End-to-End Radiosurgery tests with Lucy® Phantom

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performed by
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1. Introduction

1.1 Materials

This is a report of a series of tests conducted with the Lucy® phantom, shown in Figure 1, to test end-to-end performance of the SRS process. The Equipment used for the SRS planning and treatment process includes:

- Varian Clinac 600N (Novalis) SN 0790
- BrainLAB iPlan Image v3.0.1
- BrainLAB iPlan Dose v3.0.2
- ExacTrac v3.5
- Siemens Symphony 1.5T MRI
- Philips Brilliance Big Bore CT

Figure 1 Lucy phantom with BrainLAB headframe

1.2 Method

The tests involve every step in the SRS process, including:

- MRI scan
- CT scan
- Target contouring on MRI scan
- MRI/CT image fusion
- Treatment planning
- Localization with either head frame or image guidance
- Dose delivery

Dosimetric analysis was performed by point dose measurement with ion chamber to evaluate absolute dosimetric accuracy. Film dosimetry was used to evaluate the accuracy of the dose distribution as compared to that predicted by the planning system, including localization accuracy. Film dosimetry analysis was performed in each of three orthogonal planes intersecting the center of the target volume.

2. Imaging

2.1 Imaging insert

Imaging was performed with a prototype imaging insert provided by Standard Imaging, Inc. This imaging insert, shown in Figures 2 and 3, includes a centrally-located target volume. Two additional circular volumes were included to enhance the accuracy of image fusion. The three volumes consist of cavities filled with mineral oil that is visible on either CT or MRI.

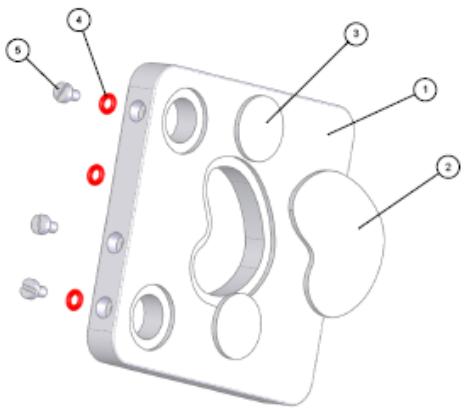

Figure 2 Schematic of prototype imaging insert

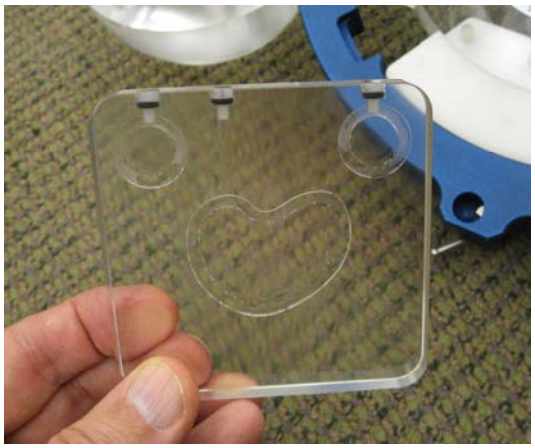

Figure 3 Prototype imaging insert

2.2 MRI

MRI scan was performed on 4/28/08 on a Siemens Symphony 1.5T scanner at Southeast Missouri Hospital. A volumetric T1-weighted scan of the entire phantom was obtained for treatment planning, with 1.2 mm axial cuts and 0.6 mm pixel size.

2.3 CT

CT scans for treatment planning were performed on the Philips Brilliance Big Bore scanner in the Radiation Therapy Department of Southeast Missouri Hospital. The spiral scans with 1 mm spacing were obtained and reconstructed to 2 mm slices with 2 mm spacing. A 512x512 matrix yields a pixel size of 0.7 mm. A scan with head frame localizer was obtained on 4/25/08. For x-ray image localization, scans were obtained that included four CT marker cylinders that each contain five 2 mm aluminum beads (Figure 4). A scan was performed on 4/25/08, with the imaging insert oriented in the transverse plane. On 5/1/08, a scan was obtained with the imaging insert oriented in the sagittal plane.

Figure 4 CT marker cylinders

3. Treatment planning

3.1 Planning system

Treatment planning was performed using BrainLAB iPlan Image 3.0.1 and iPlan Dose 3.0.2.

3.2 Image fusion and contouring

Fusion of CT and MR image data sets was performed using the autofusion function in iPlan Image. Figure 5 illustrates the successful performance of the autofusion function.

Figure 5 Results of autofusion in iPlan Image

3.3 Head frame localizer – Transverse orientation

A treatment plan was developed with four dynamic arcs, illustrated by Figure 6, to produce a conformal dose distribution to the target volume, illustrated by Figure 7.

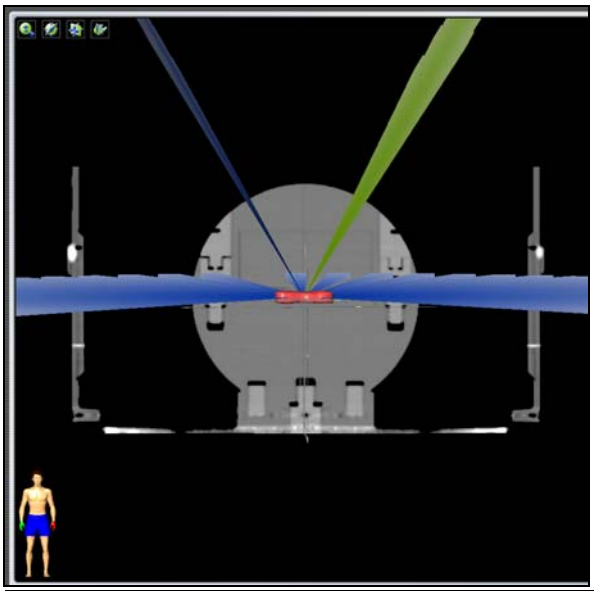

Figure 6 Four Dynamic conformal arcs

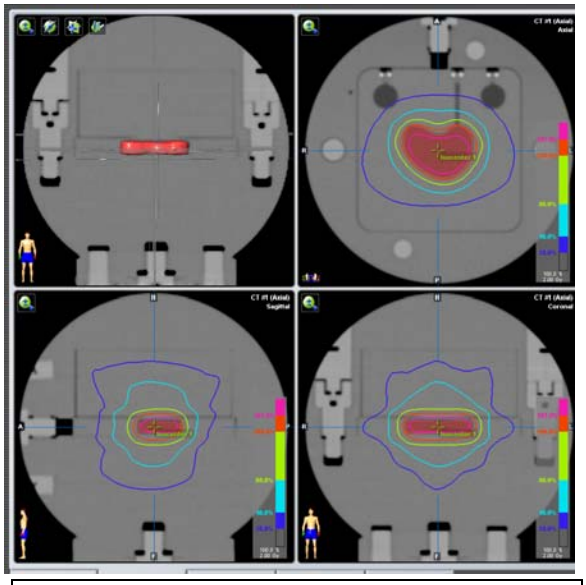

Figure 7 Conformal distribution from four dynamic conformal arcs

The plan parameters are detailed in Figure 8.

BrainLAB	iPlan RT Dose 3.0.2 Build 133244	Southeast Missouri Hospital — Commitment to Excellence. Trusted Care.
Patient Name:	Lucy Transverse 042508	
Patient ID:	000000698	
Treatment Plan:	four dynamic arcs Approved by ssh on 4/29/2008 6:15:28 PM	

Parameters for Physicist

Summary

Isocenters:

Short Name	Stereotactic Coordinates (AP/Lateral/Vertical) [mm]
Isocenter 1	0.1 / 0.8 / -0.1

Objects:

Object Name	Object Type	Volume [cm³]	Ref. Dose [Gy]
Target	PTV	4.63	2.00

Reference Set Specifications

Name	:	CT #1 (Axial)
Scan Date	:	4/25/2008
Number of Slices	:	164
Localizer	:	BrainLAB CT Localizer
Pixel Size	:	0.68 mm
Tissue Inhomogeneity Correction	:	On

Machine : SEMH Novalis

Linac Name	:	BrainLAB Novalis
Linac Convention	:	IEC
Linac Energy	:	6 MV
MLC Name	:	BrainLAB m3 Novalis
Dose Algorithm	:	BrainLAB.PencilBeam.X
Machine Profile	:	SEMH Novalis,6.0 MV XRays,6 MV,4/27/2007 9:35:28 AM
Machine Profile Checksum	:	d574f1d40f8c0a5717ea607b0392ce00
Nominal Linac Output	:	0.852 Gy / 100 MU

Isoc No.	Name	PTV Name	AP (mm)	Lateral (mm)	Vertical (mm)	Isocenter Dose [Gy]	Overall Dose [Gy]
1	Isocenter 1	Target	0.1	0.8	-0.1	2.16	2.16

Dynamic Arcs (Isocenter 1)

Name	Table Angle	Gantry Start	Gantry Stop	Dir. (cw/ccw)	Coll. Angle	X1 (mm)	X2 (mm)	Y1 (mm)	Y2 (mm)	PTV Margin [mm]	Avg. Depth Eqiv. [mm]	Dose to Isoc. [Gy]	MU
Dyn. Arc 1	60	40	150	cw	90	49.0	49.0	49.0	49.0	3.0	72.9	0.66	85 (1x85.0)
Dyn. Arc 2	0	190	320	cw	90	49.0	49.0	49.0	49.0	3.0	69.5	0.43	56 (1x56.0)
Dyn. Arc 3	0	40	180	cw	90	49.0	49.0	49.0	49.0	3.0	70.2	0.43	56 (1x56.0)
Dyn. Arc 4	300	210	320	cw	90	49.0	49.0	49.0	49.0	3.0	72.3	0.65	84 (1x84.0)

Figure 8 Plan parameters for Head Frame localizer plan with four dynamic arcs

3.4 X-ray image localization – Transverse orientation of imaging insert

A treatment plan was developed with four dynamic arcs, illustrated by Figure 6, to produce a conformal dose distribution to the target volume, illustrated by Figure 7. The plan parameters are detailed in Figure 9.

3.5 X-ray image localization – Sagittal orientation of imaging insert

A treatment plan was developed with three dynamic arcs, illustrated in Figure 10, to produce a conformal dose distribution to the target volume, illustrated by Figure 11. The plan parameters are detailed in Figure 12.

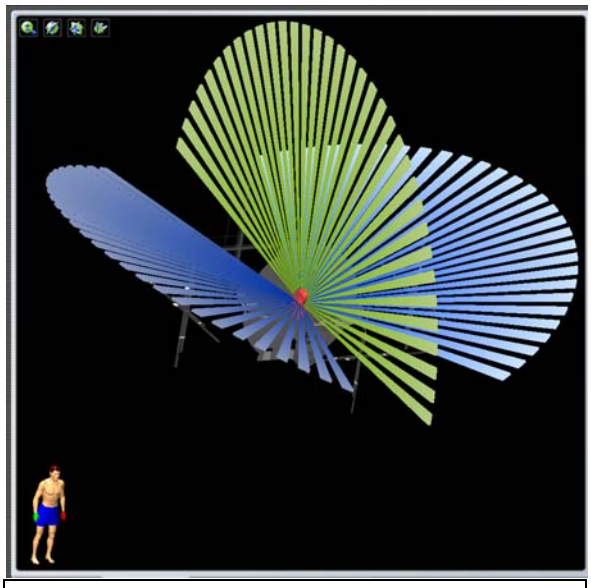

Figure 10 Three dynamic conformal arcs

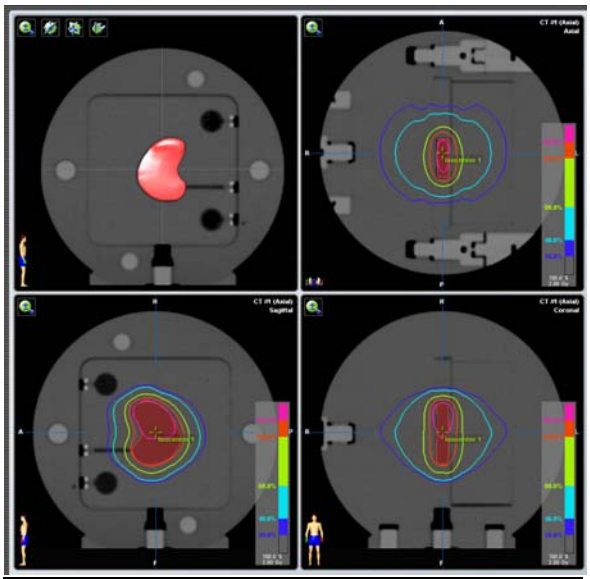

Figure 11 Conformal dose distribution from three dynamic conformal arcs

BrainLAB	iPlan RT Dose 3.0.2 Build 133244	Southeast Missouri Hospital
Patient Name:	TEST	
Patient ID:	LUCY	
Treatment Plan:	**axial, no localizer, 4 dyn arcs** Approved by ssh on 5/1/2008 2:17:09 PM	

Parameters for Physicist

Summary

Isocenters:

Short Name	External Coordinates (X/Y/Z) [mm]
Isocenter 1	0.6 / -66.0 / 108.4

Objects:

Object Name	Object Type	Volume [cm³]	Ref. Dose [Gy]
Target	PTV	5.34	2.00

Reference Set Specifications

Name	:	CT #1 (Axial)
Scan Date	:	4/25/2008
Number of Slices	:	164
Localizer	:	no localizer available
Gantry Tilt (AP)	:	0.00°
Pixel Size	:	0.68 mm
Tissue Inhomogeneity Correction	:	On

Summary

Isocenters:

Short Name	External Coordinates (X/Y/Z) [mm]
Isocenter 1	0.6 / -66.0 / 108.4

Objects:

Object Name	Object Type	Volume [cm³]	Ref. Dose [Gy]
Target	PTV	5.34	2.00

Reference Set Specifications

Name	:	CT #1 (Axial)
Scan Date	:	4/25/2008
Number of Slices	:	164
Localizer	:	no localizer available
Gantry Tilt (AP)	:	0.00°
Pixel Size	:	0.68 mm
Tissue Inhomogeneity Correction	:	On

Figure 9 Plan parameters for no localizer with four dynamic arcs to treat target in transverse orientation

BrainLAB	iPlan RT Dose 3.0.2 Build 133244	Southeast Missouri Hospital
Patient Name:	TEST	
Patient ID:	LUCY	
Treatment Plan:	**sag, no localizer, 3 dyn arcs** Approved by ssh on 5/1/2008 11:02:48 AM	

Parameters for Physicist

Summary

Isocenters:

Short Name	External Coordinates (X/Y/Z) [mm]
Isocenter 1	2.0 / -66.2 / 91.1

Objects:

Object Name	Object Type	Volume [cm³]	Ref. Dose [Gy]
Target	PTV	4.99	2.00

Reference Set Specifications

Name	:	CT #1 (Axial)
Scan Date	:	5/1/2008
Number of Slices	:	150
Localizer	:	no localizer available
Gantry Tilt (AP)	:	0.00°
Pixel Size	:	0.68 mm
Tissue Inhomogeneity Correction	:	On

Linac Name	:	BrainLAB Novalis
Linac Convention	:	IEC
Linac Energy	:	6 MV
MLC Name	:	BrainLAB m3 Novalis
Dose Algorithm	:	BrainLAB.PencilBeam.X
Machine Profile	:	SEMH Novalis,6.0 MV XRays,6 MV,4/27/2007 9:35:28 AM
Machine Profile Checksum	:	d574f1d40f8c0a5717ea607b0392ce00
Nominal Linac Output	:	0.852 Gy / 100 MU

Isoc No.	Name	PTV Name	X (mm)	Y (mm)	Z (mm)	Isocenter Dose [Gy]	Overall Dose [Gy]
1	Isocenter 1	Target	2.0	-66.2	91.1	2.15	2.15

Dynamic Arcs (Isocenter 1)

Name	Table Angle	Gantry Start	Gantry Stop	Dir. (cw/ccw)	Coll. Angle	X1 (mm)	X2 (mm)	Y1 (mm)	Y2 (mm)	PTV Margin [mm]	Avg. Depth Eqiv. [mm]	Dose to Isoc. [Gy]	MU
Dyn. Arc 1	90	0	170	cw	90	49.0	49.0	49.0	49.0	3.0	70.1	0.49	64 (1x64.0)
Dyn. Arc 2	340	200	340	cw	90	49.0	49.0	49.0	49.0	4.0	72.4	0.83	107 (1x107.0)
Dyn. Arc 3	20	20	160	cw	90	49.0	49.0	49.0	49.0	4.0	72.2	0.83	107 (1x107.0)

Figure 12 Plan parameters for no localizer with three dynamic arcs to treat target in sagittal orientation

4. Point Dose Measurement

The dose to the center of the target volume was measured with ion chamber for the plan in Figure 8, as shown in Figure 13, using the ion chamber dosimetry insert shown in Figure 14.

Figure 13 Point dose measurement with ion chamber

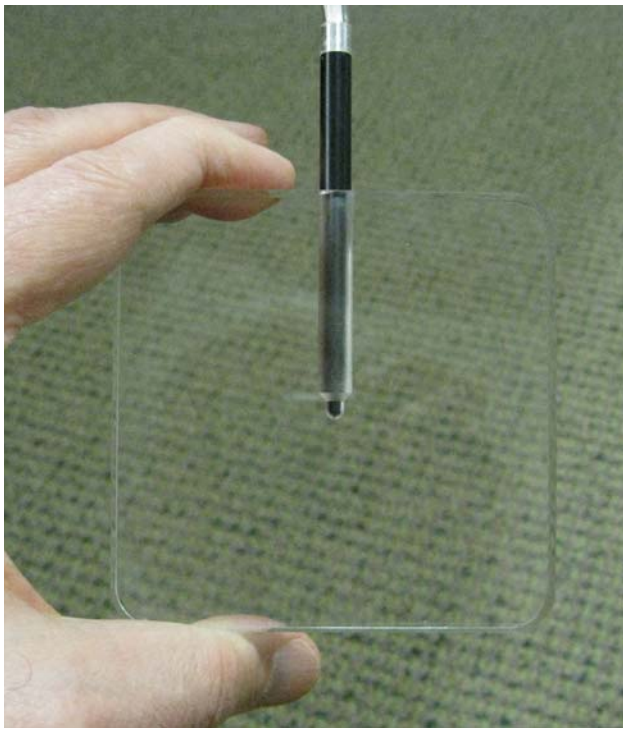

Figure 14 A16 chamber in Lucy dosimetry insert

4.1 Materials and Method

The dose measurement was made with Exradin A16 microchamber, SN XAA041266. The A16 chamber was calibrated by comparison with PTW Farmer-type chamber Model TN30013, SN 0864 on 3/25/08 in solid water. The Farmer chamber was calibrated at the University of Wisconsin ADCL on March 4, 2008. The electrometer used for these measurements, Inovision Model I35040 SN 99409, was calibrated at the University of Wisconsin ADCL on February 29, 2008.

The Lucy phantom is comprised of polymethyl methacrylate (PMM). The A16 calibration factor for measurements in PMM was determined by application of the ratio of mass-energy absorption coefficients for PMM to water. This ratio has a value of 0.970.

The calibration factors for the A16 chamber are given in the table below:

A16 Calibration Factors	
Water	374.9 cGy/nC
PMM	3856.5 cGy/nC

4.2 Results

The dose at the center of the target volume was calculated to be 216 cGy using iPlan Dose. The measured dose using the A16 chamber was 218.9. The difference was 1.3%.

Review of routine QA output checks for the Novalis linac yields a calibrated output of 1.006 cGy/MU. Correction for this calibrated output yields a measured dose discrepancy of 0.7%.

5. Film Dosimetry

Dosimetric evaluation of each treatment plan was performed by film analysis. The Lucy phantom was localized and treated, in the same manner as for patient treatments, with Kodak EDR2 film in a light-tight film cassette within the phantom, as shown in Figure 15. The film cassette includes fiducial alignment pins, shown in Figure 16, that mark the film to allow registration of the measured dose distribution to the calculated distribution.

Figure 15 Film cassette in Lucy phantom

Figure 16 Open film cassette showing fiducial alignment pins

For those treatments with head-frame localization, the film was exposed in each of three orthogonal planes intersecting the center of the phantom. For x-ray image-guided localization, the film was oriented the same as the target imaging insert.

5.1 Film Analysis

For dosimetric analysis, the films were scanned with a Vidar VXR 16 Dosimetry Pro film scanner. The films were analyzed using RIT113 Dosimetry Software, Version 5.0, from Radiological Imaging Technology, Inc.

5.2 Head Frame Localization

For the head-frame localized plan, the phantom was aligned for treatment in the usual manner as shown in Figure 17. The treatment was delivered with an EDR2 film in the film cassette as shown in Figure 18. A film was exposed in each of the transverse, sagittal, and coronal planes through the center of the phantom.

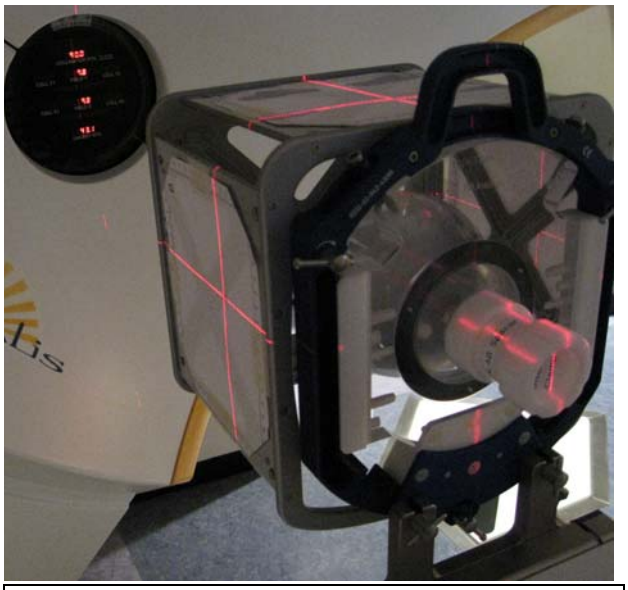

Figure 17 Lucy phantom with Head Frame localization

Figure 18 Treatment delivery with film cassette

5.3 X-ray Image Localization

X-ray image localization was performed using the BrainLAB ExacTrac X-ray system, using the reference star as a positional reference for the stereo infrared cameras. The treatment setup for ExacTrac localization is shown in Figure 19. Figure 20 demonstrates how the fiducial marker cylinders are visualized on the radiograph during treatment setup. Alignment is accomplished by 3D fusion after indicating the location of the markers on each of the pair of radiographs, as shown in Figure 21.

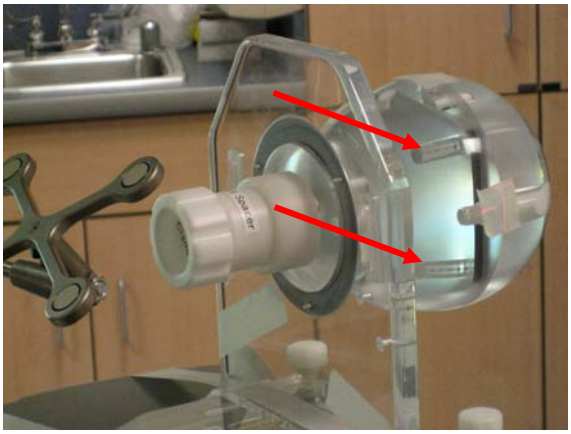

Figure 19 Treatment setup for ExacTrac image-guided localization. Arrows indicate fiducial marker cylinders.

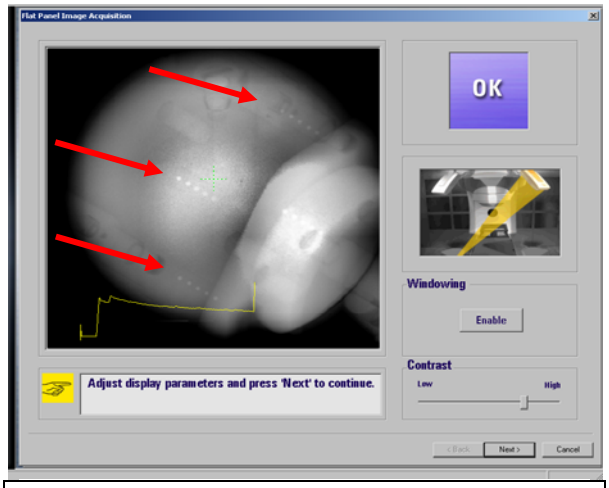

Figure 20 ExacTrac X-ray screen showing visualization of fiducial markers on radiograph, as indicated by arrows.

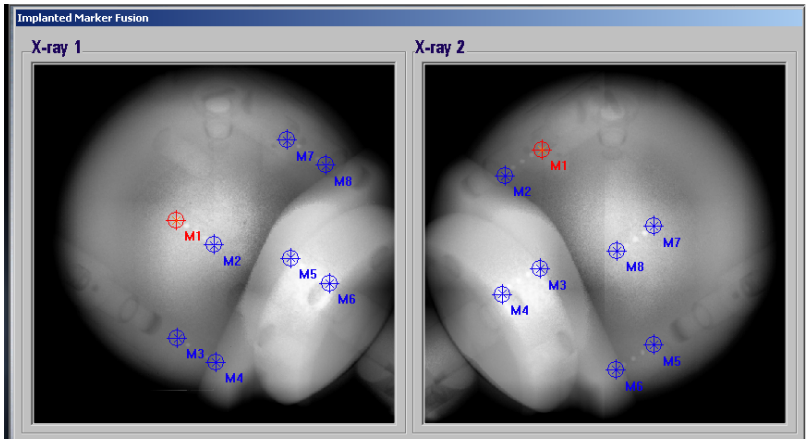

Figure 21 Marker location on stereo x-rays

5.4 Results

5.4.1 Head Frame Localization – Transverse Film Orientation

Figures 22-24 show the results of film analysis for the case of head frame localization with the film oriented in the transverse plane.

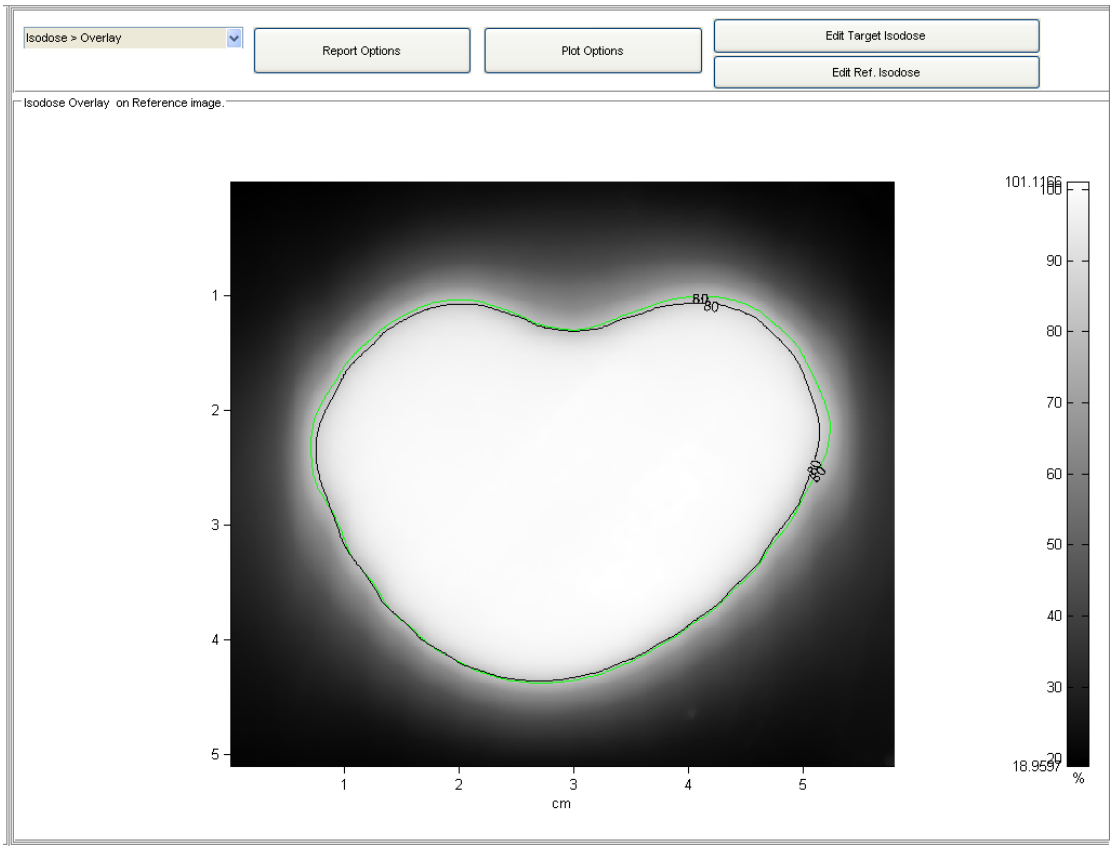

Figure 22 Isodose overlay for the case of head frame localization with film oriented in the transverse plane. Measured isodose is shown in green.

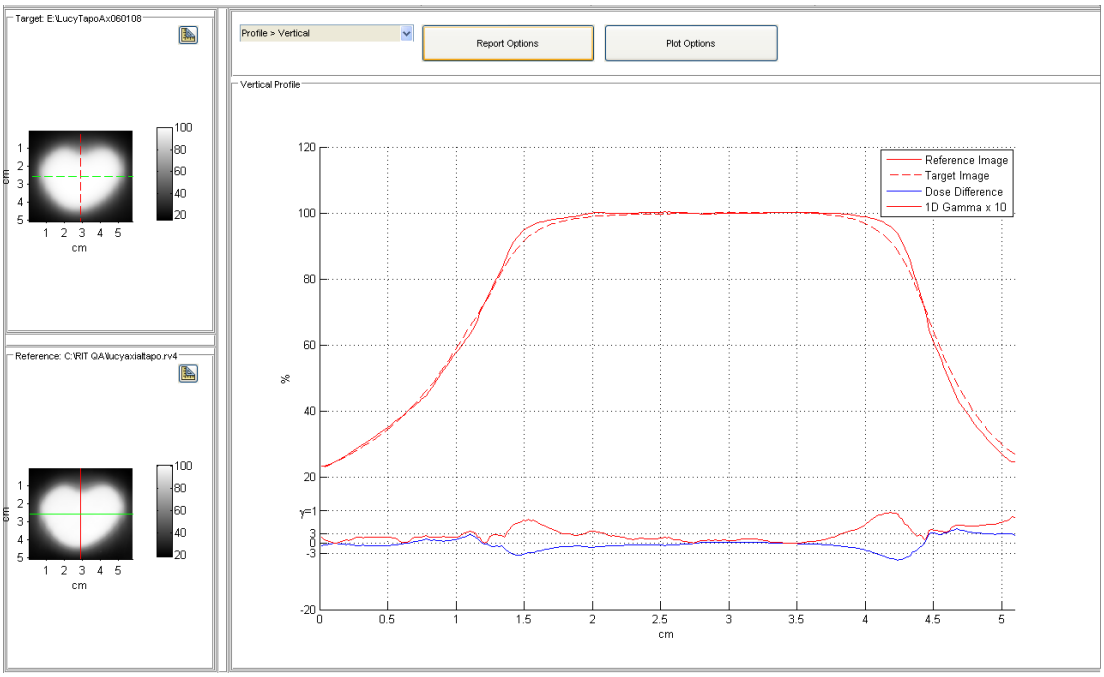

Figure 23 Vertical profiles for the case of head frame localization with film oriented in the transverse plane. Measured dose is indicated by the solid line.

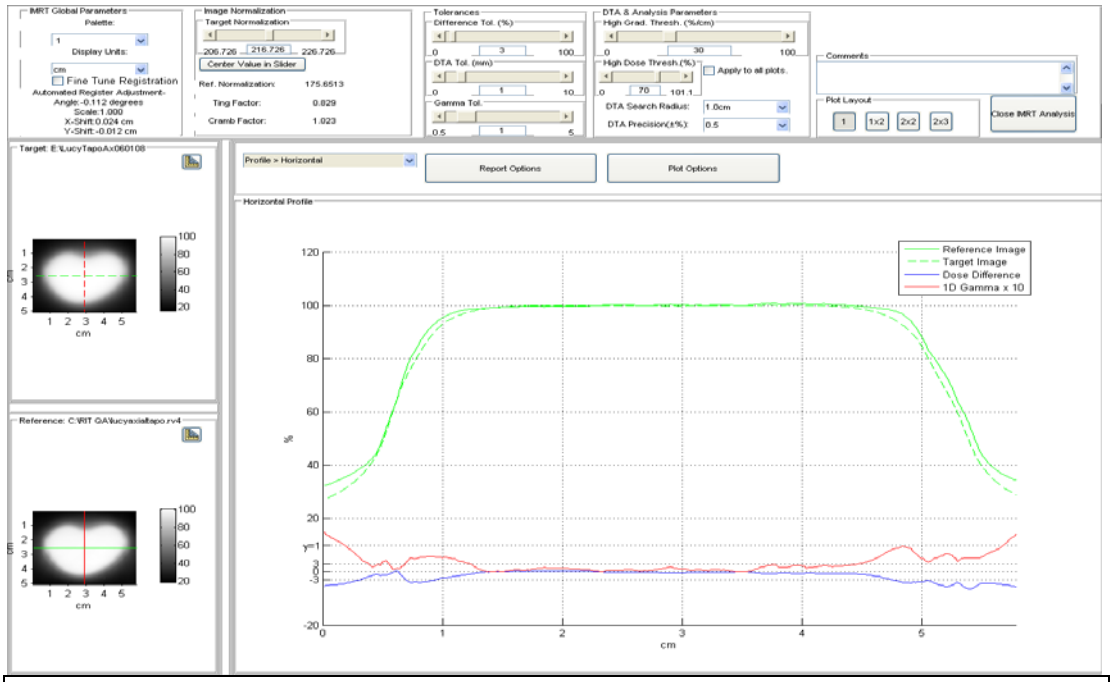

Figure 24 Horizontal profiles for the case of head frame localization with film oriented in the transverse plane. Measured dose is indicated by the solid line

The isodose overlays and dose profiles show excellent agreement between measurement and calculation. The shoulders of the measured profiles are less rounded than the calculated profiles, provided better target coverage at the 90% level than planned.

5.4.2 Head Frame Localization – Sagittal Film Orientation

Figures 25-27 show the results of film analysis for the case of head frame localization with the film oriented in the sagittal plane.

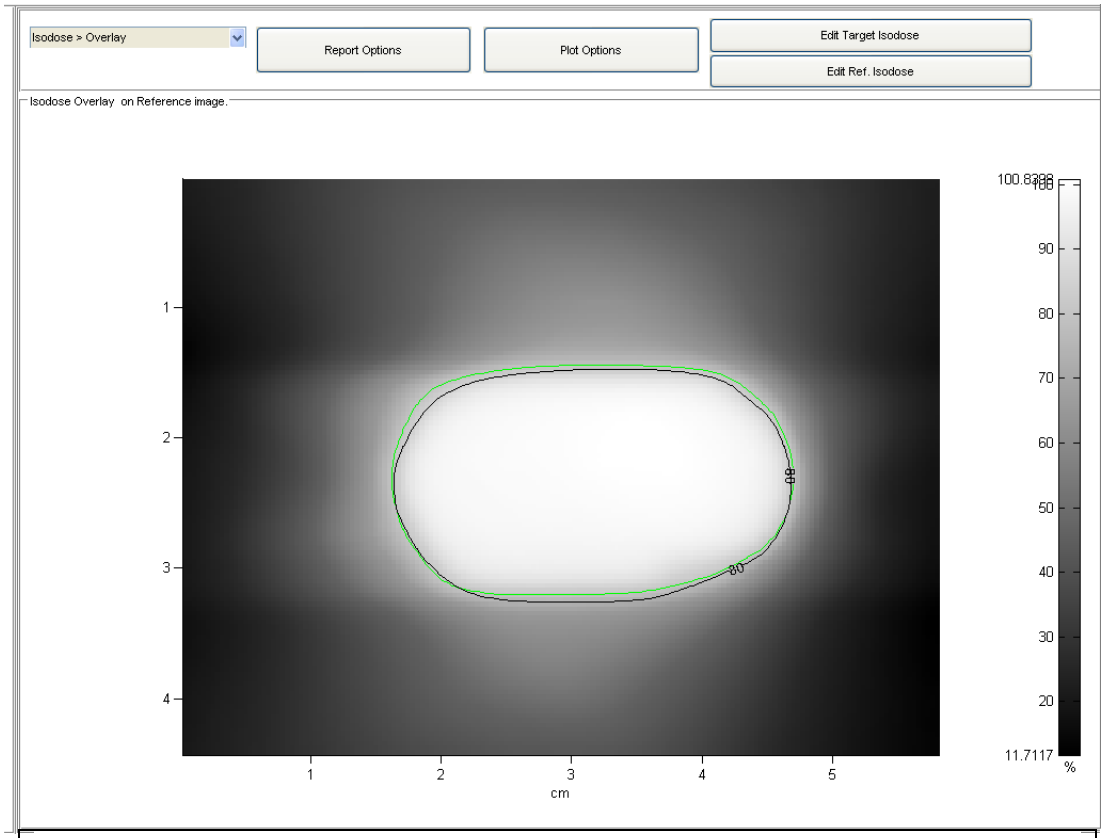

Figure 25 Isodose overlay for the case of head frame localization with film oriented in the sagittal plane. The measured dose is indicated by the green curve.

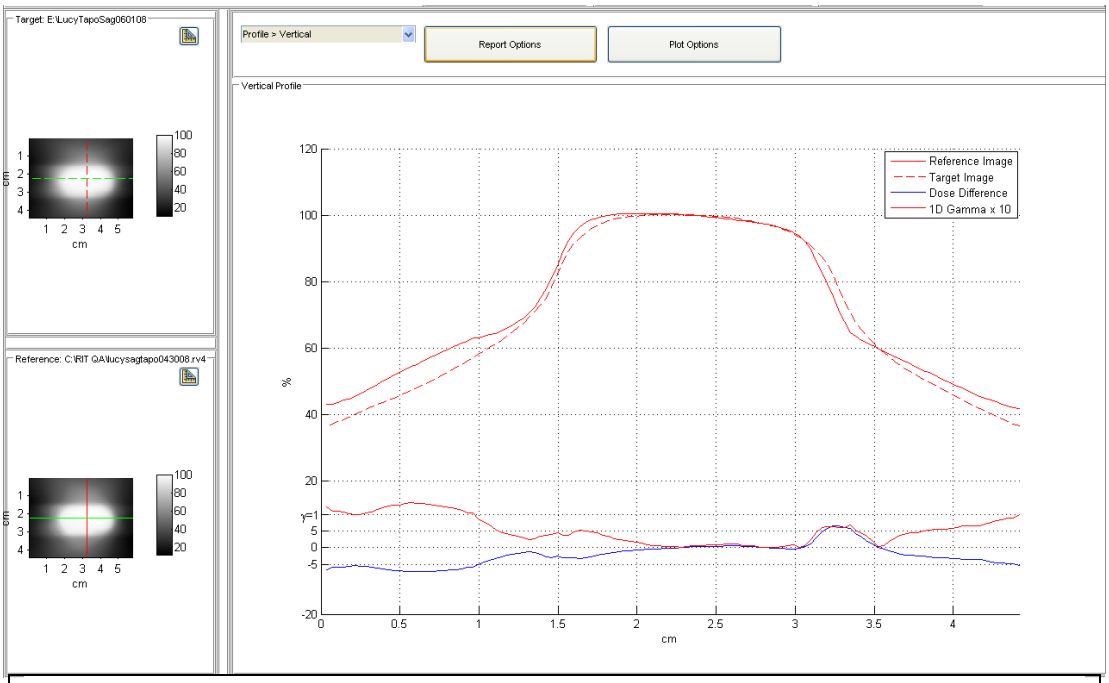

Figure 26 Vertical profiles for the case of head frame localization with film oriented in the sagittal plane. The measured dose is indicated by the solid line.

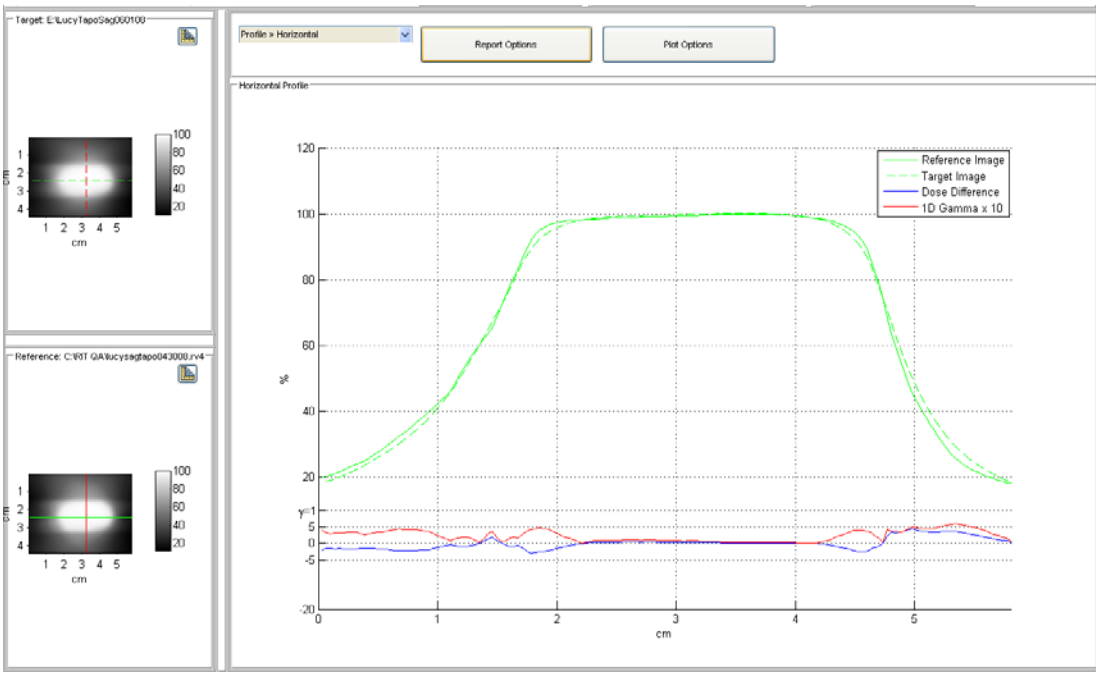

Figure 27 Horizontal profiles for the case of head frame localization with film oriented in the sagittal plane. The measured dose is indicated by the solid line.

The isodose overlays and dose profiles show excellent agreement between measurement and calculation.

5.4.3 Head Frame Localization – Coronal Film Orientation

Figures 28-30 show the results of film analysis for the case of head frame localization with the film oriented in the sagittal plane.

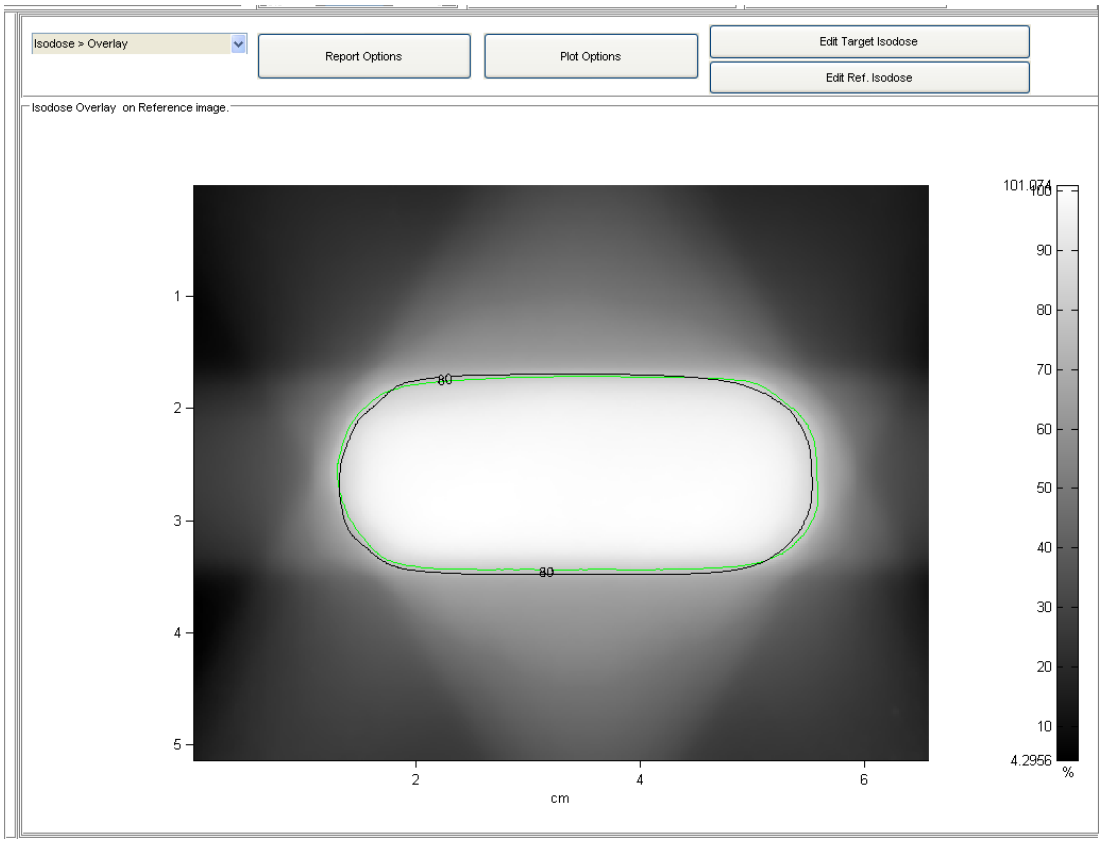

Figure 28 Isodose overlay for the case of head frame localization with film oriented in the coronal plane. The measured dose is indicated by the green curve.

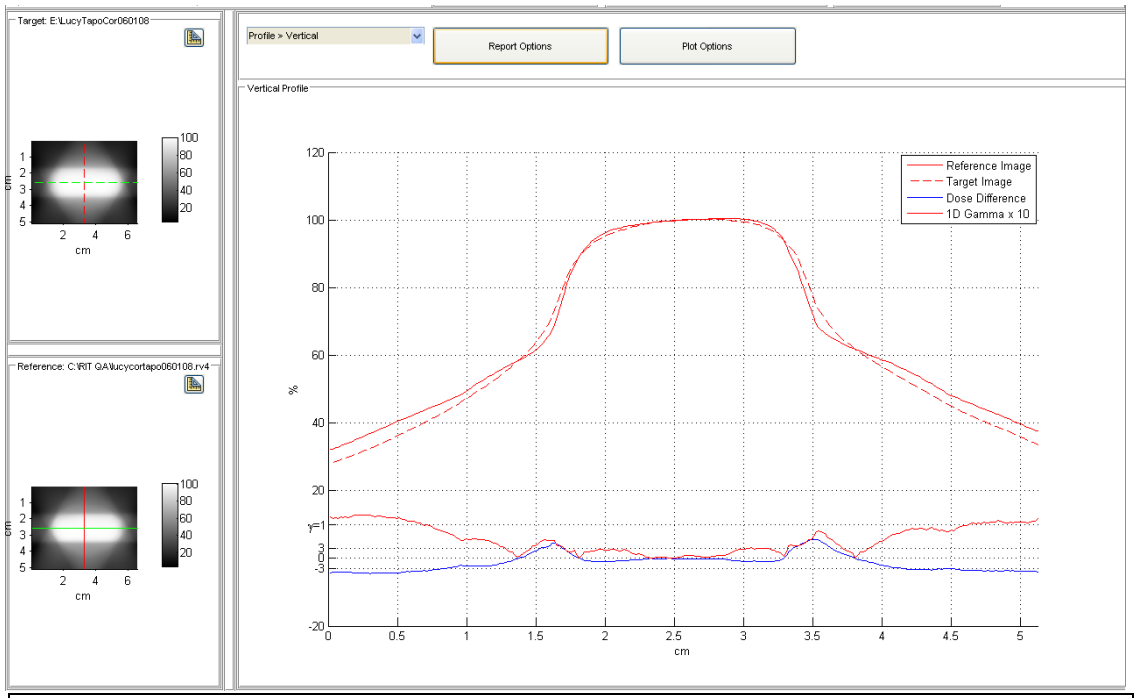

Figure 29 Vertical profiles for the case of head frame localization with film oriented in the coronal plane. The measured dose is indicated by the solid line.

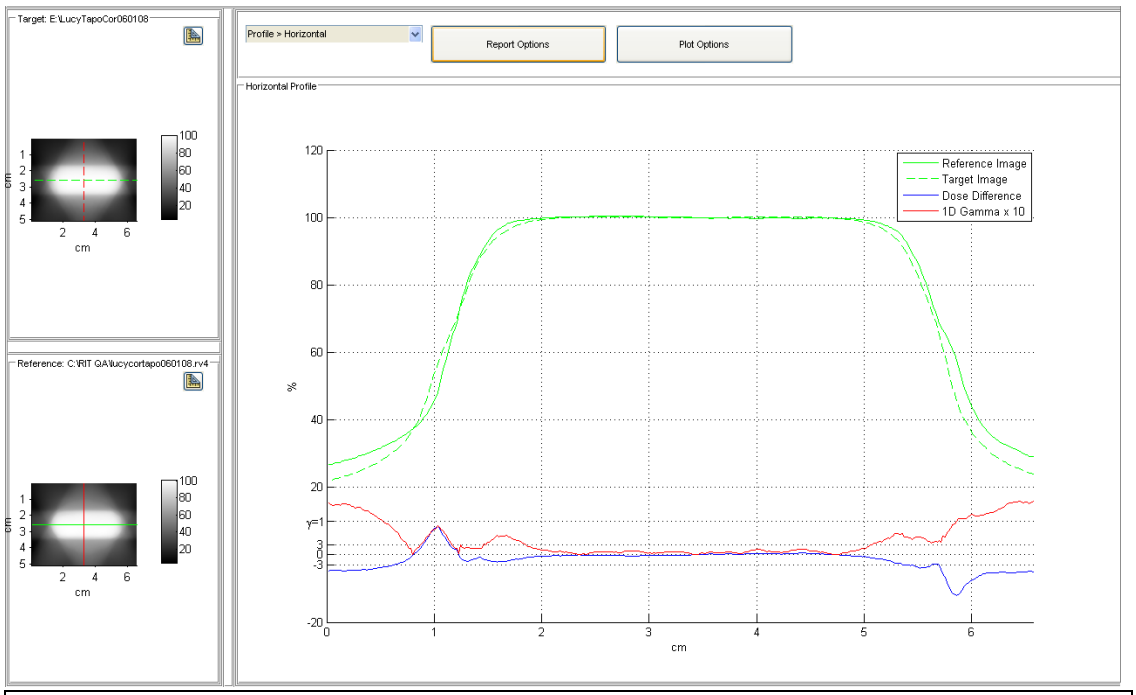

Figure 30 Horizontal profiles for the case of head frame localization with film oriented in the coronal plane. The measured dose is indicated by the solid line.

The isodose overlays and dose profiles show excellent agreement between measurement and calculation.

5.4.4 ExacTrac X-ray Localization –Transverse Film Orientation

Figures 31-33 show the results of film analysis for the case of ExacTrac X-ray localization with the film oriented in the transverse plane.

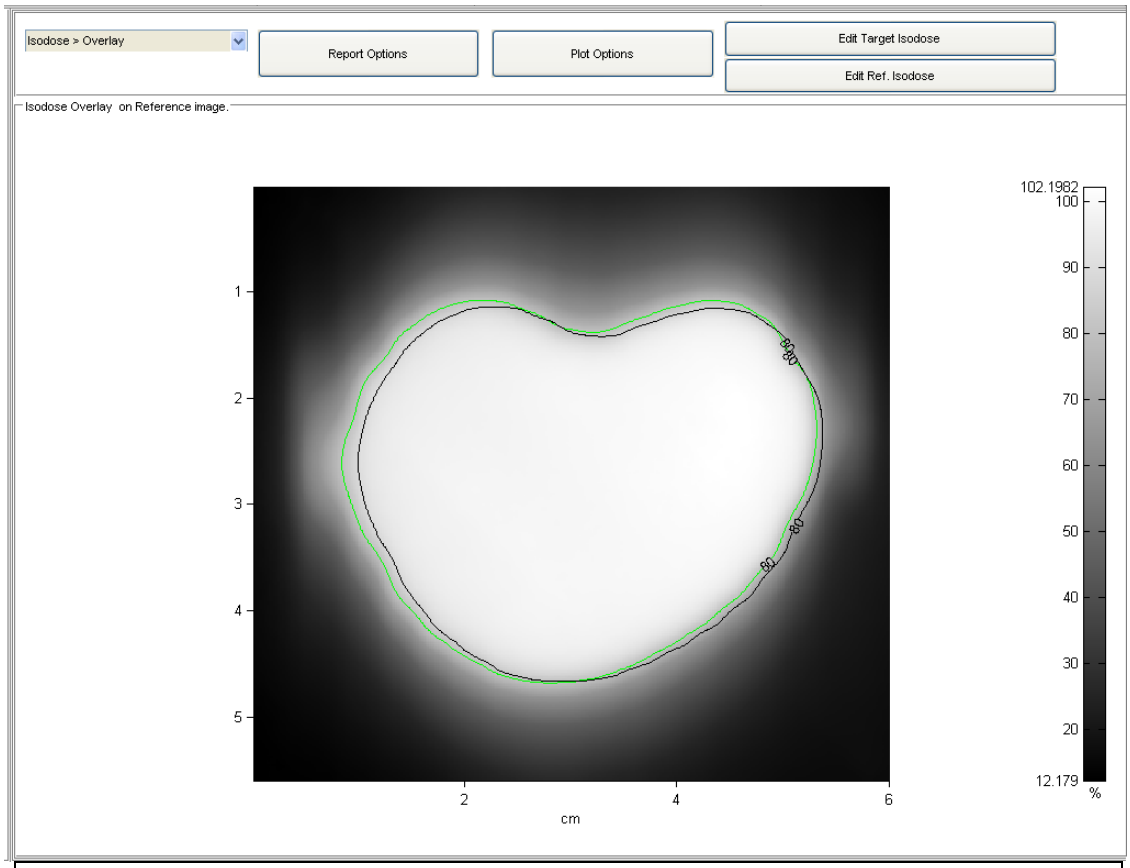

Figure 31 Isodose overlay for the case of ExacTrac X-ray localization with film oriented in the transverse plane. The measured dose is indicated by the green curve.

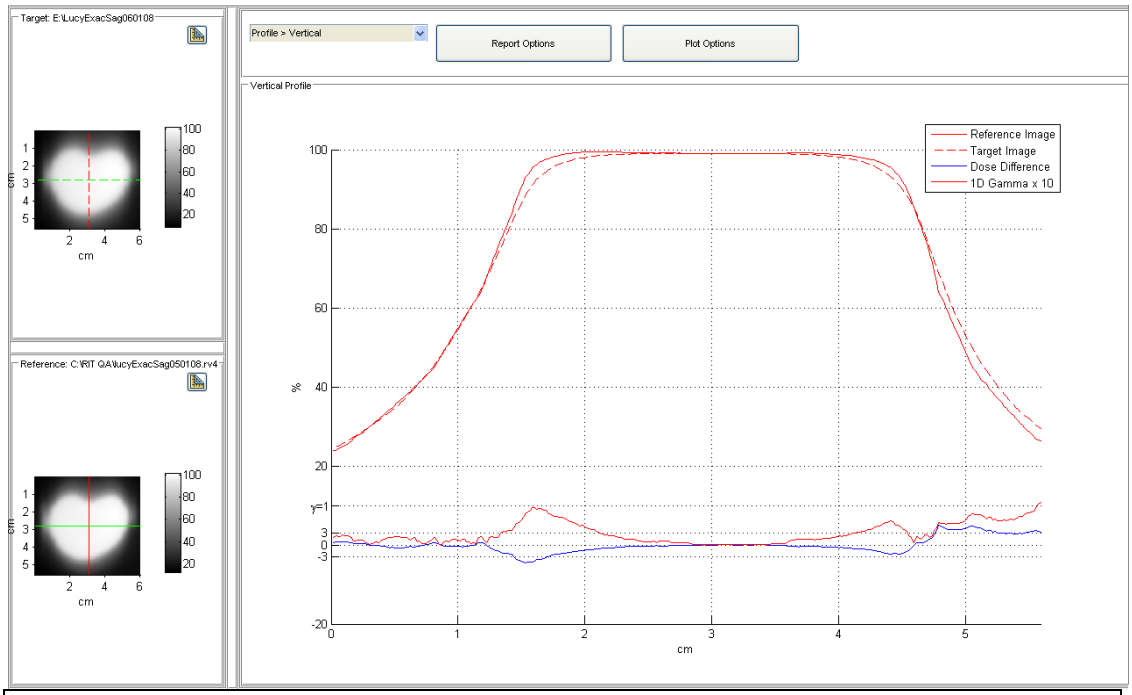

Figure 32 Vertical profiles for the case of ExacTrac X-ray localization with film oriented in the transverse plane. The measured dose is indicated by the solid line.

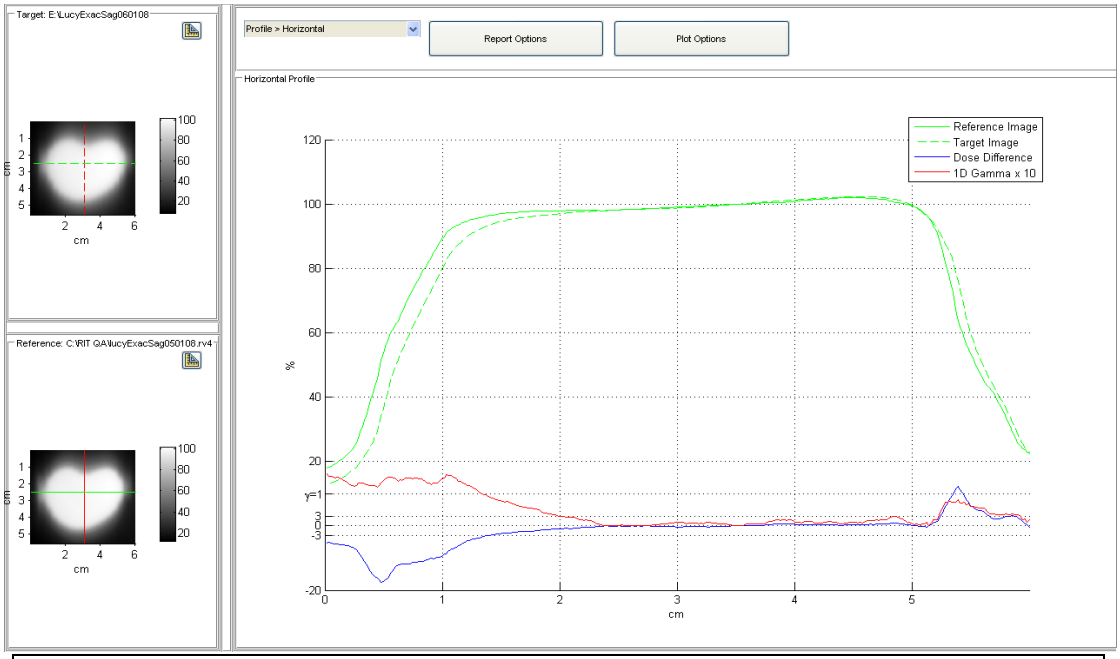

Figure 33 Horizontal profiles for the case of ExacTrac X-ray localization with film oriented in the transverse plane. The measured dose is indicated by the solid line.

The isodose overlays and dose profiles show good agreement between measurement and calculation. The measured distribution is shifted laterally approximately 1 mm.

5.4.5 ExacTrac X-ray Localization –Sagittal Film Orientation

Figures 34-36 show the results of film analysis for the case of ExacTrac X-ray localization with the film oriented in the sagittal plane.

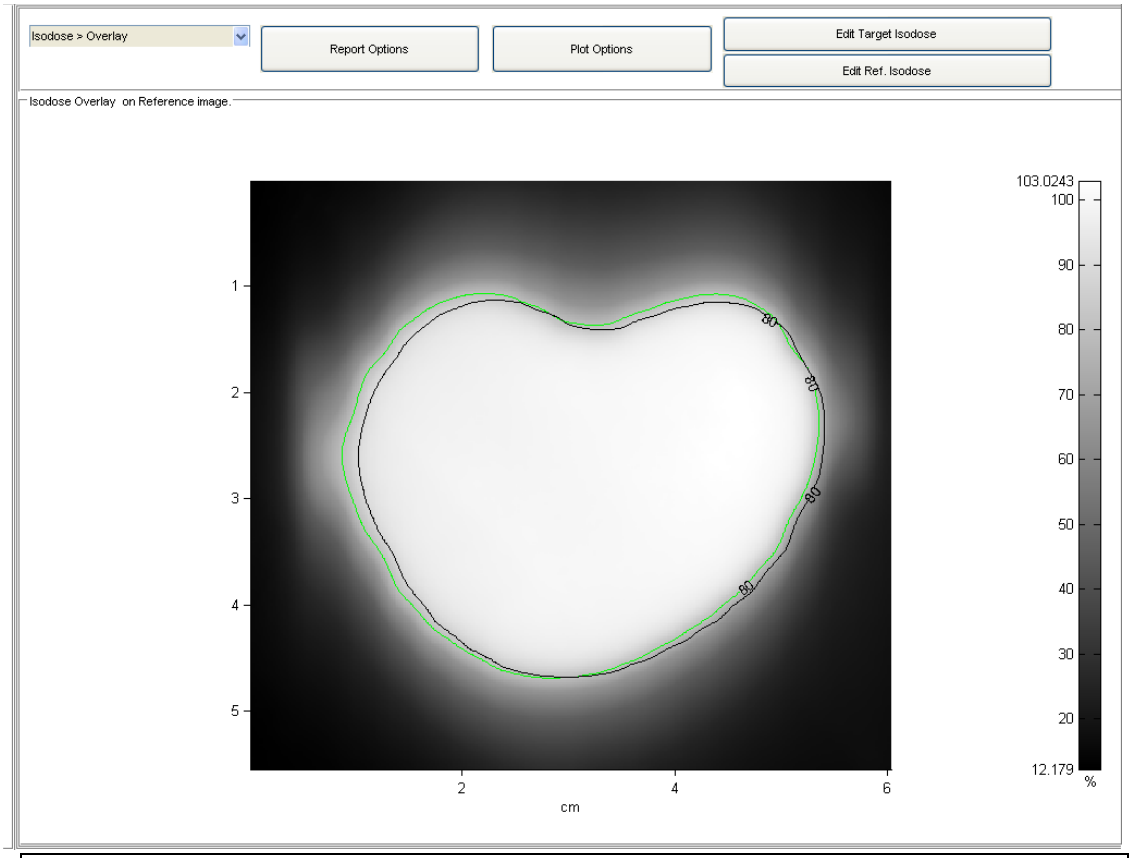

Figure 34 Isodose overlay for the case of ExacTrac X-ray localization with film oriented in the sagittal plane. The measured dose is indicated by the green curve.

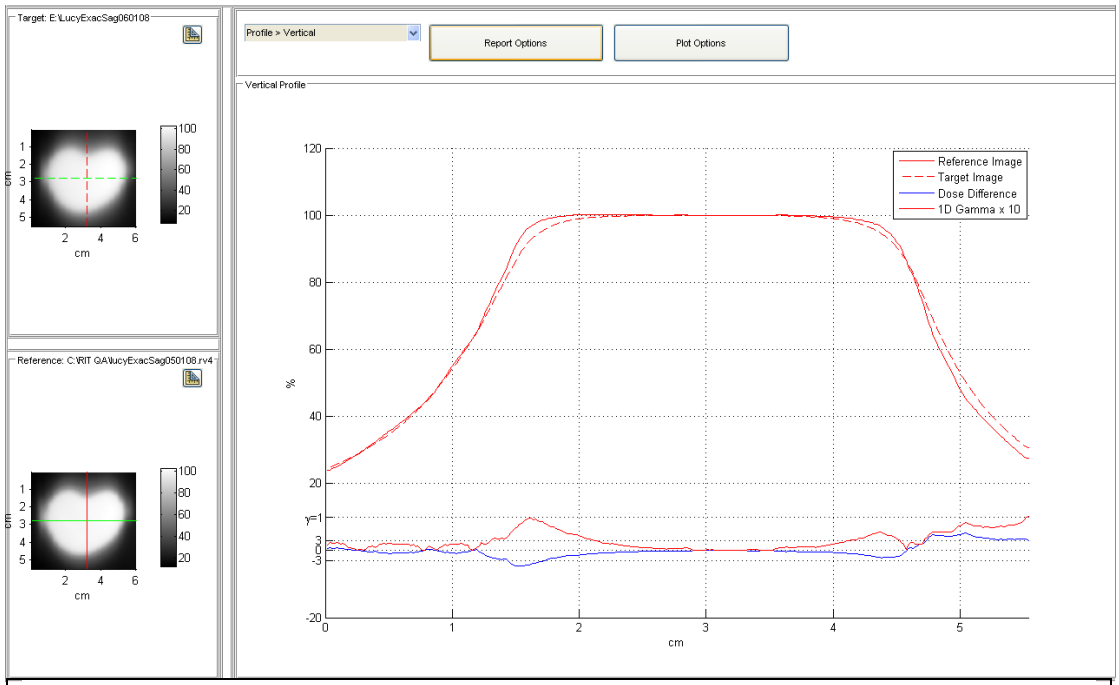

Figure 32 Vertical profiles for the case of ExacTrac X-ray localization with film oriented in the sagittal plane. The measured dose is indicated by the solid line.

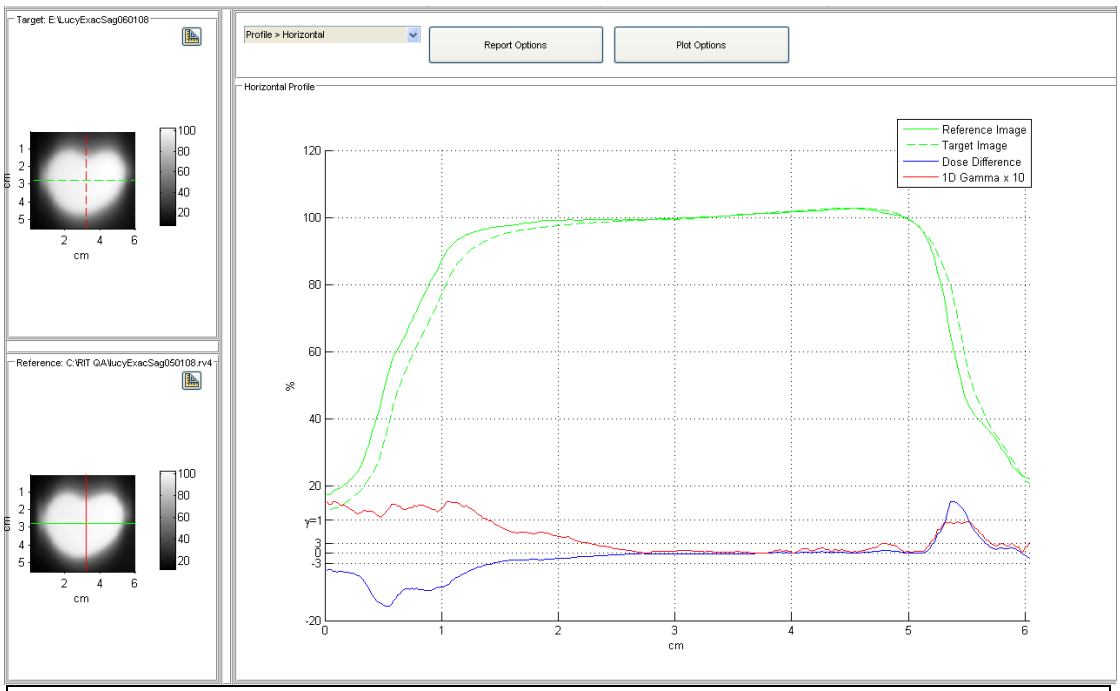

Figure 33 Horizontal profiles for the case of ExacTrac X-ray localization with film oriented in the sagittal plane. The measured dose is indicated by the solid line.

The isodose overlays and dose profiles show good agreement between measurement and calculation. The measured distribution is shifted superiorly approximately 1 mm relative to the calculated distribution.

6.0 Conclusions

The results of the end-to-end tests with the Lucy phantom demonstrates that the radiosurgery processes, with the physical components included in the tests, deliver dose distributions as planned with spatial and dosimetric accuracy appropriate for stereotactic radiosurgery.

The measured distributions had generally sharper shoulders than the planned distributions, suggesting that measured beam profiles for beam modeling was possibly affected by volume averaging of the detector.

Both tests with x-ray image localization resulted in a 1 mm horizontal shift parallel to the plane of the imaging insert.

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