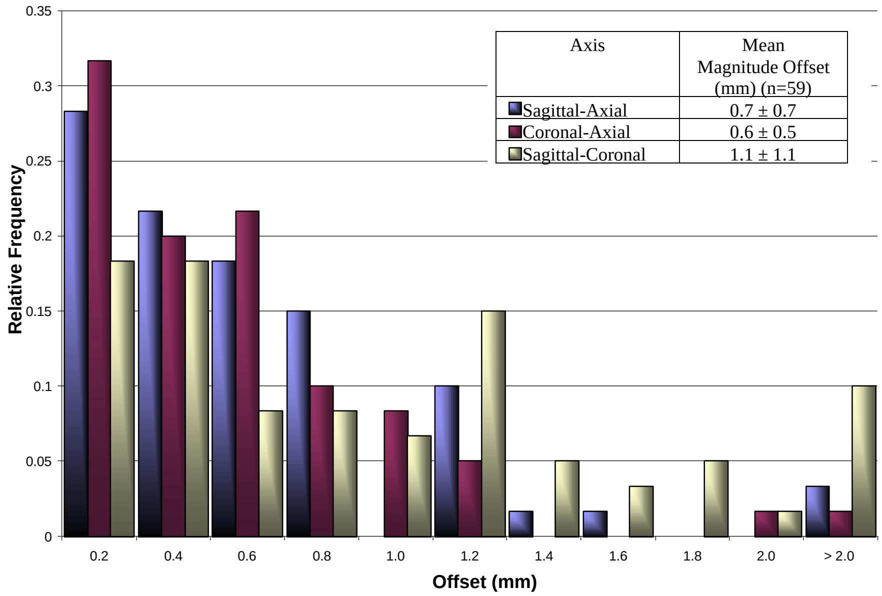


Figure 8: Magnitude of Offset by Axis (all treatment machines): This is the magnitude of the one-dimensional offset (figure 4) of the center of the prescription isodose line from the center of the target. It should be noted that the two axes along the axial plane (in-plane for CT) show better agreement than the sagittal-coronal axis (figure 4). We believe this is primarily due to CT slice spacing. Gamma Knife treatments, which use MRI almost exclusively (table 1), show better agreement on this axis, most likely due to target localization using sagittal cuts. The table shown demonstrates the mean of the magnitude of the offset for each axis by treatment machine plus or minus one standard deviation.

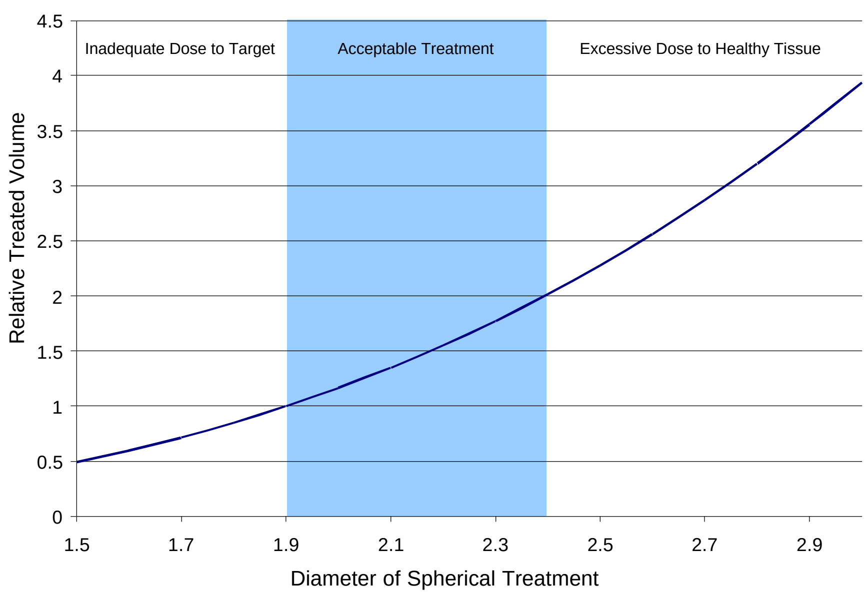


Figure 9: Relative Treated Volume vs. Diameter of a Spherical Treatment: This graph demons trates the relation between volume and diameter of an ideal spherical treatment. The graph has been normalized at 19 mm, the size of the target in the phantom. The graph demonstrates the RTOG Q.A. criterion that allows the irradiated volume to be from 1 to 2 times the size of the tumor volume. It should be noted that a doubling of irradiated volume occurs with the addition of a 2.5 mm margin around a 19 mm target.

Axis	Field Size Along Each Axis (MDACC-Inst) (n=59)	
	Mean (mm)	Mean Magnitude (mm)
Sagittal-Axial	0.1 ±0.9	0.7 ±0.6
Coronal-Axial	0.4 ±0.4	1.0 ±1.0
Sagittal-Coronal	0.2 ±1.3	1.0 ±0.9
All Axis Combined	0.2 ±1.2	0.9 ±0.8

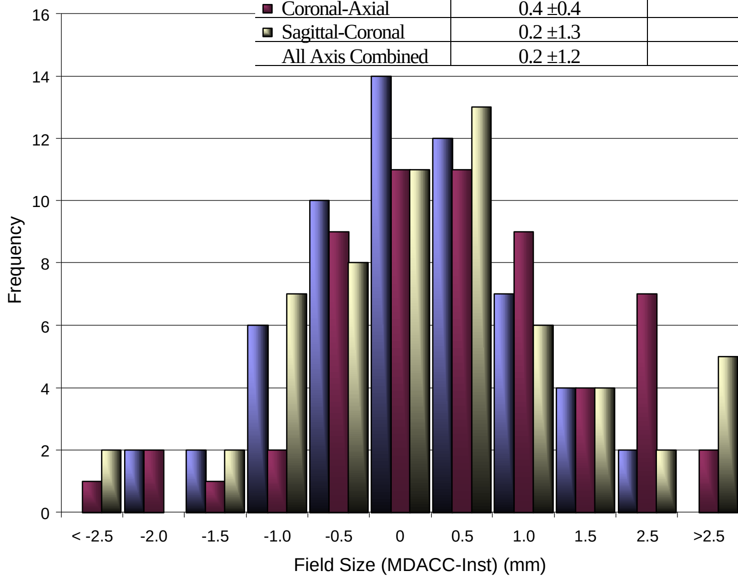


Figure 10: Field Size by Axis: This graph demonstrates the distribution of the discrepancies in field size as measured by the phantom vs. those predicted by the institutions treatment planning computer (figure 4) for all treatments, separated out by axis (figure 2A, 2B). The table presents both the mean value of the measured discrepancies plus or minus one standard deviation and the mean of the magnitude of the discrepancies plus or minus one standard deviation. The mean values are all close to zero demonstrating there is no systematic bias in our measurement system. The mean of the magnitudes and the chart demonstrate that the measured diameters of most treatment volumes are within 1 mm of that determined by the institution's treatment planning computer.

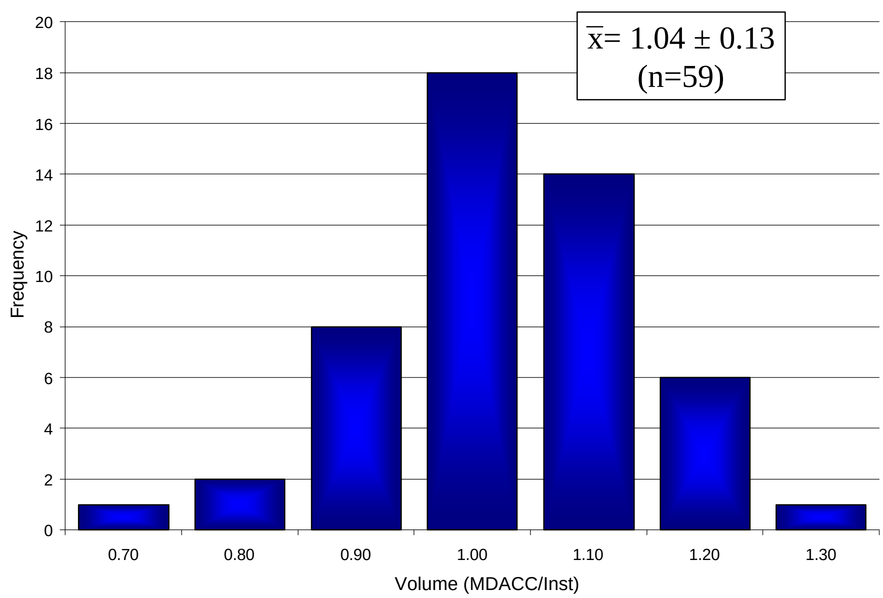
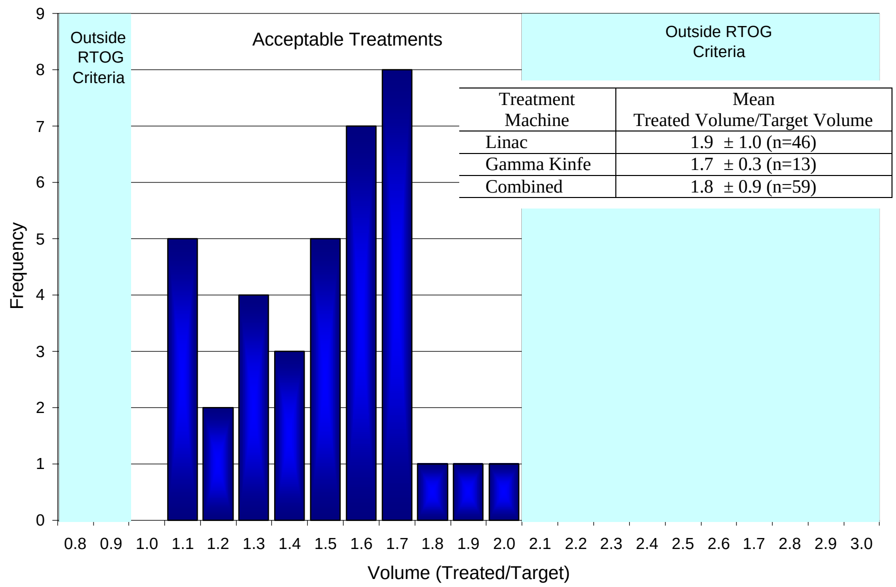
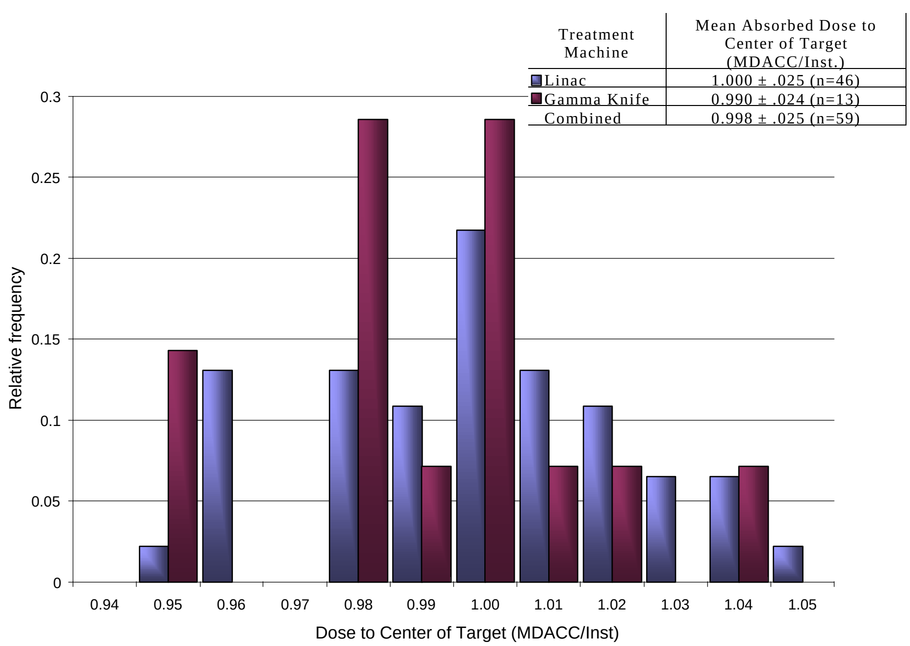


Figure 11: Volume of Target Irradiated. This figure demonstrates the distribution of the measured irradiated volume as compared with that determined by the institution's treatment-planning computer. These data are derived from that presented in figure 9, assuming the dose distribution is an ellipsoid defined by the treatment diameters along each major axis. It should be noted that a 17% discrepancy in irradiated volume only indicates a 1 mm change in the diameter of an irradiated spherical volume (see figure 8). The mean value expressed demonstrates good agreement in measured treatment volume with that determined by the institution. The spread in the mean value (one standard deviation) is consistent with the 1 mm spread demonstrated in figure 9.



Treatment Machine	Mean Treated Volume/Target Volume
Linac	1.9 ± 1.0 (n=46)
Gamma Kinfe	1.7 ± 0.3 (n=13)
Combined	1.8 ± 0.9 (n=59)

Figure 12: Ratio of Treated to Target Volume: The RTOG Q.A. guidelines for SRS allow the treated volume to be from 1 to 2 times the size of the tumor volume. This graph shows the distribution of treatments monitored. The most common volume irradiated was from 1.6 to 1.8 times the size of the treatment volume, this corresponds to a 20 mm linac cone or a 18 mm Gamma Knife collimator. The data beyond the upper boundary of the RTOG criteria for treatment volume result from excessive margins around the tumor those beyond the lower boundary of the criteria are unexplained. The table presented demonstrates the mean of the ratios of measured treatment volumes to the target volume plus or minus one standard deviation.



Treatment Machine	Mean Absorbed Dose to Center of Target (MDACC/Inst.)
Linac	1.000 ± .025 (n=46)
Gamma Knife	0.990 ± .024 (n=13)
Combined	0.998 ± .025 (n=59)

Figure 13: Dose to the Center of the Target. This figure demonstrates the distribution of measured dose at the center of the target with that determined by the institution. The dose is measured with two TLD capsules, each placed slightly off center, within the central dose plateau, so that their average value will reflect the dose to the center of the target. Treatments performed with Gamma Knife's and Linacs have been separated out. There is no statistically significant difference between the two treatment techniques. Gamma Knife treatments show a bimodal distribution of the MDACC/Institution ratio with peaks at 0.98 and 1.00. This could be due to the dose being prescribed at the maximum dose point rather than the center of the target or it could be an artifact of small number statistics. The table presented demonstrates the average value plus or minus one standard deviation

Conclusions

- Institutions are capable of meeting the RTOG Quality Assurance Guidelines for protocols involving stereotactic radiosurgery.
- Institutions are capable of delivering dose to the central plateau with the same level of uncertainty as external beam treatments. (MDACC/Inst =1.00 ± .03)
- Institutions are able to locate the center of the dose distribution at the 1 mm level on all axes.
- Institution know the size of the irradiated volume to within a 1 mm.
- The results from monitoring Gamma Knife and Linac treatments are comparable.

Emphasis for future data collection

- We need to modify our forms and instructions to be consistent with ICRU report #50 volume specification (GTV, CTV, PTV).
- We need to explicitly collect imaging modality as well as slice spacing.