DEVELOPMENT AND IMPLEMENTATION OF AN ANTHROPOMORPHIC HEAD AND NECK PHANTOM FOR THE ASSESSMENT OF PROTON THERAPY TREATMENT PROCEDURES

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Project

Why

- NCI has developed guidelines for the use of proton therapy in clinical trials. There is an "approval" process that each new proton facility has to go through before being allowed to enter a proton treated patient into NCI clinical trials.
- The Imaging and Radiation Oncology Core Houston (IROC H) QA Center is an independent institution that performs this approval and credentialing process to assure NCI that participating institutions are providing accurate, comparable and consistent proton therapy treatments.

Problem

- IROC currently does not have an anthropomorphic Proton Head and Neck Phantom that can be used in credentialing these institutions for an oropharynx cancer trial.

Hypothesis

An anthropomorphic H&N phantom can be designed and built to evaluate proton therapy H&N treatment procedures that can reproducibly (±3%) assure agreement between the measured doses and calculated doses to within ±7%/4mm .

Project Methodology

1. The phantom will be designed based on the composition, size and geometry of a generalized head and neck tumor (oropharyngeal) and critical structures, such as the parotids and the spinal cord.
2. CT images will be obtained for the phantom and two treatment plans (passive scatter and spot scanning) will be developed using the Eclipse proton planning system. The plan, approved by a radiation oncologist, will be developed based on typical clinical constraints for a generalized H&N cancer adopted at the MDACC Proton Center (PTC-H).
3. Film and TLD dosimeters will be placed in the phantom through a cylindrical insert. The phantom will be irradiated 3 separate times for each approved treatment plan in order to evaluate the reproducibility of the phantom design.
4. The 2D dose distributions and specific point doses determined from the film and TLDs will be compared with the planning system calculated values, dose profiles and dose distributions to determine the agreement and reproducibility.

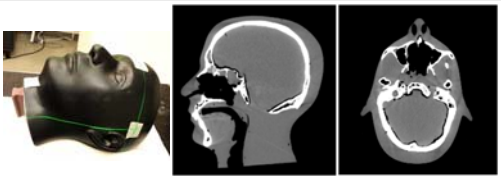

Figure 1: H&N Phantom and sagittal and axial CT scans of the original head phantom purchased prior to modifications

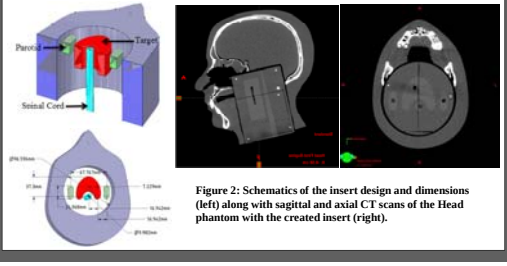

Figure 2: Schematics of the insert design and dimensions (left) along with sagittal and axial CT scans of the Head phantom with the created insert (right).

Figure 3: Passive Scattering Plan

Figure 4: Pencil Beam Plan

Figure 5: From left to right; posterior beam, right oblique beam and left oblique beam

	TLD Location	TPS Dose Calculated	Dose Measured	Ratio [Meas./Calc.]
TRIAL 1	Target Superior	646.2	654.3	1.013
	Target Inferior	648.6	627.9	0.968
TRIAL 4	Target Superior	646.2	631.6	0.977
	Target Inferior	648.6	638.1	0.984
TRIAL 5	Target Superior	646.2	631.8	0.978
	Target Inferior	648.6	625.6	0.964
TRIAL 6	Target Superior	646.2	634.8	0.982
	Target Inferior	648.6	646.3	0.996
Average Dose Values between Trials 1,4, 5 and 6 [cGy]	Target Superior	646.2	636.1	0.984
	Target Inferior	648.6	639.6	0.986
	Parotid Left	250.2	286.1	1.143
	Parotid Right	206.4	206.9	1.002
	Cord	503.4	492.7	0.978

Table 1: Spot Scanning Measurements for relevant trials – Point Dose

	TLD Location	Dose Calculated TPS	Dose measured	Ratio [Meas./Calc.]
TRIAL 2	Target Superior	646.2	656.0	1.015
	Target Inferior	648.6	637.0	0.982
	Parotid Left	250.2	453.6	1.813
	Parotid Right	206.4	459.0	2.224
	Cord	503.4	604.9	1.202
TRIAL 3	Target Superior	646.2	657.0	1.018
	Target Inferior	648.6	633.6	0.977
	Parotid Left	250.2	443.4	1.772
	Parotid Right	206.4	459.0	2.224
	Cord	503.4	604.5	1.201

Table 2: Spot Scanning Measurements for faulty trials – Point Dose

		2D Gamma Percentage of Pixels Passing		
		5%, 3mm	5%, 4 mm	7%, 4mm
TRIAL 1	Axial	86.3%	91.0%	95.5%
	Sagittal	82.6%	87.6%	94.2%
TRIAL 4	Axial	91.0%	94.0%	97.3%
	Sagittal	80.2%	87.0%	93.2%
TRIAL 5	Axial	82.1%	88.6%	93.4%
	Sagittal	76.0%	81.8%	90.0%
TRIAL 6	Axial	91.0%	93.4%	96.2%
	Sagittal	80.6%	86.4%	92.7%

Table 4: Spot Scanning Measurements for relevant trials – Relative Dose

		2D Gamma Percentage of Pixels Passing
		7%, 4mm
TRIAL 2	Axial	74.4%
	Sagittal	78.2%
TRIAL 3	Axial	79.5%
	Sagittal	79.5%

Table 3: Spot Scanning Measurements for faulty trials – Relative Dose

Results

Design and Construction

- Phantom insert was designed with appropriate imageable targets and critical structures that mimicked human anatomical dimensions and the usual extent of oropharyngeal disease, while still accommodating radiation dosimeters.
- The insert was made of solid water. The "horse shoe" shaped target along and the three relevant organs at risk were made of blue water. Both materials are proton tissue equivalent.

Treatment Planning

- A spot scanning treatment plan was created and successfully addressed clinical target and OARs doses, and therefore was approved by a PTC-H physician.
- For the passive treatment plan, the parotids were sufficiently shielded, however, the spinal cord was not protected sufficiently and the target coverage was non-uniform, with several cold and hot spots. The structures chosen to be in the insert, based on actual patient anatomy, were too close together for the passive plan to successfully achieve the treatment plan goals outlined in the clinical trial.

Point Dose Dosimetry

- Target TLD Ratios showed good agreement between the treatment planning system and the average TLD measurements, 1.6% for the sup. target and 1.4% for the inf.. Both target TLD ratios meet IROCs acceptance criterion of ±5% dose agreement tolerance.

Relative Dosimetry

- All relevant trials pass the 85% criteria used at IROC for the gamma index proposed in the hypothesis (7%/4 mm). As expected, tighter criteria show lower passing rates, but still perform well, where only Trial 5 sagittal does not pass.

Conclusion

- The target TLD doses were within IROCs acceptance criterion of ±5% dose agreement tolerance, but low when compared to the TPS calculations. One possible explanation for this outcome could be that proton therapy treatment planning systems tend to overestimate target doses by as much as 3.5% for head and neck patients when compared to Monte Carlo simulations.
- The relative dose distribution analysis was performed using ±5%/3mm, ±5%/4mm and ±7%/4mm gamma index acceptance criteria. All relevant trials pass the 85% criteria used at IROC for the gamma index proposed in the hypothesis (7%/4 mm). As expected, tighter criteria show lower passing rates, but still perform well, where only Trial 5 sagittal does not pass 5%/3mm.
- Moving forward we expect to redesign the insert so that the structures have a larger separation between them. That would be done with the intent to develop a passive treatment plan that could successfully achieve typical clinical goals.

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