Use of an innovative patient specific plan verification methodology towards highlighting treatment effectiveness in Gamma Knife SRS treatments

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Introduction - Scope

Leksell Gamma Knife
- High dose gradients / multiple shots/targets
- Minimal uncertainties in dose delivery:
  - Excellent mechanical accuracy

Dose verification in stereotactic radiosurgery
- Challenging due to the combined effect of steep dose gradients and loss of lateral electronic equilibrium.
- Development of end-to-end QA test employing 3D dosimetry

Scope of this work
- to establish and implement a patient-specific end-to-end quality assurance methodology for plan verification and overall accuracy evaluation of a GammaKnife treatment using polymer gel dosimetry and patient-specific phantom created with 3-D printing technology
Materials & Methods

Polymer gel dosimetry

- The dosimetric material is an aqueous solution of appropriate monomers and crosslinkers fixed in a gelatin matrix.
- Upon irradiation polymerization occurs, which change the chemical and physical properties of the irradiated gel such as optical opacity and MR relaxation rates (T2).
- The induced polymerization is directly related to the absorbed dose.

Materials & Methods

Patient-specific phantom created with 3-D printing technology (RTsafe Co., Greece: www.rtsafe.com)

- Patient CT-scan were utilized as input to a 3D printer
- A 3D-hollow-phantom that duplicates the patient anatomy in terms of external surface and bone structures was constructed

![Patient CT-images](image1)

![3D printer](image2)

![Phantom](image3)
Materials & Methods

Patient-specific phantom created with 3-D printing technology (RTsafe Co., Greece: www.rtsafe.com)

- The phantom was subsequently filled with a polymer-gel dosimeter (density: 1.01 g/cc).

Normoxic VIPAR formulation: linear response up to 35 Gy

![Image of phantom and dosimeter](image.jpg)

![Graph showing linear response](graph.jpg)
Materials & Methods

Patient-specific phantom created with 3-D printing technology
(RTsafe Co., Greece: www.rtsafe.com)

- The phantom was utilized to accurately reproduce every link in the GK treatment chain
Materials & Methods

Patient-specific phantom created with 3-D printing technology
(RTsafe Co., Greece: www.rtsafe.com)

Preplan in patient anatomy
- Two targets with optic chiasma and stem being in their close vicinity.
- 13 shots including plugged and composite ones was created.

Plan in patient-specific phantom anatomy
Materials & Methods

The phantom was irradiated in a Perfexion unit
Qualitative evaluation

- The irradiated phantom was MRI-scanned using a specially designed T2-pulse sequence with minimal geometric distortion (0.68x0.68x2mm³ spatial resolution)
- MR-images were imported to Gammaplan and co-registered to CT-images for qualitative evaluation of dose delivery accuracy.

Radiation-induced polymerization area is clearly evident in the corresponding MR-images and coincides to the high-dose target area while OARs are adequately spared in agreement with the planned dose distribution.
Qualitative evaluation

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Quantitative evaluation

- GammaPlan dose calculations (MR images and corresponding RTstructures and RTdoses) were exported and used for dose comparison with measurements using RTsafe software.

Dose distribution evaluation. Gammaplan isodose lines and corresponding measurements are superimposed in MR images of the patient specific phantom distribution.
Quantitative evaluation

1D dose profile evaluation
Quantitative evaluation

2D dose distribution evaluation

<table>
<thead>
<tr>
<th>3D Gamma Index</th>
<th>Global 5% DTA = 2mm Threshold = 10%</th>
<th>Global 5% DTA = 1mm Threshold = 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passing Rate</td>
<td>96.6 %</td>
<td>87.6 %</td>
</tr>
</tbody>
</table>

3D gamma index evaluation
Quantitative evaluation

DVH evaluation

Target 1

Target 2
Quantitative evaluation

DVH evaluation

Stem

Optic chiasma
Quantitative evaluation

Optic chiasma
Polymer gel – patient specific phantom approach

Advantages

• Polymer gel advantages (water equivalent phantom/detector)

• 3D printing technology and water equivalent gel material / dosimeter allows the construction of a patient-specific phantom very similar to the patient anatomy

• Capable of qualitatively evaluate dose delivery accuracy by comparing GammaPlan calculated dose distribution with radiation induced polymerization area everywhere in the brain

• 3D dosimeter with satisfied spatial resolution (< 1mm) capable of evaluated dose distributions using DVH criteria clinically used for plan evaluation and acceptance

• combined with MRI to readout the radiation induced polymerization and using GammaPlan to perform the MR image registration, the method incorporates both MR sequence independent distortions and registration uncertainties also exist in patient irradiation
Polymer gel disadvantages / areas for improvement

• Increased individual point dose uncertainty

• Need for optimized MR sequences (e.g. better spatial resolution)
Conclusions
The proposed methodology offers a unique way for 3D dose verification including DVHs and could be supportive towards:
• patient specific plan verification
• end-to-end periodic QA
• confidence building processes in GammaKnife installations

Multiple metastases case