End-to-End Stereotactic QA with the Lucy 3D QA Phantom

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Stereotactic radiosurgery (SRS) demands a high degree of precision. Ensuring your equipment meets these demands requires extremely precise QA equipment, capable of performing all the tests involved in end-to-end stereotactic QA.

The Lucy Phantom meets all of these demands. Specialized inserts and sub-millimeter accuracy ensure that the Lucy Phantom is an ideal fit for testing each link of the stereotactic chain. This versatility allows clinicians to evaluate the entire planning and treatment process with one QA phantom, while using the exact framed or frameless system used during treatment.

This paper highlights how the Lucy Phantom and inserts provide meaningful results for each step in stereotactic QA, including: CT Scan, MRI Scan, Image Fusion, Contouring & Planning, Alignment , and Treatment Delivery. Many of the steps discussed are accompanied by data from a clinical experience with the Lucy Phantom. These data are provided to illustrate why the Lucy Phantom is an integral part of many stereotactic treatment facilities. The tests were conducted by Anil Sethi, PhD, of Loyola University Medical Center.

Before you begin, review the following checklist:

A. When obtaining Dosimetric QA Measurements using:

Ion Chambers

1. Confirm you have the correct Dosimetry Insert (see Fig. 1) for the ion chamber you will be using.
2. Test the ion chamber with the Dosimetry Insert to be certain it fits.

Film

1. Confirm you have film available for the Dosimetry Film Cassette you will be using; four Dosimetry Film Cassettes (see Fig. 2) are available.
2. Confirm film pieces have been cut to the proper size.
3. Decide if a film scanning system or visual inspection will used to relate film density to dose.
4. If using film that needs to be run through an automatic processor, determine how this will be done. Typically, the small piece of film is taped to the end of a large piece of film and then both are run through the processor.

B. When obtaining MRI Imaging QA Measurements:

1. The MRI Signal Generator (see Fig. 3) must be placed in the Lucy 3D QA Phantom when the MRI Marker Cylinders (see Fig. 4) and MRI Volume Insert (see Fig. 5) are imaged.

C. Allocation of time

1. Ensure that adequate time is scheduled on imaging and treatment equipment for completing a Lucy 3D QA Phantom imaging and treatment session. Initially, several hours may be required.

GETTING STARTED

1. Secure the Lucy 3D QA Phantom to the stereotactic frame or frameless system. Level the phantom and ensure it is parallel to the CT or MRI scanning couch. Ensure the axis of the test insert being used is parallel to plane of the CT or MRI slices.

2. Scan the phantom and the patient treatment frame using a series of CT or MRI slices. Ensure a complete series of images is acquired including the entire phantom. Ensure the fiducial markers of the patient treatment frame are visible on scanned images. *Note:* The MRI Volume Chamber (see Fig. 5) may be used for either CT or MRI scans. The CT Volume Chamber (see Fig. 6) *is only used for CT scanning.*

   The CT Marker Cylinders (see Fig. 7) and MRI Marker Cylinders (see Fig. 4) are used to evaluate the fusion function of treatment planning programs. If both CT and MRI scans are obtained, place the CT Marker Cylinders in the Lucy 3D QA Phantom during the CT scanning and the MRI Marker Cylinders in Lucy 3D QA Phantom during the MRI Scanning. *Note: The MRI Signal Generator must be placed in the Lucy 3D QA Phantom when the MRI Marker Cylinders and MRI Volume Insert are imaged. Position the MRI Signal Generator in the center of the scan region.*

   Typical MR scanning parameters for a 3.0T GE scanner include: T1 weighted, TE = 5.1 msec, TR = 11.1 msec, flip angle = 28 degrees, FOV = 370 mm with 512 x 512 reconstruction. Slice thicknesses of 0.75 mm, 1 mm and 2 mm have been used. Typical CT scanning parameters include 200 mA, axial mode, and a slice thickness of 0.625 mm.

3. Record the phantom orientation for any subsequent images that may be obtained, such as, sets of axial, sagittal, and coronal images.

4. Import the CT and/or MRI images into the treatment planning software.

5. Construct a treatment plan using the imported CT and/or MRI images. The plan may be done for one of the volume inserts or for any target created by the user. Ensure the target is outlined and visible on the hard copy of the plan if required. Using your treatment planning software, calculate the volume of the three targets in the volume inserts. Compare the volumes calculated within the treatment planning system to the known target volumes to confirm the correct volumes have been established by the treatment planning software[1]. *Note: Any imaging discrepancy should be noted for further action.*

Clinical Results

When testing the delineation of critical structures , Dr. Sethi used both 2 mm and 0.75 mm slice thicknesses. Though the 2 mm-thick slices require less time to attain, this scanning technique results in greater pronounced volume averaging or partial volume errors. The drastic change in measured volume between Dr. Sethi's 2 mm and 0.75 mm slice images illustrates how taking the extra time to use thinner slices can be imperative for SRS QA.

	Known Volume (cc)	Measured Volume (cc)	Difference in Volume (%)
2 mm Slice	5250	4629	-11.8
0.75 mm Slice	5250	5116	-2.6
			(tolerance = < 3%)

Fusion QA Process

6. If both CT and MRI scans are imported into the treatment planning software, the images can be fused using the tools within the treatment planning software. The accuracy of the fused images can be evaluated to within 0.1 mm by comparing them to the known measurements described in the Lucy 3D QA Phantom specifications.

Clinical Results

Dr. Sethi set a passing tolerance of < 3% volume difference when performing a CT/CT fusion of the 3 shapes within the Lucy CT Volume Insert. For each circle he found -0.8% difference between the calculated vs. measured volume, and -2.6% difference between the calculated v. measured volume of the irregular shape.

	Known Volume (cc)	Measured Volume (cc)	Difference in Volume (%)
Circle 1	890	883	-0.8
Circle 2	890	883	-0.8
Irregular Volume	5250	5116	-2.6

Distance Measurements QA Process

7. Exact manufacturing tolerances allow you to compare the Lucy 3D QA Phantom distance measurements to the distance measurements of images in treatment planning software[2]. Distance measurements should be evaluated at every step of the imaging process as errors may occur whenever images are transferred from one program to another. The steps after which distance accuracy should be evaluated include acquisition of CT and MRI images, after transfer of the CT and MRI images to the treatment planning software, after the fusion and planning steps, and after saving and recalling plans from the record and verify software program. Distance measurements should also be verified in all planes used for treatment planning, transverse, sagittal, and coronal.

   Note: Any discrepancy should be noted for further action.

   To perform distance measurements, first identify the isocenter(s) used in the plan relative to the coordinate system of the frame. Be sure the isocenter(s) are visible on the hardcopy printout of the plan. This hard copy will be used later to compare isocenter(s) and isodose curves to the actual dose measured by film dosimetry. Plans should be done in a transverse slice corresponding to the plane at the center of the target chamber and also in a perpendicular sagittal and/or coronal plane containing one of the isocenters. Mark the isocenter(s) coordinates on the frame plates to enable treatment setup, Step 9. This description is specifically for the case where laser setup to marked points is used. For other techniques the actual setup will be different.

Clinical Results

Using the CT and MRI Marker Cylinders, Dr. Sethi conducted both CT/CT and CT/MRI fusion tests in his TPS. Using < 1 mm as a passable tolerance, Dr. Sethi evaluated the X, Y and Z differences of the five cylinder markers. He found a 0.48 ± 0.07 mm spatial discrepancy for CT/CT and 1.09 ± 0.65 mm spatial discrepancy for CT/MRI.

Dosimetry Measurements QA Set-Up Process

8. Insert the Target/Treatment Verification Film Cassette (see Fig. 8) in the Lucy 3D QA Phantom. The cassette can accept commercially available radiochromic or conventional therapy film; if light-sensitive film is used, test the film cassette to ensure it is light proof. There are sharp markers in the Target/Treatment Verification Film Cassette which produce four impressions forming a square on the film equidistant from the center. The Target/Treatment Verification Film Cassette has a fifth position indicator marker. This fifth orientation marker produces an impression on the film and indicates the orientation of the Lucy 3D QA Phantom within the treatment planning system.

9. Place the Lucy 3D QA Phantom on the treatment couch using the frame and the marked coordinates to identify the treatment isocenters. Visually ensure the orientation of the Lucy 3D QA Phantom is identical with the orientation used during CT and MRI scanning.

10. Alternatively, perform the Winston-Lutz test to verify beam alignment and phantom position prior to treatment. Insert the mid-chamber plug into the Lucy Phantom. Align the phantom to the SRS system crosshairs and acquire images of the phantom using your on-board imaging device. The images can be imported into the PIPSpro image analysis software for analysis of the imaging/radiation ioscenter.

Clinical Results

Dr. Sethi conducted a simple hidden target test with the Lucy Mid-Chamber Plug to determine isocenter. After rotating the Gantry to 0, 90 and 270 degrees, he determined an average X offset of -0.16 mm, Y offset of 0.93 mm and Z offset of -0.65 mm. These corrections ensure the positioning of Lucy Phantom matches your coordinate system and setup.

Dosimetry Measurements Treatment Process

11. Select the prescription dose, which is compatible with the sensitivity of the film, and deliver the prescription dose to the Target/Treatment Verification Film Cassette within the Lucy 3D QA Phantom. Then treat the Lucy 3D QA Phantom with the selected prescription dose.
12. Process and handle the exposed film as needed depending on the type of film being used.
13. Locate the center of the film using the four marks that are on the film located towards each corner of the square. The fifth mark on the film will indicate the orientation of the Lucy 3D QA Phantom.

Planned Dose to Delivered Dose Comparison Process

14. To compare the delivered radiation pattern with the planned dose distribution, the film density pattern must be registered with the planned dose distribution[3]. To compare the planned dose to the delivered dose, an isodose distribution must be produced from the film and overlaid on the treatment plan isodose distribution. (Use the tools available within the treatment planning system to compare the isodose distribution produced on the film to the planned isodose distribution or visually compare the developed film to the printed hard copy of the treatment plan.) *Note: Any discrepancy should be noted for further action.*
15. In a similar manner, the Dosimetry Insert for Ion Chamber may be used to confirm prescribed dose at the exact center of the Lucy 3D QA Phantom. The TLD Dosimetry Cassette and the MOSFET Dosimetry Cassette may also be used for dosimetry tests.

Clinical Results

Using the Dosimetry Insert for Ion Chambers and the 3D Volumetric Target Insert, Dr. Sethi verified that there was less than 2% dose error at isocenter, and the 95% dose distribution line was less than 2mm from its calculated location. By contouring and measuring dose within the same phantom, he was able to closely mimic the actual planning and treatment chain.

References:

1. Ramaseshan, Heydarian, "Comprehensive quality assurance for stereotactic radiosurgery treatments,". Phys. Med. Biol. 48, 2003.
2. Ramani, Ketkeo, O.Brien, Schwartz, "A QA phantom for dynamic stereotactic radiosurgery: Quantitative measurements," Medical Physics, Vol. 22(8), 1995
3. Ramani, Lightstone, Mason, O'Brien, "The use of Radiochromic film in treatment and verification of dynamic radiosurgery. Medical Physics, Vol. 21(3), 1994.
4. Clinical Dosimetry Using MOSFETS. Ramani, Russell, O'Brien. IJROBP, Vol. 7(4), 1997.

LUCY 3D QA PHANTOM

"The Lucy Phantom is a multipurpose phantom for clinical medical physicists. Not only is Lucy a very important tool for Stereotactic Radiosurgery but it is also ideal for CT and MRI QA work."

Raymond Wu, PhD, FAAPM *Chief Medical Physicist St. Joseph Hospital and Medical Center*

"Combined with the A16 chamber, the LUCY Phantom is an exceptional QA device. It is so easy to use with ExacTrac that we use it to perform patient specific QA for every SRS patient treated on our Novalis TX."

Jeff Campbell, MS *Medical Physicist Integris Southwest Medical Center*

Figure 1

Dosimetry Insert for Ion Chamber

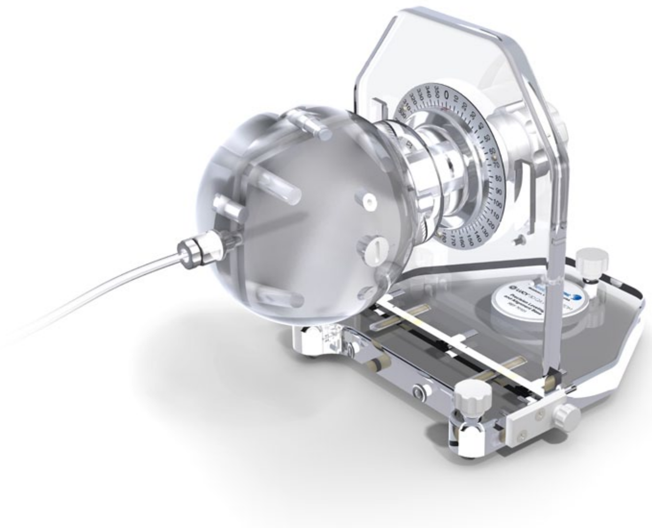

Figure 2

Dosimetry Film Cassettes

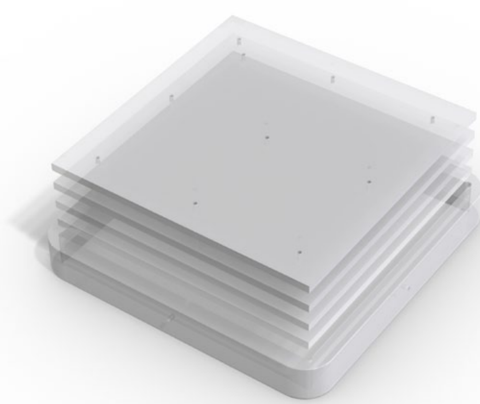

Figure 3
MRI Signal Generator

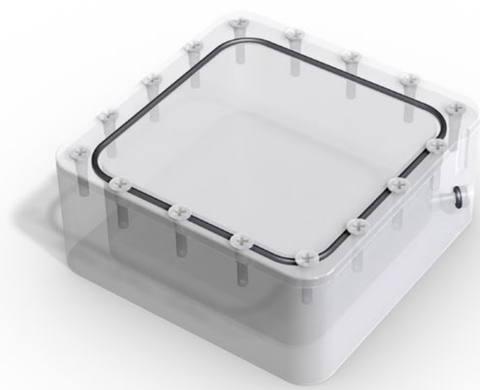

Figure 4
MRI Marker Cylinders

Figure 5
MRI Volume Insert

Figure 6
CT Volume Insert

Figure 7
CT Marker Cylinders

Figure 8
Target/Treatment Verification Film Cassette