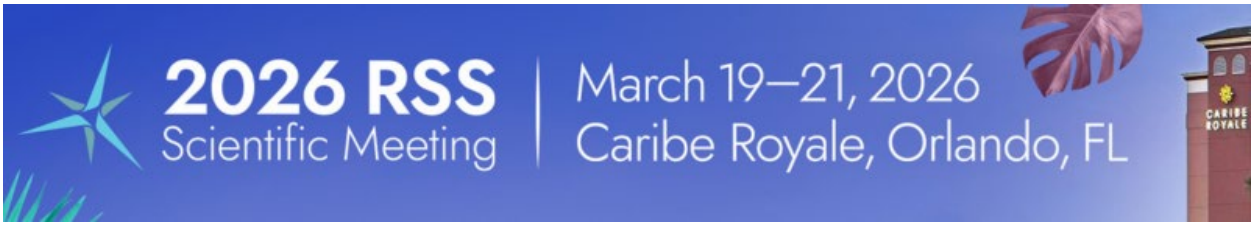

A Novel HyperArc RapidPlan Model for Stereotactic Treatment of Ocular Malignancies

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Objectives: Currently a range of radiotherapy treatment modalities are used for the treatment of ocular malignancies, each with unique advantages and challenges. Brachytherapy using COMS plaques offers exceptional dose conformity, ideal for small tumors, but is often not possible for large lesions or those adjacent to critical structures like the optic nerve. Moreover, COMS brachytherapy is not commonly available in every cancer center including community centers. LINAC-based external beam photon therapy and stereotactic radiosurgery (SRS) platforms—such as CyberKnife and Gamma Knife—provide less invasive, high-precision treatment options. However, these methods often result in greater exposure of surrounding normal tissues compared to COMS brachytherapy, influenced by beam geometry, margin definition, and fractionation protocols. Proton beam therapy demonstrates promising outcomes but faces significant barriers: it requires invasive tantalum clip implantation for motion management and suffers from limited global accessibility due to the scarcity of specialized treatment centers. Enucleation (surgical eye removal), achieves comparable local tumor control to globe-sparing techniques and therefore, is falling out of favor. There exists a need for additional, novel, minimally invasive treatments that deliver highly conformal radiation, minimize normal tissue toxicity, and are widely accessible across diverse healthcare settings. HyperArc, a stereotactic radiosurgery platform, streamlines planning and delivery by automating arc geometry, isocenter placement, and collimator angle optimization. Studies have demonstrated its superiority over conventional VMAT planning for intracranial lesions and recurrent head and neck tumors, improving efficiency and plan quality. Nevertheless, HyperArc currently relies on manual optimization as the standard workflow, which remains time-intensive and prone to inter-planner variability. RapidPlan, serves to enhance treatment planning quality and efficiency via the automated generation of optimization objectives during the treatment planning process. While the integration of HyperArc and RapidPlan has been documented in the recent literature for brain and head and neck applications, to the best of our knowledge, no study has developed or validated a RapidPlan model specifically tailored for ocular/intraocular SRS treatment using the HyperArc platform. The purpose of this study is to develop and validate a dedicated RapidPlan model for ocular malignancies treated with HyperArc. This ocular-specific model, trained with plans based on HyperArc's geometry, aims to achieve near-complete automation of the treatment planning process for ocular SRS treatments using HyperArc. By improving optimization efficiency through RapidPlan and utilizing a standardized treatment geometry with automated HyperArc module, this approach could offer substantial improvements in planning efficiency and plan quality. Ultimately, this work aims to make highly precise, globe-sparing ocular SRS more accessible, reliable, and feasible for a wider range of institutions including community practice.

Methods: RapidPlan model training and validation requires two datasets. A high-quality training dataset and a separate testing dataset for model verification. Currently, our institution utilizes COMS

plaque therapy for ocular treatments, therefore no HyperArc compatible CT datasets with ocular malignancies were available for inclusion in either dataset. To overcome the critical data gap, two distinct datasets were created: a training set of 80 anonymized HyperArc CT scans with synthetically generated tumor contours; and a testing set of 20 hybrid datasets combining 20 HyperArc CT scans with 20 COMS contrast-enhanced MRI scans (MPRAGE, gadolinium, 1-mm slices), where tumor contours from MRI were manually re-drawn onto CT slices to ensure clinically realistic geometries compatible with HyperArc planning. Manual planning followed a standardized approach. PTVs were derived from a 2-mm static expansion of the GTV. A prescription of 25 Gy in 1 fraction was prescribed. Optic pathway sparing was of notable concern, defined by an optic nerve Dmax < 12 Gy per HyTEC guidelines. Other organ-at-risk (OAR) were contoured. All plans were normalized such that PTVD95% = 25 Gy. Planning was done using the Eclipse treatment planning system (v16.12). Plans were designed for use with the HyperArc treatment module via a 6-MV FFF beam, and Accuros-XB dose calculation engine. Model development employed an iterative approach. V1.0 trained on 75 manually planned cases (5 excluded due to Eclipse memory limits); V2.0 generated from V1.0 replans; V3.0 refined from V2.0 replans, with outlier plans and/or structure sets removed to yield the final V3.1 RapidPlan model. Plan comparisons comprised qualitative review by an experienced radiation oncologist and medical physicists, and quantitative plan quality metrics (Paddick Conformity Index, Gradient Index, Heterogeneity Index). Plan deliverability was evaluated using patient-specific quality assurance via EPID-based dosimetry (2%/2mm and 3%/1mm gamma criteria, 90% pass rates), and independent Monte Carlo second checks. For comparison between manual plans and RapidPlan-generated plans, a one tailed students t-test was used ($p < 0.05$) to determine statistically significant difference between the two methods.

Results: Results demonstrate that ocular RapidPlan modeling for HyperArc-based SRS achieves clinically equivalent target coverage while significantly improving OAR sparing and dramatically enhancing planning efficiency. Comparison between the training and testing dataset revealed statistically insignificant differences in GTV (median 1.00 cc vs. 0.78 cc, $p = 0.061$) and PTV volumes (2.41 cc vs. 2.36 cc, $p = 0.284$), though the test set exhibited significantly greater median optic nerve distances (2.40 mm vs. 1.00 mm, $p = 0.007$) Target coverage metrics (Dmean, Dmax) were similar between RapidPlan and manual plans ($p > 0.05$), this is consistent with RapidPlan's reliance on manually defined target objectives. RapidPlan generated significantly lower maximum doses to adjacent OARs such as the ipsilateral optic nerve (7.18 Gy vs. 4.56 Gy, $p < 0.001$), lacrimal gland (15.52 Gy vs. 11.03 Gy, $p < 0.001$), lens (9.36 Gy vs. 7.64 Gy, $p = 0.022$), brainstem (0.99 Gy vs. 0.66 Gy, $p = 0.019$), and chiasm (0.89 Gy vs. 0.46 Gy, $p = 0.002$). RapidPlan plans resulted in higher brain maximum doses (7.20 Gy vs. 6.00 Gy, $p < 0.001$) as a trade-off for superior adjacent OAR protection. Skin dose showed no significant difference (22.88 Gy vs. 22.84 Gy, $p = 0.250$). Planning efficiency was improved, with RapidPlan reducing average planning time from 120 minutes to 15.0 ± 2.2 minutes ($p < 0.001$). Plan delivery efficiency improved with RapidPlan as demonstrated by decreases in total monitor units (10,190 vs. 11,513, $p = 0.011$), beam modulation factor (4.08 vs. 4.61, $p = 0.011$), and beam-on time (7.28 vs. 8.22 minutes, $p = 0.011$). Quality assurance metrics were comparable, with no significant difference in EPID-based portal dosimetry QA pass rates, though RapidPlan demonstrated a statistically significant improvement in Monte Carlo second-check results (98.7% vs. 97.8%, $p = 0.008$), confirming plan deliverability was acceptable using both methods.

Conclusion(s): We successfully developed and validated a HyperArc-based RapidPlan model specifically developed for ocular SRS treatments that can achieve clinically equivalent target coverage while significantly improving OAR sparing and planning efficiency. Compared with manual planning, RapidPlan reduced plan optimization time from 120 to 15 minutes, decreased beam-on time and modulation, and maintained high-quality, deliverable SRS plans. These results suggest that

integrating RapidPlan modeling with HyperArc module could streamline ocular SRS planning, enhance treatment plan consistency, and further expand access to precise, globe-sparing radiotherapy for an underserved patient population.