International Journal of Research in Medical Sciences
Gloi AM. Int J Res Med Sci. 2024 Feb;12(2):566-571
www.msjonline.org
pISSN 2320-6071 | eISSN 2320-6012

DOI: https://dx.doi.org/10.18203/2320-6012.ijrms20240228

Case Report

HyperArc multiple brain metastases report

Aime M. Gloi*

Genesiscare, Modesto, California, United States of America

Received: 16 December 2023
Revised: 06 January 2024
Accepted: 09 January 2024

***Correspondence:**
Dr. Aime M. Gloi,
E-mail: agloi7288@gmail.com

ABSTRACT

This report presents the initial clinical experience with HyperArc, a novel modality that incorporates a non-coplanar, arc-based multileaf collimator (MLC) and automated treatment optimization and dose delivery. The study focuses on a patient who had previously received whole-brain radiotherapy. The effectiveness and challenges of HyperArc were assessed by evaluating various quality indices for stereotactic radiosurgery within the RTOG protocol, as well as an additional measure of toxicity in the form of the V_{12Gy} volume. The HyperArc plan achieved quality indices of 1.13, 4.58, and 0.88 for CI, GI, and CIPaddick, respectively. The mean ICRU83 value was 0.17±0.01, and it remained consistent across all six lesions. The V_{12Gy} value was equal to 8.76 cc. The HyperArc plan successfully met the constraints for organs-at-risk (OAR). These results suggest that HyperArc is a suitable modality for treating multiple brain metastases, as indicated by the quality indices and metrics. Additionally, V_{12Gy} is a valuable indicator for assessing low-dose spillage.

Keywords: HyperArc, RTOG quality indices, Brain metastases, Stereotactic radiosurgery

INTRODUCTION

Brain metastases are among the most common intracranial tumors in both adults and children, and they are typically treated with whole-brain radiotherapy.[1] A new method involving whole-brain and high-definition linac-based radiotherapy has been implemented in various clinics and hospitals to effectively treat multiple brain lesions in different regions of the brain. HyperArc is an isocentric VMAT planning and automated treatment technique that uses a high definition multileaf collimator (HDMLC) for stereotactic radiotherapy delivery. It utilizes a single isocenter and a combination of arcs and couch rotation, as well as non-coplanar beam arrangements to reduce peripheral doses.

The optimization process includes an SRS automatic normal tissue objective (NTO) to enhance the dose decay between targets and minimize doses below 17% of the prescription from spilling.[2]

The purpose of this report is to present the first successful HyperArc treatment delivery after whole-brain irradiation at our clinic.

CASE REPORT

Patient narrative

The 73-year-old patient, who had a history of metastatic non-small cell lung cancer with multiple lesions, underwent whole-brain radiation therapy in April to target several areas of concern identified in the brain. She responded well to treatment and remained stable until an magnetic resonance imaging (MRI) in October of 2023 showed two new brain lesions which were consistent with metastatic disease. Furthermore, the patient had been experiencing intermittent headaches and occasional bouts of dizziness for quite some time and these symptoms had become a chronic condition. Despite these, there were no other changes in her neurological status or short-term memory, and a comprehensive review of her symptoms yielded no significant results.

Therefore, she was subsequently referred for HyperArc treatment, available on the TrueBeam Varian Edge 2.7 system (Varian Medical Systems, Palo Alto, USA), equipped with a high-definition multi-leaf collimator (HDMLC), to simultaneously treat multiple brain metastases with a single isocenter using non-coplanar arcs. The patient was immobilized using the Encompass SRS Immobilization System (QFix, Avondale, PA). Computed tomography (CT) scans with a slice thickness of 1.25 mm were obtained in the supine position, and MRI T1 post-contrast scans were used to delineate the target volumes. Six lesions ranging in size from 0.23 cc to 1.46 cc were identified and included in the treatment; these are listed in Table 1.

Table 1: Lesions characteristics.

Lesions	Volume (cc)
Left medial front	0.23
Left medial ventricular	0.56
Left post ventricular	1.46
Right inf cerebellum	0.28
Right post occipital	0.36
Lt occipital	0.80
Total volume	3.69

The planning was performed using the treatment planning system (TPS) (Eclipse, v15.6.04, Varian Medical Systems, Palo Alto, USA). The plans were optimized using a 6 FFF flattened, filter-free beam with a maximum dose rate of 1400 MU/min. The HyperArc software selected the isocenter at the center of mass of all brain metastases lesions and optimized the collimator angles for each arc to minimize the dose to normal brain tissue. The organs at risk (OARs) considered for optimization included the brain (excluding the PTV), eyes, lenses, optic chiasm, optic nerves, brainstem, and hippocampi.

Plan quality

The plan quality was assessed using metrics from the radiation therapy oncology group (RTOG), including the conformity index, Paddick conformity index, gradient index, ICRU83 index, and falloff index PIV50%/TV.[3-6]

Quality assurance

Patient-specific quality assurance (PSQA) pretreatment was performed using portal dosimetry, a Multimet Cube (Sun Nuclear Corporation, Melbourne, Florida, USA), and an MPC-enhanced couch.

Patient setup and verification

The patient setup involved the use of surface guided AlignRT (Vision RT Ltd, London, UK, Version 5.1.2) for initial positioning. This was followed by KV/KV imaging to assess the bony anatomy and CBCT for tumor localization.

Results

The beam arrangements, isodose distribution, and dose-volume histogram (DVH) for a patient with six metastatic brain lesions are shown in Figure 1.

Figure 1: Arc1.

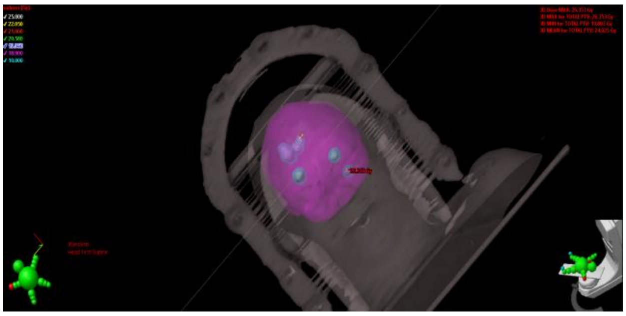

Figure 2: Arc2.

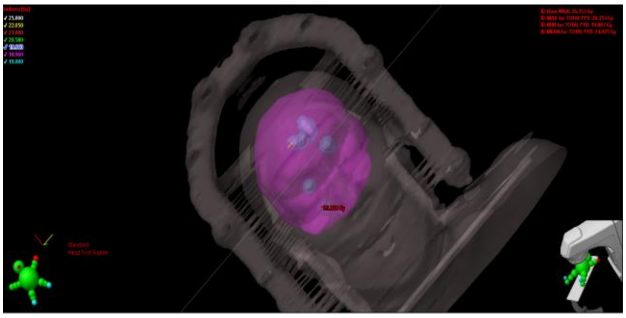

Figure 3: Arc3.

The plan exhibited a steep dose gradient, with a PTV of 3.69 cm^3 and maximum 50% and 100% isodose volumes of 16.90 cm^3 and 4.16 cm^3, respectively. The collimator, gantry, and couch beam arrangements, along with their corresponding monitor units (MUs), are listed in Table 2.

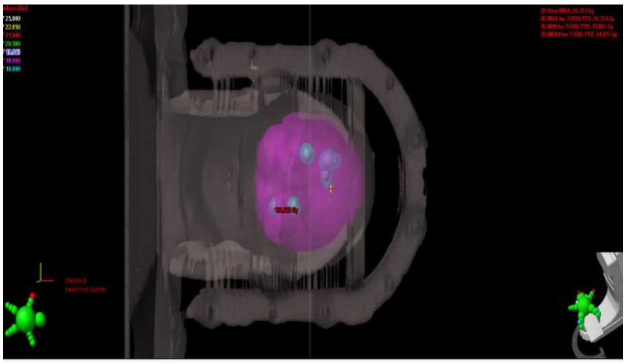

Figure 4: Arc4.

Table 2: HyperArc plan characteristics for this report.

Arcs	Gantry	Collimator	Couch	MU
1	180.1-179.9	78	0	2648.1
2	179.9-0.0	78	315	1795.6
3	0.0-180.1	129	45	2218.7
4	180.1-0.0	108	129	1780.6

Table 3 provides the maximum dose to adjacent organs at risk (OARs). The results demonstrate that the treatment planning technique generated clinically acceptable plans for metastases of various sizes.

The quality metrics for the HyperArc plan are summarized in Table 4. The V_{12Gy}, calculated from healthy brain tissue, was 8.76 cm³. The volume of tissue outside the PTV receiving a dose greater than 105% of the prescription dose was 0.11 cm³, which corresponds to 2.90% of the PTV volume. This indicates a small amount of intermediate dose spillage in the adjacent normal tissues, which is desirable for re-irradiation of the brain. An additional checklist for evaluating plans is provided in Table 5.

Table 3: Oars maximum dose (Gy).

OARS	Maximum dose (Gy)
Brainstem	3.41
Optic chiasm	2.193
Optic nerve left	1.246
Optic nerve right	1.644
Lens right	0.739
Lens left	0.536
Optic nerve right	1.644
Optic nerve left	1.246

The plan quality metrics for the HyperArc plan are summarized in Table 4.

Quality assurance

Pretreatment QA

Patient-specific quality assurance (PSQA) was performed using portal dose verification, achieving a passing rate of 95% and a gamma index of 99.9-100% for all fields. The calculations were computed with a tolerance of (3 mm, 2%). The HyperArc plan met the tolerance limit criteria recommended by the AAPM TG-218, with a gamma passing rate of 95% using 3%/2 mm criteria.[7] Figure 4 illustrates this concept for an arc.

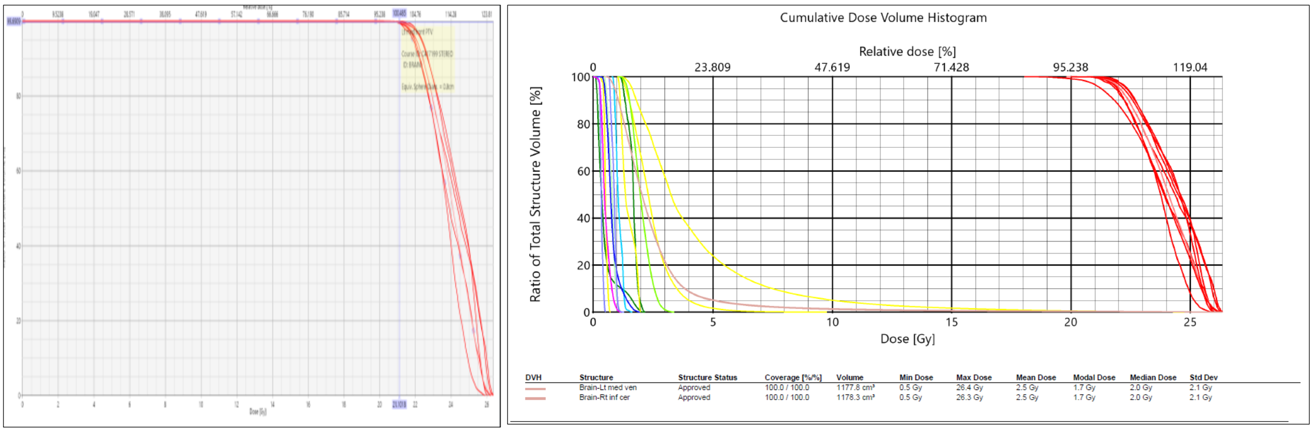

Figure 5: Dose distributions and cumulative dose volume histograms of all PTVs and OARs, from HA plan, for a patient with six lesions treated in a single fraction with a prescription dose of 21 Gy.

Table 4: Hyperarc quality metrics.

PTVs	RTOG CI	Paddick CI	GI	ICRU83 HI	Volume	Diameter (cm)
Left occ	1.33	0.68	3.47	0.16	0.8	1.2
Left med Front	1.62	0.50	5.22	0.17	0.23	0.8
Left med vent	1.42	0.62	12.46	0.16	0.56	1.0
Left post vent	1.27	0.69	4.56	0.15	1.46	1.4

Continued.

PTVs	RTOG CI	Paddick CI	GI	ICRU83 HI	Volume	Diameter (cm)
Right inf cerebellum	1.58	0.55	4.47	0.17	0.28	0.8
Rt post occ	1.42	0.59	4.33	0.19	0.36	0.9
Mean	1.44	0.605	5.75	0.17	0.615	1.016
SD	0.13	0.067	3.04	0.01	0.423	0.219

Table 5: SRS plan evaluation.

SRS plan evaluation	Evaluating parameters						
Treatment site	Multiple brain metastases						
Number of fields	4	Modality	ARCS	Technique	Hyperarc		
Energies	6FFF	No. of Fx	1	PD (cGy)	2100		
MU check passed?	Yes			IMRT QA passed?	Yes		
Maximum dose (dose statistics/DVHs)				**PD (cGy)**	**D_{max} (cGy)**	**PD (%)**	**Yes/no**
Is maximum dose within PTV?				2100	2635.3		Yes
Is prescription dose ≥60% and <90% of the maximum dose?						79.69%	Yes
Prescription isodose surface coverage (cumulative DVHs)						**PTV V_{Rx}**	**Yes/no**
Is 95% of PTV conformally covered by the prescription dose (PTV V100%PD ≥95%)?						100	Yes
Does 99% of PTV receive a minimum of the prescription dose (PTV V90%PD ≥99%)?						100	Yes
High dose spillage (:105% isodose volume minus PTV)							
The cumulative volume of all tissue outside the PTV receiving					**V(cc)**	**V (%)**	**Yes/no**
a dose >105% of the prescription dose should be no more than 15% of the PTV volume					0.11	2.90	Yes
PTV volume (cc)	3.69	TV_{PIV} (cc)	3.68	CI	1.13	GI	4.58
100% V_{Rx} (cc)	4.16			$CI_{Paddick}$ (³ 0.8 & £ 1.0)	0.88		
50% V_{Rx} (cc)	16.90						

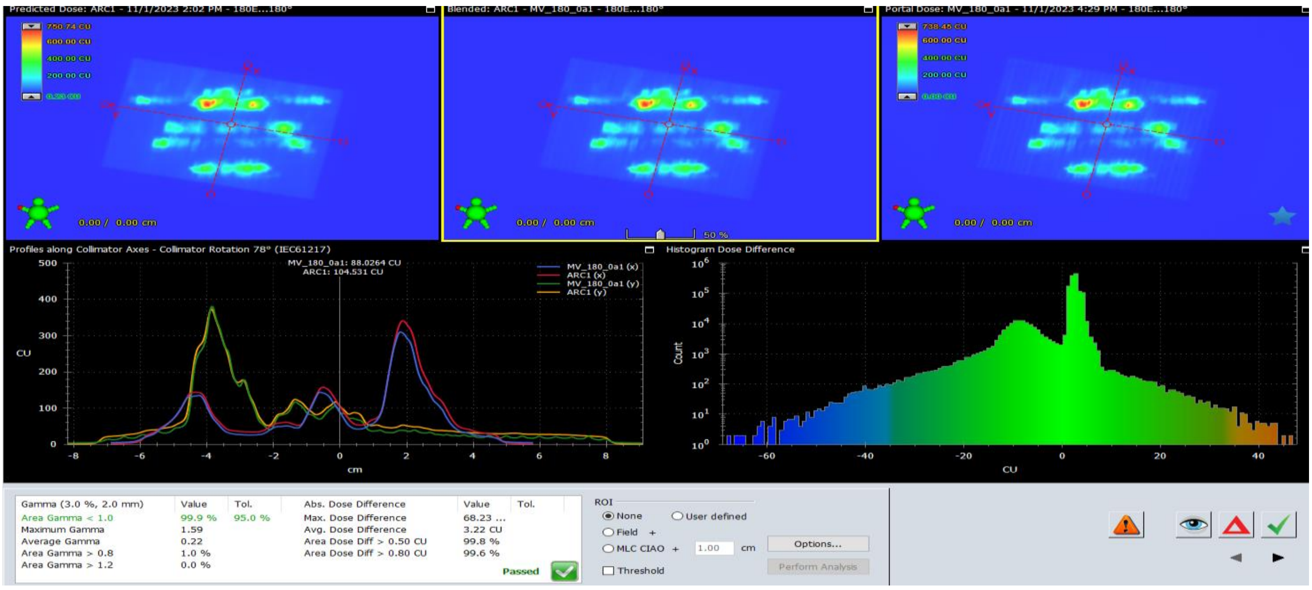

Figure 6: Visual representation of the gamma analysis for tolerances (3%/2mm) for the portal dosimetry qa resulting from the HyperArc plan.

Machine performance check (MPC)

The machine performance check (MPC) included an enhanced couch module to test the size of the treatment isocenter and its alignment with the imaging system. It also confirmed the accuracy of the imaging system's positioning, the collimator, the gantry, jaws, MLC leaves, and the couch position. Dosimetry checks were conducted to ensure that the beam output, uniformity, and center shift met the requirements.

The dimensions of the MPC-enhanced couch were compared with standard couch measurements across an extended range of positions, and the results are presented in Table 6.

Table 6: MPC enhanced couch.

Parameters	Within thresholds	Values	
Enhanced couch			
Maximum positioning error (mm)	Within thresholds	0.32	±0.70
Lateral (mm)		0.19	±0.70
Longitudinal (mm)		0.28	±0.70
Vertical (mm)		0.23	±0.70
Rotation (fine) (°)		0.05	±0.30
Rotation (large) (°)		0.08	±0.40
Pitch (°)		0.00	±0.10
Roll (°)		0.02	±0.10
Rotation-induced couch shift (full) (mm)		0.57	±0.75
Beam			
Output change (%)	Within thresholds	0.09	±2.00
Uniformity change (%)		0.10	±2.00
Center shift (mm)		0.02	±0.50

Pretreatment

Patient immobilization

Pretreatment patient immobilization was achieved using an open-face mask, which allowed for initial patient positioning (Figure 7). The exposed area was then used as the region of interest for AlignRT's optical surface imaging. A KV/KV X-ray was performed to match the bony anatomy of the skull, followed by CBCT for tumor localization.

Figure 7: Open-face mask immobilization system used in AlignRT for pre-treatment surface tracking before and after alignment.

DISCUSSION

This case describes the initial application of the non-coplanar mono-isocenter HyperArc SRS technique for treating brain metastases after whole-brain radiotherapy. The treatment protocol involved an initial setup with AlignRT using an open mask, followed by KV/KV imaging for bony anatomy and CBCT for tumor localization. The imaging, collision check, dry run, and treatment all took less than 15 minutes. The optimization was performed using the stereotactic normal tissue objective (SRS-NTO), which automatically created virtual shells around the intended GTVs to meet dose constraints. This involved achieving a sharp dose falloff and preventing dose bridging in adjacent tissues.[8] HyperArc plans aim to consistently reduce the radiation dose to multiple OARs while ensuring tumor coverage and dose conformity using non-coplanar arcs. The quality of the plan was assessed using indices commonly employed in stereotactic treatments. The conformity index (CI), gradient index (GI), and CIPaddick were found to be 1.13, 4.58, and 0.88, respectively. These results are comparable to those reported for the HyperArc treatment of multiple brain metastases.[9-11] The ideal values for a GI of ≤3, as proposed by Paddick et al are recommended.[12] The treatment was for a single-lesion stereotactic radiosurgery (SRS). However, in this case, the GI was slightly higher at 4.58 for multiple brain metastases (BMs). Factors that can influence GI include the size and shape of the target. A higher GI is associated with larger doses and is correlated with radiation-induced brain necrosis. It is also highly correlated with a V12Gy volume, which in this case is 8.76 cc, well below the threshold for a single lesion as described by Kirkpatrick et al.[13] Furthermore, the homogeneity index (HI), as defined by ICRU 83, was consistent across all lesions, with a value of 0.17±0.01, indicating a more uniform dose distribution. The current study has some limitations, such as the inclusion of only one patient, which makes comparisons difficult. In addition, due to the small target size, treatment delivery requires strict adherence to the mechanical parameters outlined by AAPM TG101.[14] Successfully, Gloi et al demonstrated that the Winston-Lutz test, using the Multimet Cube and the MPC-enhanced couch, could improve the overall isocentric accuracy to within 0.30 mm.[15] Furthermore, HyperArc is an automated delivery method using a flattening filter-free (FFF) system operating at 1400 MU/min, which reduces treatment time and enhances patient comfort.

CONCLUSION

HyperArc offers a combination of highly conformal dose distribution, rapid dose fall-off, and effective treatment for multiple brain lesions while minimizing damage to nearby organs within a short timeframe.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: Not required

REFERENCES

1. Patchell RA. The Management of Brain Metastases. Cancer Treat Rev. 2003;29(6):533-40.
2. Ohira S, Ueda Y, Akino Y, Hashimoto M, Masaoka A, Hirata T, et al. HyperArc VMAT planning for single and multiple brain metastases stereotactic radiosurgery: a new treatment planning approach. Radiat Oncol. 2018;13(1):13.
3. Shaw E, Kline R, Gillin M, Souhami L, Hirschfeld A, Dinapoli R, et al. Radiation Therapy Oncology Group: radiosurgery quality assurance guidelines. Int J Radiat Oncol Biol Phys. 1993;27(5):1231-9.
4. Paddick I. A simple scoring ratio to index the conformity of radiosurgical treatment plans. Technical note. J Neurosurg. 2000;93(3):219-22.
5. Paddick I, Lippitz B. A simple dose gradient measurement tool to complement the conformity index. J Neurosurg. 2006;105:194-201.
6. ICRU. Report 83: Prescribing, Recording, and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT). J ICRU. 2010;10(1):1-106.
7. Miften M, Olch A, Mihailidis D, Moran J, Pawlicki T, Molineu A, et al. Tolerance limits and methodologies for IMRT measurement-based verification QA: Recommendations of AAPM Task Group No. 218. Med Phys. 2018;45(4):e53-e83.
8. Ohira S, Ueda Y, Akino Y, Hashimoto M, Masaoka A, Hirata T, et al. HyperArc VMAT planning for single and multiple brain metastases stereotactic radiosurgery: a new treatment planning approach. Radiat Oncol. 2018;13(1):13.
9. Simon M, Papp J, Csiki E, Kovács Á. Plan Quality Assessment of Fractionated Stereotactic Radiotherapy Treatment Plans in Patients With Brain Metastases. Front Oncol. 2022;12:846609.
10. Ruggieri R, Naccarato S, Mazzola R, Ricchetti F, Corradini S, Fiorentino A, et al. Linac-Based Radiosurgery for Multiple Brain Metastases: Comparison Between Two Mono-Isocenter Techniques with Multiple Non-Coplanar Arcs. Radiother Oncol. 2019;132:70-8.
11. Hsu SM, Lai YC, Jeng CC, Tseng CY. Dosimetric Comparison of Different Treatment Modalities for Stereotactic Radiotherapy. Radiat Oncol. 2017;12(1):1-11.
12. Paddick I, Lippitz B. A simple dose gradient measurement tool to complement the conformity index. J Neurosurg. 2006;105:194-201.
13. Kirkpatrick JP, Soltys SG, Lo SS, Beal K, Shrieve DC, Brown PD. The radiosurgery fractionation quandary: single fraction or hypofractionation? Neuro Oncol. 2017;19(2):38-49.
14. Benedict SH, Yenice KM, Followill D, Galvin JM, Hinson W, Kavanagh B, et al. Stereotactic body radiation therapy: the report of AAPM Task Group 101. Med Phys. 2010;37(8):4078-101.
15. Gloi AM. Feasibility of MPC enhanced couch as SRS/SBRT Pretreatment QA. Int J Sci Res Updates. 2023;6(2):1-16.

Cite this article as: Gloi AM. HyperArc multiple brain metastases report. Int J Res Med Sci 2024;12:566-71.