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End-to-end audit tests for advanced radiotherapy treatment modalities involving patient-specific 3D dosimetry phantoms

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Introduction of the study

Dosimetry audits in external radiotherapy are mainly performed by national and international organizations implementing thermoluminescence dosimetry, ionization chamber measurements and radiochromic film dosimetry. However, the introduction of contemporary complex radiotherapy techniques with high target conformality and steep dose gradients has revealed the necessity to validate 3D spatial and dosimetric accuracy as a part of a quality assurance program. The scope of this study is to investigate the feasibility of including a real 3D relative dosimetry (as opposed to existing pseudo-3D techniques) end-to-end test on external auditing procedures. For this purpose, patient specific head phantoms (also acting as dosimeters) were developed and implemented for external auditing on Stereotactic Radiosurgery (SRS) and Intensity Modulated Radiation Therapy (IMRT) techniques.

Methodology

Two identical hollow head phantoms with radiologically equivalent bone material (in terms of Hounsfield Units) were constructed by a 3D printer based on anonymized CT DICOM data of a real patient. Subsequently, the phantoms were filled with water equivalent normoxic VIPAR polymer gel 3D dosimeters. Irradiations of phantoms were performed by CyberKnife and TomoTherapy modalities implementing SRS and IMRT techniques, respectively. The irradiation plan for an SRS treatment simulating a hypothetical multiple brain metastases case consisted of 7 small targets spread all around the brain, while for the IMRT treatment the plan consisted by one centrally located target with the brain stem being the spared Organ at Risk (OAR). All steps of the radiotherapy chain of the specific cases studied were strictly followed providing an end-to-end auditing procedure. R2 relaxation rates of the irradiated-polymerized gel filled phantoms were performed by the department's MRI unit clinically employed for SRS and IMRT treatment planning. For this purpose, appropriate multi-echo pulse sequences were used that combine adequate spatial resolution (of approximately 1×1×2mm3) with acceptable scan time of the order of 30 minutes. This step also offered the attractive feature of including MR-related geometric distortions in this end-to-end audit test. A mutual information based spatial registration was performed between the two modalities (i.e., CT and MR image stacks). Relative 3D dose maps for both phantoms were obtained by normalizing the R2 relaxation rates after a background subtraction step. DICOM-RT data including contoured PTVs and OAR as well as calculated 3D dose distributions were exported from the Treatment Planning Systems (TPSs) in order to perform a detailed qualitative and quantitative 3D dose comparison between measured and calculated distributions. The aforementioned comparison involved spatial agreement, 1D profile comparison, 2D isodoses, Dose Volume Histograms (DVHs) and plan quality metrics (e.g., the minimum dose received by at least the 95% (D95) and 50% (D50) of the structure's volume). Gamma Index (GI) test was also employed with passing criteria of 5% local dose difference and 2mm distance to agreement.

Results

Although all sources of geometric uncertainties (i.e., set-up errors, MR-related geometric distortions, dose delivery geometric uncertainties and registration uncertainties) were involved, 3D spatial comparison between measured and calculated dose distributions did not reveal any concerns for either modalities. All 1D profiles evaluated showed agreement within experimental uncertainties in high dose areas, while an increased gel

over-response was observed in the low dose shower (<2.5 Gy) of the IMRT modality which can be attributed to the limited low-dose resolution of the polymer gel formulation. Similar remarks were deduced following the DVH comparison for both targets and OAR. In agreement with isodose comparison, GI analysis yielded failing points mainly in the low dose regions. Regarding target coverage metrics, a maximum difference of 0.6% for the D50 metric and 2% for the D95 one was measured for the SRS irradiation, while for the IMRT application corresponding differences were both found to be less than 0.5%.

Conclusion

An end-to-end dosimetric quality assurance test, using patient specific head phantoms which involved bone equivalent inhomogeneities, was performed to validate 3D spatial and dosimetric accuracy of SRS and IMRT techniques as part of an external audit procedure. The implemented methodology is in advantage compared to common practice auditing dosimetry in terms of the ability to evaluate complicated plans involving multiple small targets in a single measurement as well as to offer the possibility of real 3D dose and DVH measurements. Despite that dose prescription or gel formulation should be further optimized to avoid gel over-response in low dose areas, the introduced methodology has also the advantage of being a time efficient 3D dosimetry test for auditing purposes of clinical modalities as the whole implementation did not burden the clinical workflow by more than four hours.

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