Design, development, and evaluation of a modified, anthropomorphic, head and neck, quality assurance phantom for use in stereotactic radiosurgery

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Radiological Physics Center (RPC)

- Primary responsibility is assure NCI and cooperative groups of clinically comparable and consistent radiation doses
  - adequate QA
  - no systematic discrepancies
- Must monitor machine output/source strength, dosimetry data, calculation algorithms, and quality control
- On site reviews and remote audit tools accomplish this all

On-Site Review

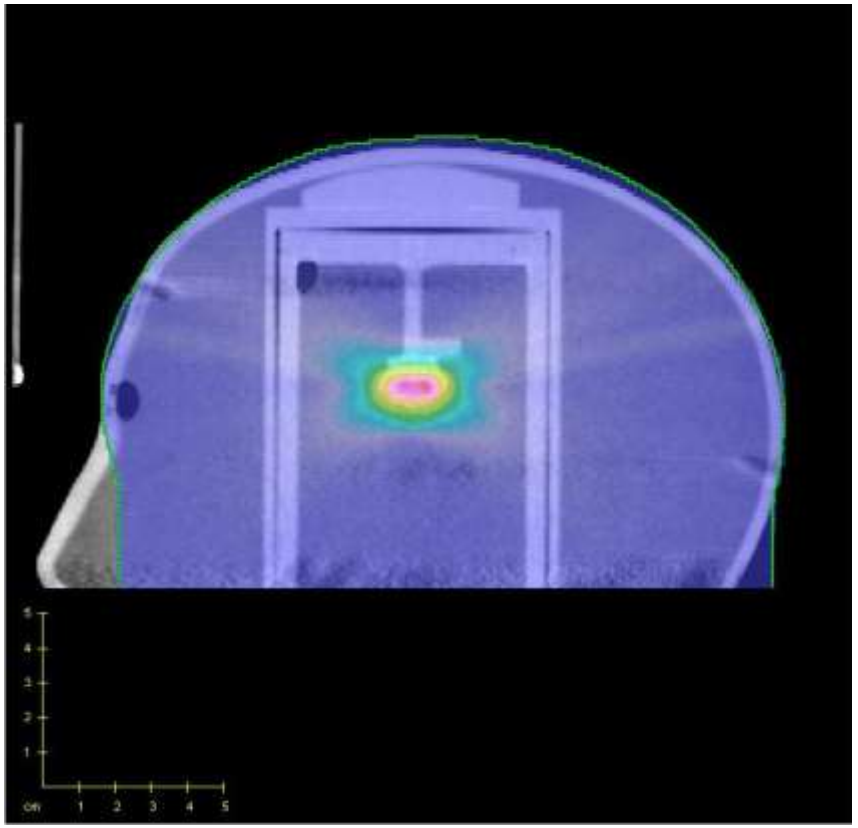
- Interview of physicists and oncology personnel
- Physical measurements on machines
  - Output
  - Beam shaping
  - Depth dose data
- Review dosimetry data, dose calculations, and quality control procedures
- Concludes with report to institution detailing findings

Remote Auditing Program

- Checking machine output with OSLDs
- Comparison of dosimetry data with RPC standard
- Verification of treatment-planning algorithms and manual calculations
- Review of written QA procedures
- Use of anthropomorphic phantoms to verify tumor dose in special procedures

Stereotactic Radiosurgery (SRS)

- Delivery of single high dose fraction (≈25 Gy)
- Radiobiological advantages and throughput advantages
- Tight margins and steep dose gradients
- Doses/gradients used necessitate adequate QA



Sagittal view of Gamma Knife treatment plan

SRS Treatment Delivery

- Linac Based
  - Varian Trilogy
- Gamma Knife
- CyberKnife

Varian Medical Systems
Elekta AB
Accuray Inc.

Phantom Design

Image of phantom (left) evaluated with imaging insert (center) and dosimetric insert (right)

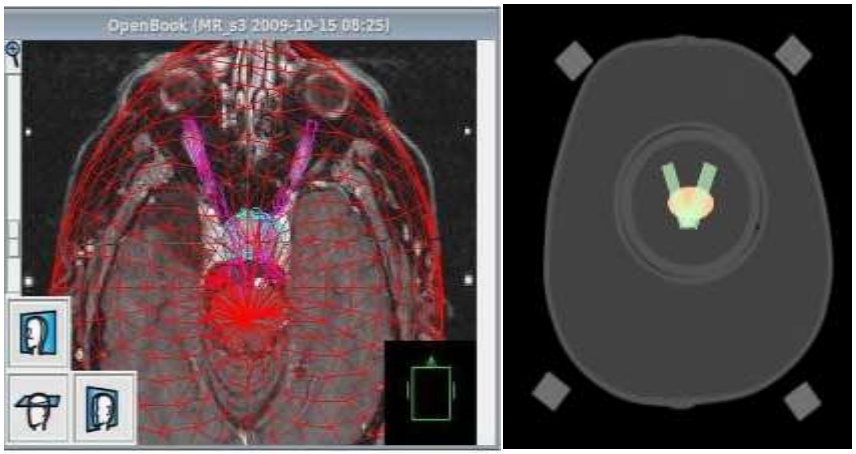
- Anthropomorphic outer plastic shell tests realistic situations
- Light weight reduces shipping costs
- Fill with water to mimic tissue where possible

Phantom Design Cont.

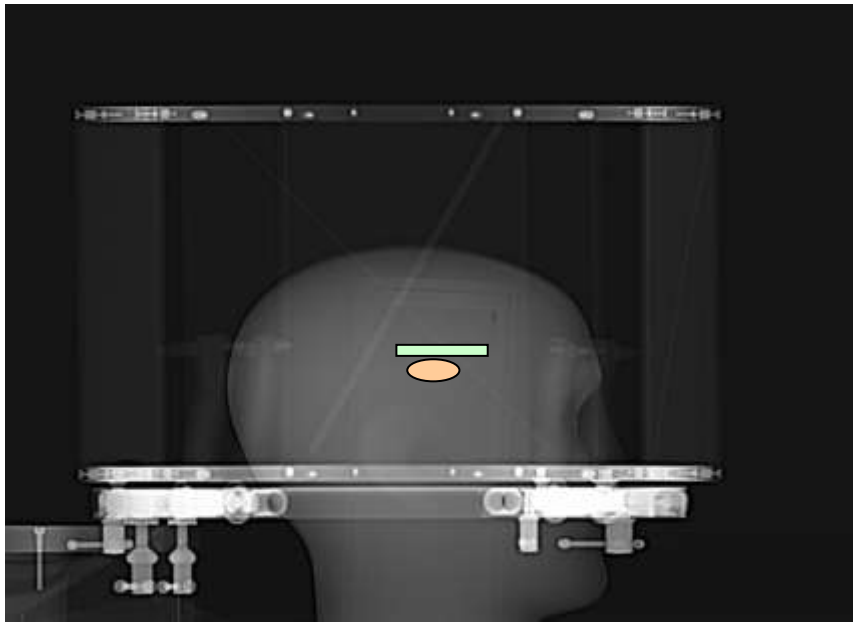
Image of phantom (left) evaluated with imaging insert (center) and dosimetric insert (right)

- Phantom should contain a mock PTV and OAR
- Must include dosimeter(s)
  - TLD for absolute dosimetry
  - Radiochromic film for relative dosimetry
- Have to be able to CT the phantom

Phantom Design Cont.

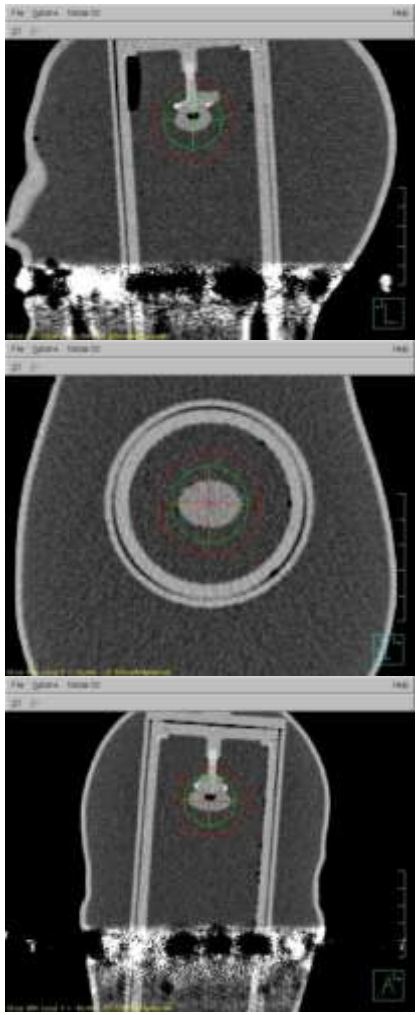


Transverse view of patient MRI (left) with pituitary (blue) and optic apparatus (purple) contoured and transverse view of phantom with proposed target (red) and OAR (green).



Sagittal view of original phantom design with proposed addition of target (red) and organ at risk (green).

Geometry Verification



- Spatial correlation between inserts was verified with AcQsim CT scanner
  - 0.2mm – LR direction
  - 0.2mm – AP direction
  - 0.7mm – SI direction

Reproducibility Study

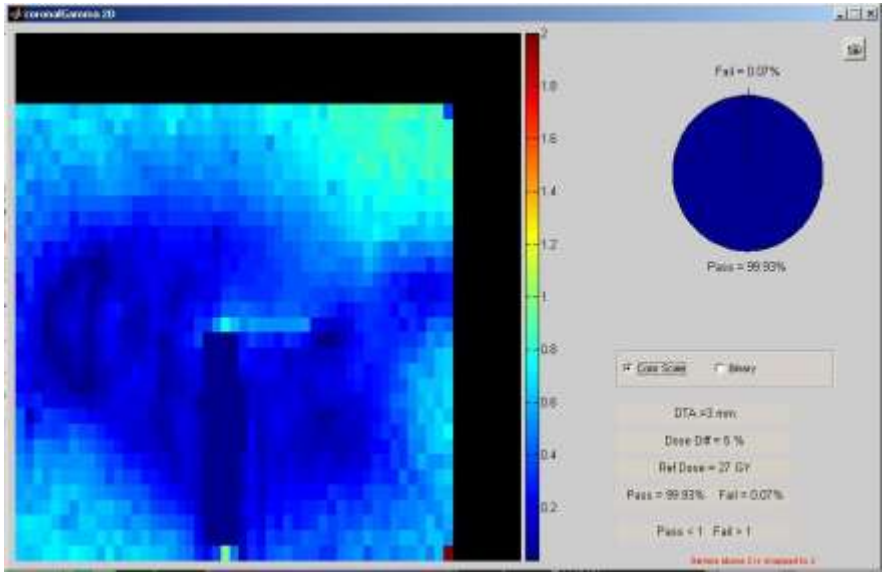
- Phantom was imaged with an ACQSIM CT scanner
- Treatment plan generated according to cooperative group protocol

Structure	Proposed Specifications	Modified Specifications
Pituitary Adenoma	25 Gy (RBE) to at least 90% of GTV	25 Gy (RBE) to at least 90% of GTV
Optic Apparatus (chiasm and optic nerves)	< 10 Gy (RBE) maximum dose (0.01cc)	< 10 Gy (RBE) maximum dose (0.01cc)
	<=1% volume should receive 8 Gy (RBE)	<=10% volume should receive 8 Gy (RBE)

- Plan delivered 3 times with Gamma Knife, CyberKnife, cone based linac plan, and MLC based linac plan

Results

- Gamma index evaluates dose distributions
  - Scored as % of pixels meeting criterion
  - Two criteria used
    - 5%/3mm
    - 3%/2mm
- TLD allow for point comparisons with institutional data
  - Expressed as ratio Measurement/Reported



Gamma analysis of a coronal film slice from Gamma Knife irradiation using 5%/3mm distance to agreement criteria

Radiosurgery System	TLD (Measured/Reported)			
	Left Posterior Superior	σ	Right Anterior Inferior	σ
Gamma Knife	0.96	0.02	0.96	0.02
CyberKnife	0.99	0.01	1.05	0.01
MLC- based linac	0.29	0.04	1.06	0.01
Cone-based linac	0.62	0.01	0.95	0.01

Table 2: Summary of point dose comparison between calculated and measured data

Radiosurgery System	Gamma Analysis - 5%/3mm (% passing)				Gamma Analysis – 3%/2mm (% passing)			
	Coronal Film	σ	Sagittal Film	σ	Coronal Film	σ	Sagittal Film	σ
Gamma Knife	99.9	0.1	99.4	0.7	87.2	5.8	78.6	1.9
CyberKnife	98.8	1.0	99.5	0.2	88.5	5.9	87.0	2.1
MLC-based linac	77.1	3.2	76.8	0.1	49.0	0.6	43.0	11

Table 3: Summary of film analysis using two different gamma criteria.

Conclusion

- A lightweight, head and neck phantom was developed for evaluating start to finish SRS treatment delivery
- Modifications to inserts allow for realistic clinical planning and delivery challenges
- Phantom will be a valuable QA and credentialing tool in off-site auditing program