Efficacy and Safety of Donut-Shaped Circumferential Spine CyberKnife Stereotactic Body Radiotherapy for Metastatic Spine Disease

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Stanford MEDICINE Neurosurgery

Introduction

- Spinal metastases (SM) with epidural spinal cord compression (ESCC) present a significant challenge due to the high risk of radiation-induced injury to critical structures such as the spinal cord and nerve roots.
- Traditional treatment approaches often avoid circumferential stereotactic body radiotherapy (SBRT) to reduce these risks.
- The efficacy and safety of donut-shaped circumferential SBRT, designed to target the spinal column while sparing the spinal cord, remains underexplored.

Objectives

- This study aims to evaluate the safety and efficacy of donut-shaped circumferential CyberKnife SBRT for spinal metastases, particularly in preventing radiation-induced myelopathy and achieving local tumor control.

Methods

- We retrospectively analyzed data from patients treated with donut-shaped circumferential SBRT between 2014 and 2023.
- Key parameters examined included patient demographics, ESCC grade (Bilsky), prior treatments, clinical symptoms, and treatment parameters.
- We focused on SBRT dosimetric data, radiation exposure to the spinal cord and cauda equina, adherence to dose-volume constraints, and post-SBRT outcomes, including myelopathy and local tumor control.

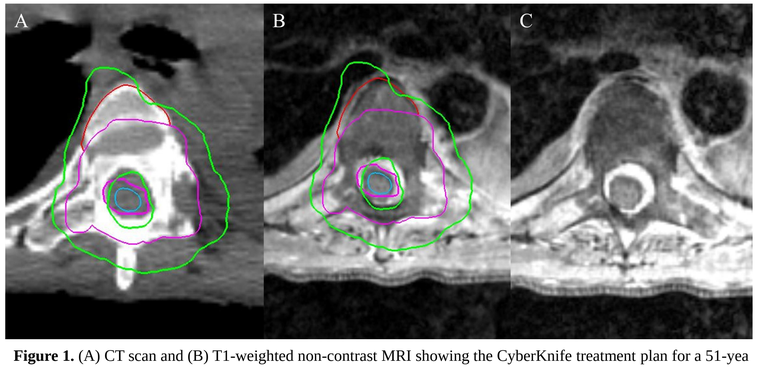

Figure 1. (A) CT scan and (B) T1-weighted non-contrast MRI showing the CyberKnife treatment plan for a 51-year-old female patient with metastatic colorectal carcinoma. The patient presented with spinal metastasis at T5-7 and Bilsky grade 3 ESCC. She underwent circumferential CyberKnife SBRT, receiving a marginal dose of 27 Gy and a maximum dose of 33.92 Gy in 3 fractions to the 80% isodose line. The gross tumor volume (GTV) is contoured in pink, and the clinical target volume (CTV) is contoured in red. The spinal cord, the organ at risk (OAR) in this treatment, is contoured in blue, while the green line represents the 80% isodose line. (C) A 4-month follow-up MRI shows a stable tumor size with no evidence of radiographic myelopathy in the spinal cord.

Table 1. Patient Demographics

Characteristics	N (%)
Total patients	**43 (100%)**
Age	
Median	65
Range	20-78
Gender	
Female	18 (41.86%)
Male	25 (58.14%)
Pathology	
Primary of metastasis	
Lung	14 (32.56%)
Prostate	8 (18.60%)
Kidney	6 (13.95%)
Breast	3 (6.98%)
Skin	3 (6.98%)
Salivary gland	2 (4.65%)
Colorectal	2 (4.65%)
Thyroid	1 (2.33%)
Bone	1 (2.33%)
Bladder	1 (2.33%)
Peripheral nerve	1 (2.33%)
Pancreas	1 (2.33%)
Previous Treatments	
Immunotherapy	26 (54.17%)
Chemotherapy	38 (88.37%)
Radiation therapy	12 (27.91%)
Total lesions	**48 (100%)**
Location of the tumor	
Cervical	6 (12.50%)
Cervicothoracic	2 (4.17%)
Thoracic	27 (56.25%)
Thoracolumbar	3 (6.25%)
Lumbar	10 (20.83%)
ESCC Bilsky Grade	
0	13 (27.08%)
1a	3 (6.25%)
1b	10 (20.83%)
1c	12 (25.00%)
2	8 (16.67%)
3	2 (4.17%)

ESCC, Epidural spinal cord compression

Table 2. SBRT Treatment Parameters

Analysis of the treated lesion	Median (range)
Volume of lesion (cm^3)	63.77 (20.31-270.05)
Margin dose (Gy)	24.00 (18.00-30.00)
Maximum dose (Gy)	30 (22.50-39.47)
Fractions	3 (1-5)
Coverage (%)	92.00 (79.00-96.00)
Isodose line (%)	79.00 (70.00-83.00)
Conformality Index	1.45 (1.10-1.97)
Biologically Effective Dose (Gy)	51.30 (43.20-70.40)
Single Fraction Equivalent Dose (Gy)	18.19 (16.38-22.00)
Mean dose to spinal cord/cauda equina (Gy)	9.36 (2.36-25.93)
Minimum dose to spinal cord/cauda equina (Gy)	1.25 (0.02-8.21)
Maximum dose to spinal cord/cauda equina (Gy)	18.88 (12.76-31.25)
Lesions exceeding dose constraints to spinal cord/cauda equina (%)	43.75
Maximum volume exceeding dose constraints (cc)	0.33 (0.00-7.80)

Table 3. Radiological and Clinical Outcomes

Outcome	(%)
Local Tumor Control	
6-month	91.10%
1-year	87.10%
3-years	82.80%
5-years	62.10%
Progression Free Survival	
Median (months)	7.50
Overall Survival	
6-month	62.10%
Median (months)	17.00
Radiographic myleopathy	
Pre-SRS	0%
Post-SRS (last follow-up)	0%
Clinical myelopathy	
Pre-SRS	0%
Post-SRS (last follow-up)	2.22%

SRS, stereotactic radiosurgery

Results

- Forty-eight lesions in 43 patients (median age: 65; range: 20-78) were reviewed. One patient required separation surgery for severe ESCC (Bilsky grade 3).
- The median clinical target volume (CTV) was 63.77 cm^3, and the median margin dose was 24 Gy.
- Over a median follow-up of 8 months, local tumor control was 91.1% at 6 months, 87.1% at 1 year, 82.8% at 3 years, and 62.1% at 5 years.
- Median overall survival was 17 months.
- Of the 21 lesions exceeding dose constraints, only one patient exhibited clinical myelopathy, which correlated with local tumor recurrence.
- No radiographic myelopathy or other radiation-induced complications were observed.

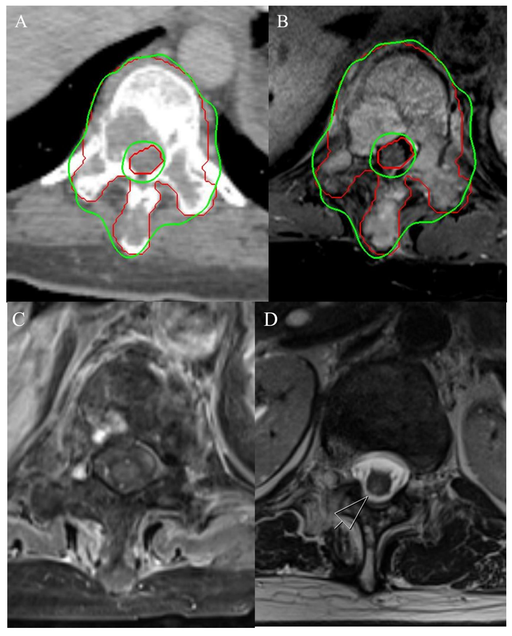

Figure 2. (A) CT scan and (B) T1-weighted contrast-enhanced MRI at the T11 level showing the CyberKnife treatment plan for a 72-year-old female patient with metastatic lung adenocarcinoma. The patient presented with spinal metastasis spanning T9-L1, with Bilsky grade 2 ESCC. The contoured target volume is outlined in red, while the green line represents the 80% isodose line, where a marginal dose of 30 Gy was delivered in 5 fractions. This patient experienced tumor recurrence at the 6-month follow-up and was the only case to present with clinical signs of myelopathy following SRS treatment. (C) T1-weighted and (D) T2-weighted MR images at the L1 level from the 6-month follow-up reveal a small new focus of abnormality with suspicious mild edema within the conus at the L1 level (indicated by the white arrow in D).

Conclusion

- Donut-shaped circumferential CyberKnife SBRT is a safe and effective treatment for spinal metastases, achieving high local tumor control with minimal radiation-induced complications, including myelopathy.

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