Section: Radiation Oncology

Original Research Article

ROLE OF STEREOTACTIC BODY RADIOTHERAPY / STEREOTACTIC RADIO SURGERY IN VARIOUS METASTATIC SITES – AN OBSERVATIONAL STUDY

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ABSTRACT

Background: Stereotactic radiosurgery (SRS) and stereotactic body radiotherapy (SBRT) have emerged as precise and effective modalities for the management of metastatic lesions in the brain and liver. This study aimed to evaluate treatment outcomes, dosimetric parameters, and toxicity profiles associated with these techniques.

Materials and Methods: This observational study included 12 patients treated between May 2023 and February 2025 . Ten patients underwent SRS or fractionated SRS for brain metastases, while two patients received SBRT for liver metastases. Treatment response was assessed at 3 months using RECIST/PERCIST criteria. Dosimetric indices, toxicity profiles (graded as per CTCAE), and correlations between treatment variables and outcomes were analyzed.

Results: The mean age of patients was 54.5 ± 10.0 years with equal gender distribution. Brain metastases were the most common site (75%). Fractionated SRS demonstrated a trend toward improved tumor control and reduced toxicity compared to single-fraction SRS, particularly in larger lesions. Dosimetric evaluation showed optimal conformity index (mean 1.02) and acceptable gradient indices, indicating high-quality treatment planning.At 3 months, disease control (complete/partial response and stable disease) was achieved in 75% of patients. Most patients experienced only grade 1–2 toxicities, with no grade 3 or higher adverse events observed. Correlation analysis revealed moderate associations between dose per fraction and toxicity, and between number of lesions and tumor control; however, these findings were not statistically significant. SBRT for liver metastases demonstrated acceptable dosimetric and clinical outcomes, although interpretation was limited by small sample size.

Conclusion: SRS and SBRT are effective and well-tolerated treatment modalities for metastatic brain and liver lesions, offering favorable tumor control with minimal toxicity. Fractionated SRS may provide advantages in selected patients with larger or critically located lesions. These findings support individualized stereotactic treatment approaches, although larger prospective studies are required to validate these results.

Keywords: Stereotactic radiosurgery; SRS; SBRT; brain metastases; liver metastases; dosimetric indices; toxicity; tumor control.

INTRODUCTION

The term “Stereotactic” refers to the use of a precise three-dimensional mapping technique to guide a procedure. The terminology in stereotactic irradiation can be confusing. The term "radiosurgery" or "stereotactic radiosurgery" (SRS) is best used for stereotactically guided conformal irradiation of a defined target volume in a single session but may also apply to treatments delivered in 2 to 5 sessions, although the term "fractionated stereotactic radiosurgery" more accurately describes this approach. The terms "stereotactic radiation therapy" (SRT), "stereotactic body radiotherapy" (SBRT), and "stereotactic ablative radiotherapy" (SABR) are used for stereotactically guided delivery of highly conformal radiation to a defined target volume in six or more fractions, typically using noninvasive positioning techniques, although they are commonly used for regimens with 2 to 5 fractions. While SRT could potentially refer to precision image-guided radiotherapy used with the same doses and schedules used for conventional radiotherapy, SABR is normally reserved for high, ablative doses of radiation usually with hypofractionated schedules.[1]

Stereotactic radiosurgery (SRS) and stereotactic radiotherapy (SRT) are techniques to administer precisely directed, high-dose irradiation that tightly conforms to an intracranial target to create a desired radiobiologic response while minimizing radiation dose to surrounding normal tissue. The term radiosurgery is used when all of the irradiation is done in 1 to 5 sessions or fractions, whereas the term stereotactic radiotherapy (SRT) is appropriate when 6 or more radiation fractions are administered, but SRS delivers a large dose of radiation on a single day and SRT has a fractionated treatment schedule more often. Although, the total dose in SRT may be larger than in SRS any single day will have a much smaller dose delivery. Both are used for the treatment of localized tumors in the brain. Advances in imaging, computers, and treatment planning in the last two decades have led to the development of a variety of different stereotactic radiosurgery/radiotherapy techniques and their wider applications.[1]

Stereotactic body radiation therapy (SBRT) is the term applied in the United States by the American Society of Therapeutic Radiology and Oncology (ASTRO) for the management and delivery of image-guided high-dose radiation therapy with tumor-ablative intent within a course of treatment that does not exceed 5 fractions to a tumor target of any body sites other than brain. The ability to deliver a single or a few fractions of high-dose ionizing radiation with high targeting accuracy and rapid dose falloff gradients encompassing tumors within a patient provides the basis for the development of SBRT. SBRT can be applied using noninvasive or minimally invasive stereotactic localization and radiation delivery techniques. It requires significantly improved delivery precision over that required for conventional radiotherapy. Pioneers in the field initially used customized ancillary equipment constructed in their own institutions to immobilize patients and to adapt ordinary linear accelerators for the task of precise internal tumor targeting. Now, however, the administration of high-dose, tightly focused external-beam radiation therapy is greatly facilitated by a wide assortment of commercially available systems that immobilize patients, address the problem of respiratory motion during treatment, and ensure accurate treatment with the use of image guidance.[1,2]

SBRT is used in the treatment of spinal tumors, liver tumors, and other sites as well. Treating lung cancer with SBRT is an excellent alternative choice for patients with medically inoperable tumors, elderly patients who are considered high risk for surgery, or patients who refuse surgical treatment. SBRT can deliver an optimal radiation dose to both new primary and metastatic cancer sites. It can also be used on previously irradiated sites safely to avoid damage to the critical structure, such as the spinal cord.[1]

MATERIALS AND METHODS

Study design: Prospective observational study (Single group)

Source of data: MNJ Institute of Oncology and Regional Cancer Center, Hyderabad

Study setting: Study conducted in Department of Radiation Oncology, MNJIO & RCC , Hyderabad.

Sample size: 12 (minimum)

Sampling method: All the eligible subjects willing to participate in the study will be sampled consecutively into the study.

Duration of study: 24 months from IEC clearance.

Study population: Patients attending the study setting with ≤ 3 metastatic liver lesions with maximum diameter of 6 cm or less elected for treatment with SBRT and / or 1-3 metastatic brain lesions ≤ 4cm for SRS is considered as study population.

Inclusion Criteria

Age- 18-70 , Patients with ECOG performance status 0,1,2, 1-3 liver metastases unequivocally seen on contrast enhanced CT and / or MRI in patients with previously histologically diagnosed carcinoma with a maximum size of single metastasis ≤ 6cm. Adequate organ function, defined as: >700 cc normal liver (liver-GTV) Hb 9.0 g/dL, platelets >80 bil/L, bilirubin <3.0 times upper limit of normal, AST or ALT <5.0 times upper limit of normal. Class A from Child’s Pugh Liver Score. Patients with brain metastases from any primary Contrast enhanced MRI showing 1-3 metastatic brain lesions with maximum size up to 4cm.

Exclusion Criteria

Age <18 and >70 with ECOG performance status: 3 & 4, Pregnancy, Serious medical comorbidities precluding radiotherapy, such as ataxia-telangiectasia or scleroderma, Wide spread metastatic disease, Active hepatitis or clinically significant liver failure

(encephalopathy, portal hypertension, varices), Clinically apparent ascites. Any previous radiotherapy where the mean dose to the liver ≥15Gy (conventional fractionation), where beams would be likely to overlap with those used to deliver SABR, or where previous doses to other critical normal structures would make re-irradiation unsafe.

Short life expectancy (i.e., <6 months), Unable to achieve target dose due to location or size of the lesion(s), Size of the brain lesion >4cm, Metastasis in the brainstem or within 1cm of optic apparatus and Patients who have neurological deficits and requires immediate surgery.

Methodology: Patients attending the study setting with ≤ 3 metastatic liver lesions with maximum diameter of 6 cm or less elected for treatment with SBRT and / or 1-3 metastatic brain lesions ≤ 4cm elected for treatment with SRS / SRT in whom oligo-metastatic status have been confirmed with imaging ideally by PET-CT within the 2 months preceding the treatment or MRI with contrast in case of brain lesions are been sampled consecutively into the study after obtaining the informed consent.

Pre-treatment evaluation

All the patients allocated for the study undergo the following investigations and work up.

- Complete blood picture (CBP)
- Renal Function Tests (RFT)
- Viral screening (HIV, HBsAg, HCV)
- Liver Function Test (LFT)
- Serum Electrolytes
- Whole body PET CT / Contrast enhanced CT of abdomen & Pelvis (CECT) in case of liver metastases.
- Histopathology of metastatic lesion in case of solitary liver lesion.
- Contrast enhanced MRI brain in metastatic brain lesions.

SRS / SRT Brain Immobilization and simulation

Patient is placed supine position in AIO (all in one) Board with hands by side and immobilized with a thermoplastic head only ray cast and appropriate neck rest. CT simulation is done from vertex to lower border of C2 vertebrae with 1mm slices. Fiducials are placed over glabella to create a user origin. Hair is removed to ensure consistent positioning during treatment and throughout all treatment sessions.

Target Delineation: Images were transferred to treatment planning system and fused with the contrast enhanced MRI of the brain. T1 weighted contrast images were used to delineate GTV. No separate margin is given for CTV, that is GTV = CTV. PTV is created with a 1 mm margin from GTV to account for the potential setup error. Organ at risk structures were created like, optic nerves, optic chiasm, eyes, lens, pituitary, hippocampus, brain stem, spinal cord, temporal lobe and rest of the brain. No separate PRVs (Planning Organ at Risk Volume) were created.[13]

Dose prescription and planning

The radio-surgical dose was delivered in 1-3 fractions. Dose was determined by the maximum diameter of the tumor volume and no of lesions and location of the metastases. metastases measuring > 14 cm3 and / or > 3 cm in diameter, dural metastases and more than 1 lesion were treated with 24-30 Gy in 3 fractions. Single fraction radio-surgical dose was determined according to RTOG PROTOCOL 90-05, except for tumour diameter more than 3 cm. Dose was prescribed to the 80–90% isodose line, which was to encompass the entire enhancing target volume. Treatment planning was performed using a LINAC-based approach with image guidance on a Truebeam LINAC machine, utilizing 6 to 8 non-coplanar fields. Cone Beam CT (CBCT) was taken before treatment delivery to ensure the tumour localization.[13]

Radio-surgical dose according to tumor diameter (RTOG PROTOCOL 90-05)

Maximum tumour diameter	Assigned dose
<2 cm	24 Gy
2.1-3 cm	18 Gy
3.1-4 cm	15Gy

Plan evaluation and treatment delivery: All patients were prescribed the desired dose per protocol to a reference isodose line of 80-90% such that prescribed dose covers the 100% of PTV; (for example: 18 Gy in 1 fraction prescribed to the 80% isodose line covering 100% of the PTV). This approach leads to a hotter center (central maximum dose > prescription dose), creating a steeper dose fall-off, to protect surrounding normal tissues. Plans are evaluated by seeing proper coverage of PTV, acceptable hotspot inside PTV up to 130%. Conformity index and gradient index are calculated and checked.

Conformity index is given by:

- RTOG Conformity Index

CI = VRI / VPTV

VRI: Volume enclosed by the Reference Isodose (usually prescription isodose) VPTV: Volume of the Planning Target Volume

- **Paddick Conformity Index**

CI = (TVPIV)2 / (TV x PIV)

TVPIV: Target volume covered by the prescription isodose

TV: Total target volume

PIV: Prescription isodose volume

Ideally Conformity Index is 1; and a good plan will have conformity index close to 1.24 Gradient index is calculated by the distance between isodose lines at 40%, 60% and 80%. Ideally, distance from Isodose 40% to 80% is < 8 mm, isodose 60% to 80% is < 2 mm. Plans with distance between isodose 60% to 80% < 3 mm were accepted while strictly confined to distance between isodose 40% to 80% <8 mm. Since the SRS / SRT plans are more heterogeneous by design, accepting hot spots inside the target, homogeneity index was not calculated or checked.

OAR dose constraints

Organs at risk	Dose constraint
Brain - PTV	V10 Gy < 12 cc or v12 Gy < 10cc
Brain stem	D max <15 Gy
Optic Apparatus	D max < 8 Gy

Cochlea	Mean <9 Gy
Spinal canal	D max< 14 Gy

After treatment approval patient specific QA (quality assurance) is done using TPS parameters. All SRS / SRT patients are admitted 2 days prior to the treatment and primed with injection dexamethasone of 8 mg twice daily for 2 days. All patients planned for fractionated SRS underwent treatment in alternate days whereas single fraction SRS took treatment after priming with dexamethasone in one day. Patient is positioned in treatment couch and after aligning a CBCT is taken and confirmed the location by a 3D - 3D match and treatment is delivered. After treatment patient is being sent home with tapered oral dexamethasone tablets.

Figure 1: (a) showing SRS planning using arc beams in truebeam , (b) showing target planned to an isodose line of 90% with sharp dose fall off.

Follow up and evaluation: All patients were followed up during and after treatment for a period of 3-6 months for CNS toxicities and response. CNS toxicities were graded according to RTOG criteria and assessed for all patients. A contrast enhanced MRI scan was taken after 3 months of protocol radio-surgical treatment and response was assessed using RECIST criteria. Outcomes was measured in terms of tumour control, CNS toxicities which accounts for the safety of the procedure.[13]

Figure 2: Dose Volume histogram of a patient planned for SRS single fraction 24 Gy. Red line represents the PTV showing 100% dose covering 100% of PTV and other lines represents OARs showing sharp dose fall off sparing all the OARs.

SBRT Liver: Immobilization and simulation. All patients assigned for SBRT liver will be immobilized with an abdomino - pelvic thermoplastic ray cast with hands placed above the head. CT simulation is done from manubrium sternum till pubic symphysis with 1 mm slice thickness. CT simulation is performed in four phases to account for respiratory motion: one during deep inspiration, one during deep expiration, one with intravenous contrast and one using a continuous free-breathing technique. There is no separate immobilization device used such as respiratory dampening techniques.

Target Delineation: PET CT and contrast enhanced MRI images are fused with the simulation CT images. GTV is contoured in each phase of respiration. CT image in free breathing phase is used to treat the patient. All the GTVs contoured in each phase of respiration is combined to get a final GTV. A margin of 5mm is given as ITV to account for target internal motion. A 5 mm margin was incorporated into the Planning Target Volume (PTV) to account for potential setup errors.

Critical organs at risk (OARs)—including the stomach, kidneys, remaining liver tissue, spleen, small bowel, heart, lungs, and duodenum—were meticulously delineated to assess and minimize radiation exposure during treatment planning. Normal liver should be taken as “whole liver” minus the GTV. Care should be taken not to inadvertently include the liver vasculature and/or gall bladder. The entirety of each kidney should be outlined separately to allow evaluation of individual kidney dose. A summation of the two volumes should also be created to evaluate total kidney dose. The stomach should be contoured from gastro-esophageal junction to duodenum using mediastinal windowing.

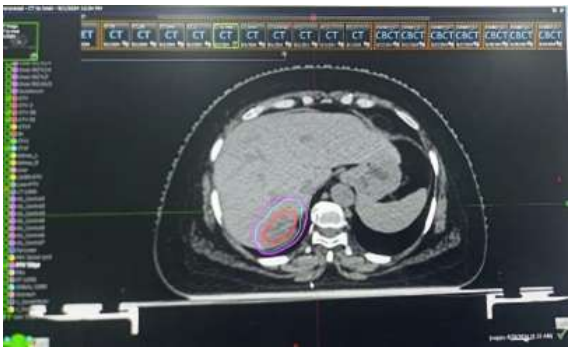


Figure 3: Red contours represents GTVs in different phases of respiration and combined GTV, blue contour represents the ITV and magenta contour represents the PTV. Dose prescription and planning.

Prescribed dose is planned to the PTV using 6-8 non coplanar beams in Truebeam LINAC machine using 6 MV and 15 MV photons. Dose prescription and planning is based on SABR UK Consortium guidelines. The dose distribution should be normalized so that 95% of the target volume receives at least 100% of the prescribed dose.

Suggested dose fractionation were;

- 45 - 60 Gy in 3 fractions
- 50 - 60 Gy in 5 fractions.

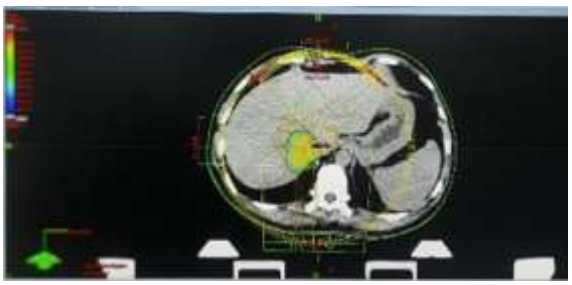


Figure 4: Treatment plan using non co-planar beams ensuring 100 % coverage of PTV with sharp dose fall off.

Plan evaluation and treatment delivery

Good conformity of the prescription isodose to the target volume and a steep dose gradient surrounding the target volume are the hall-marks of SABR planning. The SABR CtE QA program (Stereotactic Ablative Body Radiotherapy Commissioning through Evaluation Quality Assurance) modified the conformity and gradient indices to increase the sensitivity to detect poor conformity of the plan. The new indices were

- Prescription dose spillage = Vol(100%) / PTV V100%
- Modified Gradient index = Vol(50%) / PTV V100%

Where: "Vol(100%)" and "Vol(50%)" are the volumes of the patient receiving at least 100% and at least 50% of the prescription dose respectively and "PTV V100%" is the volume of PTV receiving at least 100% of the prescription dose.

Prescription dose spillage requirements

Volume PTV (cc)	Target
< 20	1.20
20-40	1.10
> 40	1.10

Modified Gradient Index requirements for non- lung sites

Volume PTV (cc)	Target
< 20	5.5
20-40	4.5
> 40	4.5

OAR dose constraints

Organs at risk	Dose constraint	
	3 fraction	5 fraction
Duodenum	D max < 22.2 Gy	D max < 35 Gy
Stomach	D max < 22.2 Gy	D max < 35 Gy
Small Bowel	D 5cc < 17.7 Gy	D 5cc < 25 Gy
Esophagus	D max < 25.2 Gy	D max < 34 Gy
Normal liver (Liver minus GTV)	Doseto≥700cc< 19.2Gy	D mean < 15.2 Gy
Kidneys.	Dose to ≥ 200 cc <16 Gy	D mean < 10 Gy.

Plan is approved after achieving the desired OAR constraints and required prescription dose spillage and modified gradient index to ensure the conformity of the plan. After approving the plan patient specific QA is done prior to treatment delivery. Patient is being admitted and given pre-medications with proton pump inhibitors (PPI) to reduce the risk of GI ulceration and anti- emetics for nausea prior to the treatment and entire course of treatment. A cone beam CT is taken before every fraction and matched to localize the lesion. Fractions are given in alternate days.

Follow up and evaluation: All patients receiving SBRT are reviewed weekly on treatment by physical examination, full blood count, urea and electrolytes, liver function and coagulation screen. All patients were followed up after treatment for a period of 3-6 months for liver and GI toxicities and response. A PET CT / MRI is done at 3 months after protocol treatment. Response was assessed according to RECIST / PERCIST criteria depending upon the investigations used. Toxicities were graded according to RTOG liver and GI toxicity criteria.

Statistical analysis: The following statistical methods and analyses were used in the study.

Descriptive Statistics: Used to summarize age, sex, lesion count, tumor volumes, and dose parameters. The outputs included mean, standard deviation, minimum, and maximum values. Frequency Distribution Applied to assess the distribution of metastatic sites, primary diagnosis, dose levels, and toxicity grades.

Correlation Analysis (Pearson): Pearson correlation coefficients were used to measure linear relationships between numeric variables such as total dose, dose per fraction, number of lesions, PTV volume, and local control outcomes. No formal hypothesis tests (e.g., t-tests, Chi-square, Cox regression, or survival analysis) were performed due to limited sample size and absence of survival follow-up duration.

RESULTS

Between May 2023 and February 2025, 12 patients were entered in the protocol treatment from the study setting. 10 patients underwent SRS / fractionated SRS for brain metastases while 2 patients received SBRT for liver metastases. All 12 cases were analysed to attain the following observations and results.

Table 1: Patient Characteristics

Characteristic	Value / Description
Total number of patients	12
Age (mean ± SD)	54.5 ± 10.0 years
Sex distribution	Female: 6 (50%), Male: 6 (50%)
Common primary diagnoses	Carcinoma Breast (5), Carcinoma Lung (3), Others (4)
Common site of metastasis	Brain (9), Liver (2), Dural Brain Mets (1)
ECOG Performance Status	ECOG 2: 11, ECOG 1: 1

Most patients were between 40–70 years of age, with a predominance of brain metastases. The majority had ECOG 2, indicating symptomatic but ambulatory status.

Table 2: PTV Volume by Treatment Modality

Treatment	Mean PTV Volume (cc)	Min Volume (cc)	Max Volume (cc)
SRS	6.17	0.80	16.40
SBRT	67.60	40.20	95.00

SRS was the predominant treatment modality. Among the 10 SRS patients, 5 received single-fraction treatment (18–24 Gy), while 5 received fractionated SRS (24–30 Gy in 3 fractions). Two patients with liver metastases received SBRT (45 Gy/3 fractions and 50 Gy/5 fractions).

PTV volumes were significantly smaller in SRS-treated brain lesions compared to SBRT-treated liver lesions, reflecting differences in target size and anatomical location.

Table 3: Dose and Fractionation Schedule

SRS Brain	Dose	No of patients		
		1 fraction	3 fractions	5 fractions
	18Gy	2		
	24Gy	2	2	
	27Gy		1	
	30Gy		1	
SBRT Liver	45Gy			1
	50Gy			1

Both single-fraction and hypofractionated SRS regimens were used for brain metastases. SBRT liver treatments followed standard hypofractionated schedules.

Table 4: Dosimetric Indices

SRS Dosimetric Indices	Mean	Min	Max	Standard Deviation (SD)
Conformity Index	1.02	0.94	1.08	0.05
Gradient Index (iso 60 - iso 80)	2.57	2.00	3.00	0.30
Gradient Index (iso 40 - iso 80)	6.57	4.50	7.80	1.07
SBRT Dosimetric Indices				
Prescription Dose Spillage	1.20	1.15	1.25	0.07
Modified Gradient Index	4.53	4.34	4.72	0.27

SRS plans demonstrated excellent conformity and acceptable gradient fall-off. SBRT plans showed adequate dose spillage and gradient characteristics within clinically acceptable limits.

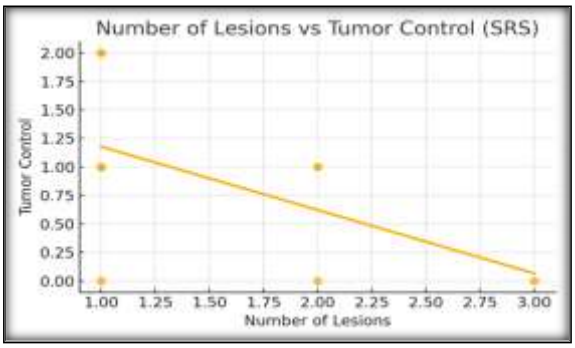
Toxicity Outcomes: Most patients experienced grade 1–2 toxicities, with no grade 3 or 4 toxicities observed. SBRT-treated patients exhibited only grade 2 gastrointestinal and hepatic toxicities.

Performance Status: At follow-up, 9 patients remained at ECOG 2, 2 patients deteriorated to ECOG 3, and 1 patient worsened from ECOG 1 to ECOG 2.

Table 5: Tumor Response at 3 Months

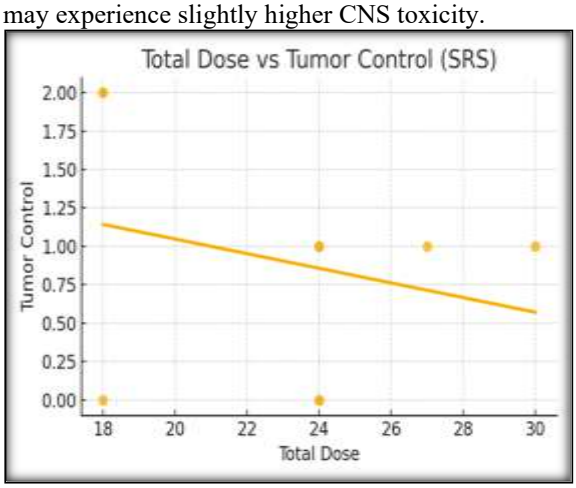
Tumor Response	Number of Patients
Improved	2
Unchanged	7
Progressed	3

Disease control rate (improved + stable) was 75%. Response was assessed using RECIST/PERCIST criteria.



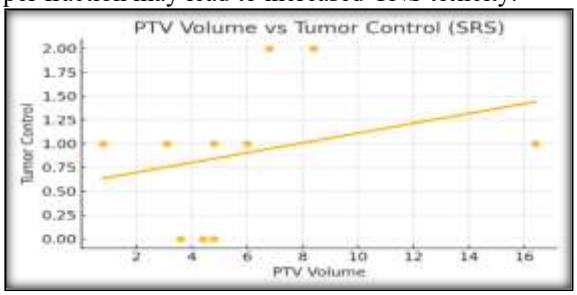
Graph 1: Relationship between the number of metastatic brain lesions and CNS toxicity grade in patients treated with SRS

A weak positive correlation ($r \approx 0.23$, $p > 0.5$) was observed, indicating that patients with more lesions may experience slightly higher CNS toxicity.

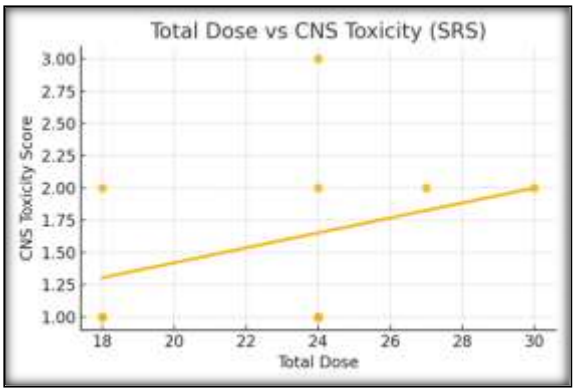


Graph 2: Relationship between the tumour control and total dose in patients treated with SRS

A moderate positive correlation ($r \approx 0.53$, $p \approx 0.12$) was identified on correlation of dose per fraction and CNS toxicity. This trend suggests that higher doses per fraction may lead to increased CNS toxicity.

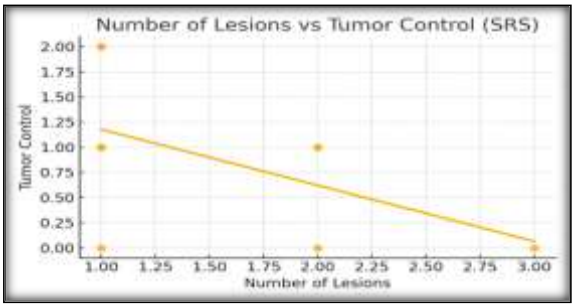


Graph 3: Relationship between the PTV volume and tumor control in patients treated with SRS



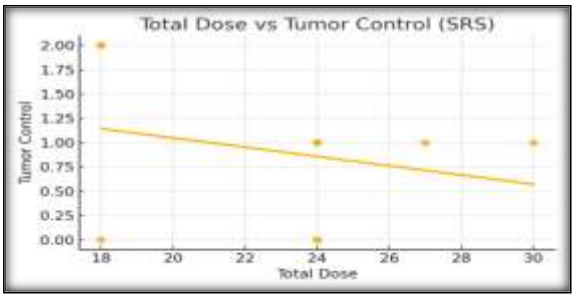
Graph 4: Relationship between the between total dose and CNS toxicity inpatients treated with SRS

This graph shows a weak positive correlation ($r \approx 0.33$, $p > 0.3$) between total dose and CNS toxicity. This suggests that patients receiving higher total doses might experience higher toxicity.



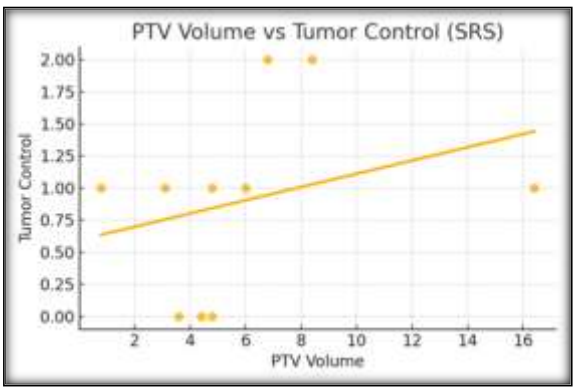
Graph 5: Relationship between the between number of lesions and tumor control in patients treated with SRS

The number of lesions showed a moderate negative correlation ($r = -0.532$, $p = 0.1131$) with tumor control. This suggests that patients with more brain metastases tend to show poorer local control.



Graph 6: Relationship between the between tumor control and total dose in patients treated with SRS

Total dose exhibited a weak positive correlation ($r = -0.259$, $p = 0.4700$) with tumor control. This indicates that patients who received higher total doses may have had better control over treated lesions.

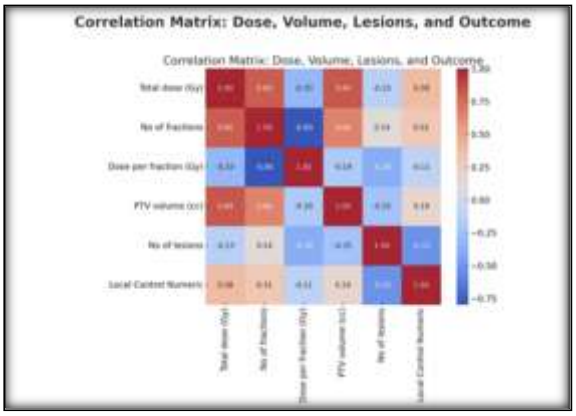


Graph 7: Relationship between the between PTV tumor volume and tumor control in patients treated with SRS.

PTV volume demonstrated a weak negative correlation ($r = 0.296$, $p = 0.4067$) with tumor control. This suggests that larger target volumes are more challenging to control.

All of the above correlation values are not significant statistically, due to less number of samples and lesser follow up with respect to tumour control. Correlation of toxicities and tumour response with other variables for SBRT liver could not be assessed because of very less number of patients (2) treated with SBRT to liver. But on observation patients received SBRT to

liver had a Grade 2 liver and GI toxicity and a stable disease (unchanged).



Graph 8: Correlation Matrix Analysis

The heat map above illustrates the Pearson correlation coefficients among key treatment parameters—total dose, number of fractions, dose per fraction, PTV volume, number of lesions—and tumor control. The color intensity represents the strength and direction of correlation, with blue indicating negative and red indicating positive correlation.

DISCUSSION

This observational study was undertaken as part of an academic dissertation project which was aimed to evaluate the efficacy and safety of SBRT for liver and SRS for brain metastases. The study included 12 patients—10 treated with SRS for brain lesions and 2 with SBRT for liver lesions with different primary malignancy, breast being the most common followed by lung. The primary objective was to assess local tumor control at 3 Months post protocol treatment with acute toxicity evaluation as the secondary goal.

The study enrolled a total of 12 patients, with an equal gender distribution (6 males and 6 females). The mean age of the cohort was 54.5 years (±10.0), reflecting a typical middle-aged population affected by metastatic disease. In terms of performance status, the majority of patients (92%) had an ECOG score of 2, indicating they were ambulatory and capable of self-care but unable to carry out work activities. Only one patient had an ECOG score of 1. The mean PTV Volume for SRS brain was 6.17 cc (Range: 0.80 – 16.40 cc), reflecting the small, well-defined nature of intracranial metastatic lesions typically selected for stereotactic radiosurgery. These volumes are consistent with clinical practice guidelines, such as those referenced in the RTOG 90-05 protocol, which recommend SRS for lesions ≤3–4 cm in diameter due to the need for precise and high-dose delivery with minimal collateral damage whereas the mean PTV Volume for SBRT liver was 67.60 cc (Range: 40.20 – 95.00 cc) which was significantly higher. Larger treatment volumes are common in SBRT for liver lesions due to greater respiratory motion, organ deformation, and the need for expanded margins to ensure dose coverage. This variation in PTV volume between brain and liver treatments in the present study highlights the adaptability of stereotactic radiotherapy across different anatomical sites, the average number of lesions treated per patient was 1.4 (±0.7), indicating that most patients presented with a limited metastatic burden, which is consistent with current criteria for stereotactic treatments like SRS and SBRT.[3,4]

This study included both single-fraction and fractionated SRS treatments for brain metastases, with the choice of regimen largely guided by lesion size, location, and proximity to critical structures. In our cohort, 5 patients received single-fraction SRS typically had smaller lesions (PTV < 10 cc) and fewer in number (1 - 2), while those underwent fractionated SRS had slightly larger or more complex lesions, and 1 patient had single intracranial dural metastases aligning with contemporary practice. According to the RTOG 90-05 protocol, which provides foundational guidance for SRS in brain lesions, a maximum dose of 24 Gy in a single fraction is recommended for lesions ≤20 mm, 18 Gy for 21–30 mm, and 15 Gy for 31–40 mm in maximum diameter. Our study adhered closely to these principles, particularly for small-volume, solitary brain metastases. For larger or critically located lesions, fractionation was applied to reduce toxicity risk while preserving local control. In terms of SBRT for liver lesions, the SABR UK Consortium guidelines recommend dose ranges of 45–60 Gy in 3–5 fractions, targeting a biologically effective dose (BED) >100 Gy for optimal tumor control. Our two SBRT liver cases received fractionated regimens consistent with these recommendations.[3,4]

Dosimetric quality was assessed using key indices: the conformity index (CI), gradient index (GI), and prescription dose spillage. The conformity index in our plans was within an acceptable clinical range (CI ≈ 1.0–1.2 is optimal), suggesting good coverage of target volumes with minimal normal tissue exposure. The distance between various isodose lines were taken as the gradient index. The ideal difference between 80% and 60% isodose lines should be < 2 mm and the ideal difference between 80% and 40% isodose lines should be < 8 mm according to Patro et-al 2023. In our Cohort the mean value was 2.57 mm and 6.57 mm respectively. The ideal difference between 80% and 40% isodose lines was strictly followed while difference between 80% and 60% isodose lines was given a relaxation of ≤ 3mm.[5]

In case of SBRT prescription dose spillage and modified gradient index were assessed as per the SABR UK consortium guidelines. The ideal value were 1.10 and 4.5 respectively considering the larger PTV (PTV >40 cc). in our study for the 2 patients we attained a mean value of 1.2 and 4.53 respectively which were close enough to the ideal values.[6]

Overall, the plan quality observed in this study was consistent with the benchmark criteria set by RTOG 9005 for brain SRS and the SABR UK Consortium for liver SBRT. The selection of fractionation was

guided by lesion volume, location, and normal tissue constraints factors critical in minimizing acute toxicity while achieving robust local control. Future studies should continue to monitor dosimetric indices alongside clinical outcomes and expand evaluation to include late toxicities, neurologic function, and integration with systemic therapies. The use of newer indices such as conformity number and NTCP models may further refine quality assurance in stereotactic planning.[4,5]

The analysis incorporated clinical parameters including PTV volume, total dose, dose per fraction, number of lesions, and number of fractions, all of which were statistically correlated with tumor control and acute toxicity. Pearson correlation coefficients were calculated to evaluate the strength and direction of relationships among these variables. One of the most noteworthy findings in the brain metastasis subgroup was a moderate negative correlation ($r = -0.53$) between the number of lesions and tumor control, indicating that patients with fewer lesions tended to show better local control following SRS. This finding is consistent with the outcomes of Minniti et al., who demonstrated that SRS for patients with a limited number of brain metastases (≤3) yields high rates of local control and acceptable toxicity profiles. Furthermore, the RTOG 9005 protocol, which set the foundation for safe SRS dosing regimens, supports high-dose single fraction SRS in carefully selected cases, reinforcing the importance of lesion number in prognostication.[6]

In terms of fractionation, a weak positive correlation ($r = 0.31$) between the number of fractions and tumor control was noted suggesting that fractionated regimens may be associated with slightly improved local control compared to single-fraction treatments. This may be taken as a simple observation as the data is not statistically significant. By distributing the total dose over multiple sessions, clinicians can better spare normal tissues while maintaining cytotoxic efficacy against the tumor. This is especially relevant in larger PTV volumes, where a single fraction may inadequately cover tumor heterogeneity or result in steep dose gradients. Conversely, a slight negative correlation ($r = -0.11$) was observed between dose per fraction and tumor control, which may reflect the limitations of higher per-fraction doses due to the risk of exceeding organ-at-risk tolerances. These observations align with the general principles of radiobiology, where fractionated doses are known to allow better normal tissue repair, potentially preserving efficacy while minimizing toxicity.[3,7]

Regarding toxicity, several correlations were found. Notably, there was a moderate positive correlation between dose per fraction and CNS toxicity ($r \approx 0.53$), indicating that patients receiving higher doses per fraction may experience greater acute toxicity. In contrast, the number of fractions demonstrated a weak negative correlation ($r \approx -0.30$) with CNS toxicity, suggesting that increased fractionation may mitigate adverse effects — a finding supported by the RTOG 9005 experience. Additionally, a moderate negative correlation ($r = -0.46$) between PTV volume and CNS toxicity was identified, suggesting that smaller volumes may concentrate dose more intensely in sensitive areas, increasing the risk of neurotoxicity.[3,7]

For the liver SBRT subgroup, the sample size (n=2) was insufficient to permit meaningful statistical analysis; however, contextualization with existing literature provides valuable insight. In the present study, both patients treated with SBRT experienced only mild (grade 2) gastrointestinal and hepatic toxicities. At 3-month follow-up, PET imaging demonstrated stable disease with a reduction in metabolic activity (decreased SUV uptake), suggesting a favorable biological response despite the absence of radiological regression.

These findings are consistent with previously published data. Scorsetti et al,[8] have reported excellent local control rates exceeding 80–90% with SBRT dose schedules of 45–75 Gy delivered in 3–6 fractions, along with minimal high-grade toxicity. Similarly, the SABR UK Consortium recommends hypofractionated regimens of 45–60 Gy in 3–5 fractions, demonstrating high efficacy with acceptable safety profiles.[9]

In addition, Rusthoven et al,[10] reported 2-year local control rates of approximately 92% following SBRT for liver metastases, with low incidence of grade ≥3 toxicity. van der Pool et al,[11] and Joo et al,[12] have also highlighted the role of SBRT as a safe and effective non-invasive alternative for patients unsuitable for surgical resection, emphasizing its ability to achieve durable local control with minimal hepatic toxicity.

Taken together, these findings reinforce the feasibility, safety, and clinical effectiveness of SBRT in the management of liver metastases when applied in appropriately selected patients. Although limited by small sample size, the current observations align with established evidence and provide a rationale for further expansion of this cohort in future prospective studies.[13]

The major strength of this study lies in its practical, real-world setting with protocol-based response assessment and follow-up. Though limited by sample size, particularly in the SBRT cohort, the data provide directional insights into optimal dose-fractionation strategies and their impact on tumor control and safety outcomes. Despite being a single-institution study, the findings lay a foundation for refining stereotactic treatment strategies in future, larger -scale investigations.[3,4]

In comparison to high-volume, multi-centric studies, the single-institution nature of this project allows detailed patient-level analysis and tight protocol adherence. Additionally, the inclusion of both SRS and SBRT modalities allows cross-comparison across two distinct yet biologically similar hypofractionated regimens. This serves as a platform for future research exploring biomarkers, volumetric imaging changes, and late toxicity profiles.

CONCLUSION

In conclusion, this study reiterates the clinical utility of stereotactic radiation in managing metastatic lesions in the brain and liver, and underscores the importance of individualized treatment planning based on tumor burden, volume, and anatomical considerations. While further research with larger patient cohorts is warranted, the current findings support the role of SRS and SBRT as effective, well-tolerated treatment options in metastatic disease management.

Future directions for this research include extending the patient sample size, incorporating longer follow-up intervals for assessing late toxicities, and leveraging advanced imaging and dosimetric metrics such as BED (Biologically Effective Dose) and NTCP (Normal Tissue Complication Probability) modeling. The eventual goal would be to contribute to personalized stereotactic treatment planning algorithms that integrate patient-specific clinical and radiographic data to optimize outcomes.

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