Overall Spatial Uncertainty in Single-Isocenter Multi-Focal SRS for Multiple Brain Metastases: End-to-End QA Results Related to 208 Targets

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PURPOSE / OBJECTIVE(s)

Single-isocenter multi-focal stereotactic radiosurgery (SRS) is a contemporary yet challenging treatment approach for the management of multiple brain metastases[1, 2]. This study aims to quantify the overall spatial uncertainties of such treatment techniques by statistically analyzing patient-specific 3D dosimetric data from a total of 33 cases, involving 208 targets and 29 delivery units.

MATERIAL & METHODS

A rigorous patient-specific end-to-end quality assurance protocol was established which involved head phantoms, 3D-printed with bone mimicking material and modelled based on anonymized real patient CT scans (a commercially available service). The phantoms were filled with 3D polymer gel dosimeters. All phantoms were treated as if they were the actual patients, following all steps of the treatment chain (immobilization, imaging, spatial co-registration, planning, set-up, etc.), and using the patients' treatment plans with the original targets in terms of size, shape and position. In particular, the 33 cases included in this analysis involved targets with diameters ranging from 2.3 to 18 mm and a median diameter of 6.5 mm, located at up to 74 mm from the isocenter with a median distance of 37 mm. Treatment deliveries involved the majority of the commercially available linac-based SRS units, offering this technique. Gel dose read-outs were performed by 1.5T MR units using maximum receiver bandwidth in order to minimize MR-related geometric distortions. Overall spatial offsets were measured independently for each target by comparing in 3D the center-of-mass of polymerized area with the center-of-mass of planned high-dose area[3]. Results were statistically analyzed, with emphasis on investigating the correlation between distance from the isocenter and detected spatial offset.

RESULTS

Two cases were excluded from further analysis as unacceptable offsets of several millimeters were detected and attributed to rotational phantom positioning errors. Although the remaining results were quite scattered, a statistically significant positive correlation between overall spatial offset and distance from the isocenter was revealed (Spearman test[4] p-value: 0.018). More specifically, for targets lying >4cm from the isocenter, median spatial offset reached 1.6 mm, while a maximum deviation of 3.4 mm was detected. The effect was even more pronounced with decreasing target size.

Figure 1: Results of the spatial offsets measured by comparing the center-of-mass of the polymerized area and the center-of-mass of the planned high-dose area for each target, for both analyzed datasets: targets lying at distances less than 4cm and targets lying at distances greater than 4cm, from the planning isocenter.

Figure 1.

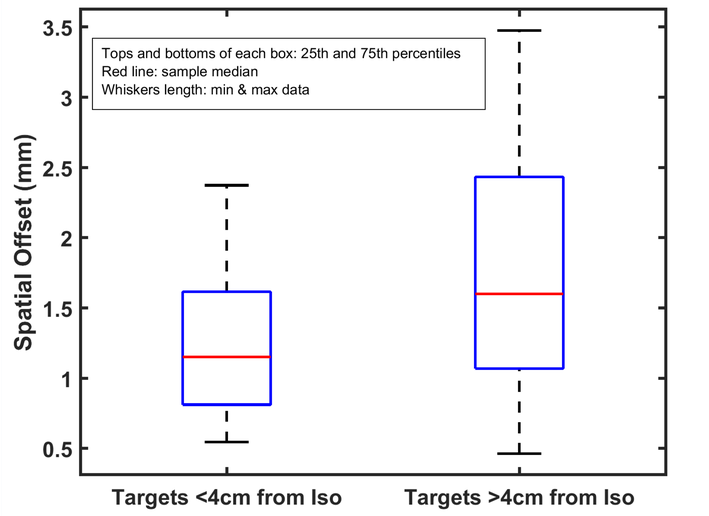

Figure 2.

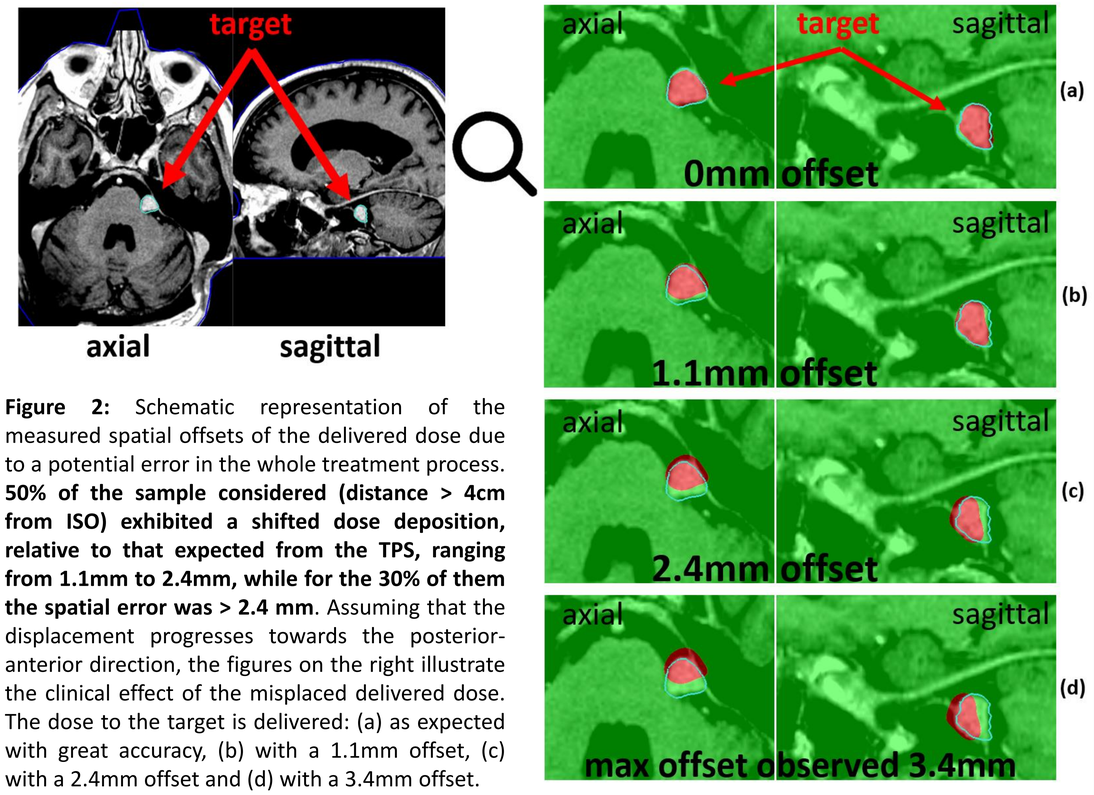

Figure 2: Schematic representation of the measured spatial offsets of the delivered dose due to a potential error in the whole treatment process. **50% of the sample considered (distance > 4cm from ISO) exhibited a shifted dose deposition, relative to that expected from the TPS, ranging from 1.1mm to 2.4mm, while for the 30% of them the spatial error was > 2.4 mm**. Assuming that the displacement progresses towards the posterior-anterior direction, the figures on the right illustrate the clinical effect of the misplaced delivered dose. The dose to the target is delivered: (a) as expected with great accuracy, (b) with a 1.1mm offset, (c) with a 2.4mm offset and (d) with a 3.4mm offset.

SUMMARY / CONCLUSION

This study provides useful statistics, derived by experimental End-to-End QA results, related to the overall spatial uncertainties governing the entire treatment chain of single-isocenter multi-focal cranial SRS. Spatial accuracy was found to deteriorate with increasing distance from the isocenter. The presented results suggest that a millimeter-level margin should be considered at least for the most distant and small size targets.

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