Synergy-S Stereotactic Radiosurgery for Spinal Tumors

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ABSTRACT: **Background:** Radiation treatment of spinal and paraspinal tumors has been limited by the tolerance of the spinal cord. As such, therapeutic options are restricted to surgically accessible lesions or the use of suboptimal dosing of external beam irradiation.

Objectives: To evaluate the safety and applicability of the Elekta Synergy-S radiation unit for the treatment of spinal tumors.

Methods: We retrospectively reviewed all patients treated with stereotactic radiosurgery for spinal tumors between November 2007 and June 2011.

Results: Thirty-four patients were treated for 41 lesions. Treatment indications were local tumor control and pain palliation. The mean follow-up was 10.8 ± 11.6 months (range 0.5–38 months). No acute radiation toxicity or new neurological deficits occurred during the follow-up period. Local tumor control was achieved in 21 of the 24 lesions (87.5%) available for radiological follow-up at a median of 9.8 months (range 3–32 months). Good analgesia was achieved in 24/30 lesions (80%) that presented with intractable pain.

Conclusions: The safety and feasibility of delivering single and multiple-fraction stereotactic spinal irradiation was demonstrated and became a standard treatment option in our institution.

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The role of radiation therapy in the treatment of spinal tumors is well established [1–3]. It is considered the mainstay of treatment for painful lesions that do not cause mechanical instability and do not involve neural structures. The treatment of spinal tumors aims at reducing pain and achieving local tumor control to prevent secondary complications such as pathological fractures and neurological compromise from local compression [1,2]. However, the relatively low tolerance of the spinal cord to radiation is a primary factor that limits the radiation dose in conventional radiotherapy [4–6].

Radiosurgery uses a stereotactic approach to deliver a conformal high radiation dose to a localized target, thereby increasing the likelihood of successful tumor control while minimizing the risk of radiation damage to the spinal cord. Since the first description of LINAC-based spinal stereotactic radiosurgery [7], multiple centers have reported the use of large fraction conformal radiation to spinal lesions using various technologies [8–15].

The Elekta Synergy-S system is a LINAC-based stereotactic radiosurgery unit equipped with on-board cone beam computed tomography used for image guidance. We have been using the Synergy-S system for treatment of intracranial tumors since February 2007 and for the treatment of spinal tumors since November 2007. The purpose of the present study was to evaluate the safety and applicability of the system for the treatment of spinal tumors. To date, we have treated 34 patients with 41 lesions. The main indications for treatment were local tumor control and pain palliation.

PATIENTS AND METHODS

Between November 2007 and June 2011, 34 patients underwent stereotactic radiosurgery treatment for 41 spinal tumors at the Tel Aviv Medical Center Stereotactic Radiosurgery Center. This review was approved by the local ethics committee. The Elekta Synergy-S system consists of a 6 MV photon energy Linear Accelerator and a micro-multileaf collimator, which uses 40 pairs of leaves to alter the shape of the beam. Cone-beam CT is used for volumetric image guidance.

Non-invasive body fixation is achieved using the BlueBAG™ BodyFIX® Vacuum (Medical Intelligence, Inc., Germany) for thoracic to sacral lesions and thermoplastic masks (Orfit Industries, Belgium) for treating cervical lesions.

At the first stage patients were positioned supine on the treatment table in the fixating device and a simulation CT scan was acquired with 1.5 mm axial continuous cuts.

*** The first two authors contributed equally to this study**

Images were then transferred to a dedicated stereotactic planning station (3D-Line, ERGO). Treatment planning was based on magnetic resonance images (T1 contrast and T2 axial sequences) fused with the pretreatment CT images. A stereotactic radiosurgical treatment plan was designed based on tumor geometry, location and proximity to spinal cord with the spinal cord outlined as a critical structure. In one case where imaging distortions due to implanted hardware prevented the accurate identification of the spinal cord, we used CT-myelography. Dose-volume histograms were created to examine the doses given to the target and nearby critical organs.

For the treatment delivery, patients were placed on the treatment table in a supine position in the appropriate immobilization device (bluebag or face-neck mask). Before beginning the treatment delivery initial CBCT images were obtained (ini-CBCT) and fused with the pretreatment simulation CT for accurate real-time patient positioning relative to the linear accelerator [Figure 1]. For verification of patient positioning the system compared internal bony structures on the CT images, and the treatment bed was moved to correct for any translational displacement. Another CBCT scan was performed immediately following the correction to verify the target position accuracy (veri-CBCT). The treatment was delivered only after accurate positioning could be confirmed according to the CBCT scans.

CBCT = cone-beam CT

Patients were routinely evaluated clinically 2 weeks after treatment by the senior author (A.K.) and then continued follow-up by the treating neuro-oncologist. Radiological tumor control was assessed by an independent senior neuroradiologist (T.J.K.) not aware of the patient's disease status. The size of the tumor was evaluated in the vertebral body and in the adjacent paravertebral spaces. Radiological tumor control was defined as stable if linear measurements demonstrated shrinkage of the tumor or did not vary more than 15%, or if improvement in uptake was noted on positron emission tomography-CT. Remission was defined as no uptake on PET-CT. Progression was defined as progressive destruction of the vertebral body and/or enlargement of the soft tissue mass.

RESULTS

TECHNICAL DESCRIPTORS

The study group included 34 patients (17 women) with 41 spinal tumors. Median age was 63 years (range 37–80 years) and median Karnofsky Performance Status score was 70 (range 50–90). Treated lesions consisted of both metastatic tumors (35 lesions) and primary bony spinal tumors (6 lesions) [Table 1]. Treated lesions were distributed along the spine from cervical to sacral levels.

The indications for treatment were local tumor control in all patients and palliation of pain in 30/41 lesions in patients

PET = positron emission tomography-CT

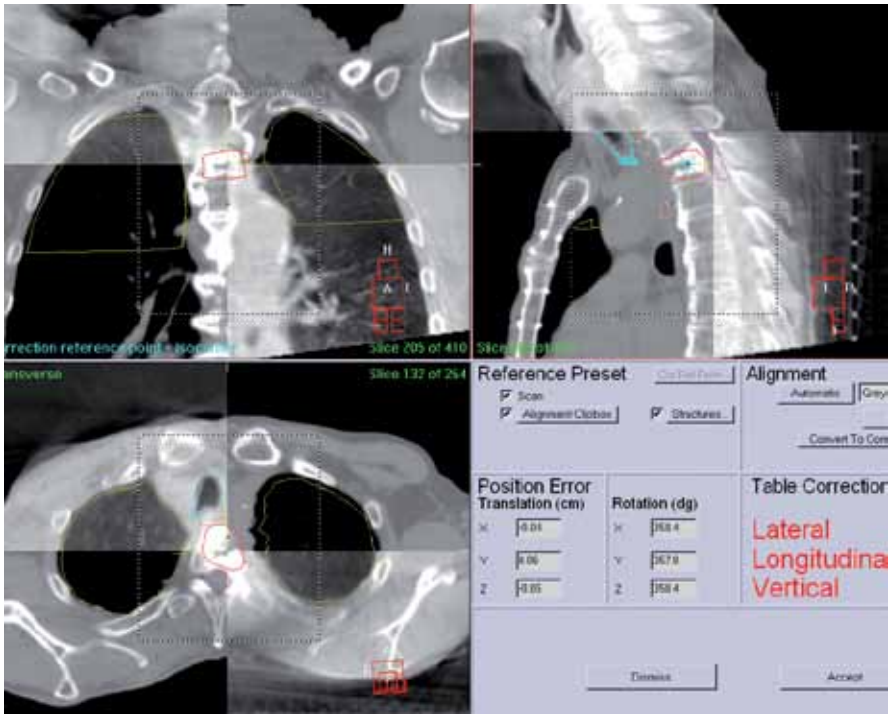

Figure 1. Position verification. Cone beam CT fused to diagnostic CT (coronal, sagittal and axial cuts) during positioning of the patient for treatment of a T3 non-small cell lung carcinoma metastasis. Displayed on the bottom right corner are displacement measurements between treatment plan and pretreatment CT. Outlined are the tumor (red), spinal cord (pink), trachea (cyan), esophagus (orange) and lungs (yellow).

Table 1. Characteristics of treated lesions

	No. of cases
Levels treated	
Cervical	2
Thoracic	18
Lumbar	18
Sacral	3
Metastases	
Non-small cell lung carcinoma	11
Breast carcinoma	4
Renal cell carcinoma	7
Malignant melanoma	2
Prostate carcinoma	3
Other	8
Primary bony spinal tumors	
Sarcoma	4
Chondrosarcoma	2
Previous treatments	
Conventional radiotherapy	8
Surgery	16

who presented with intractable pain. Sixteen lesions (39%) were treated with stereotactic radiosurgery after tumor resection instead of conventional radiotherapy for local control. Six of the 16 operated patients and 2 further patients had failed previous external beam radiation treatment, precluding further conventional irradiation of the involved level [Table 1]. The remaining 23 lesions (56%) received upfront treatment with stereotactic radiosurgery.

Tumor volume ranged from 0.8 to 59 ml (median 14.9). Thirty lesions (73%) were treated with a single fraction with a median dose to the tumor border of 1600 cGy (range 800–2200 cGy). Eleven lesions (27%) with epidural involvement and radiological spinal cord compression received fractionated treatment using 5 fractions; the median tumor dose was 500 cGy per fraction (range 300–700 cGy), resulting in a total median marginal dose of 2500 cGy (range 1500–3500 cGy).

Mean spinal canal volume irradiated was 3.95 ± 1.6 ml; the median average radiation dose to the spinal cord was 562 cGy (range 234–1032 cGy) with a mean spinal canal volume of 0.48 ± 0.9 ml receiving more than 10 Gy. In the hypofractionated group mean spinal volume receiving more than 10 Gy was significantly larger than in the single fraction group (6.36 ± 2.62 ml vs. 3.75 ± 0.5 ml, respectively; $P < 0.01$, *t*-test).

During the first 21 treatment sessions we recorded treatment planning time and treatment delivery times. Median planning time was 52 minutes (range 34–185 min) and median treatment delivery time was 25 minutes (range 20–55 min).

All treatments were successfully completed and well tolerated. No patients experienced exacerbation of their symptoms, hemorrhage or new neurological deficit after the treatment.

FOLLOW-UP AND OUTCOME

The mean follow-up after treatment was 10.8 ± 11.6 months (median 7 months, range 0.5–38 months). Fourteen patients died during the follow-up period due to progressive systemic disease; none of the deaths was related to the spinal lesion or stereotactic radiosurgery treatment. Median survival after treatment was 9.8 months (range 3.5 weeks–44 months).

Local tumor control was achieved in 21/24 lesions (87.5%) available for radiological follow-up at a median of 42 weeks (range 12–141 weeks). Four patients were lost to follow-up and 12 patients (13 lesions) succumbed to their systemic disease within a median of 2.5 months (range 3 weeks to 4 months) and were not available for radiological follow-up. Local failure was noted in three patients: in one case the patient initially responded with resolution of the back pain and was stable on imaging for 2 years, after which the back pain returned and imaging studies showed local recurrence. The patient received re-irradiation using stereotactic radiosurgery to the involved segment and has been stable for 18 months since. In two other cases progressive vertebral body destruction with pathological fracture was noted 4 and 5 months post-treatment. In one case it was decided to retreat using conventional radiation treatment due to new multiple metastases in the adjacent vertebrae; the other patient suffered from progressive systemic disease and died one month later.

Good analgesia was achieved in 24/30 lesions (80%) in patients presenting with intractable pain; 2 lesions responded partially with only mild improvement, 3 patients did not respond and 1 patient was lost to follow-up and died 3 months after treatment. In most cases pain palliation was achieved rapidly, usually within weeks. No patient experienced worsening of pain. No patient developed treatment-related complications; specifically, no patient developed radiation-induced myelopathy.

DISCUSSION

Over the past decade stereotactic radiosurgery treatment of spinal and paraspinal lesions has emerged as a viable treatment modality [7,8,12,16,17]. The main issues that limited the use of stereotactic radiosurgery in lesions located below the foramen magnum were patient immobilization and target tracking. Elegant solutions are now available for both of these problems. The most-studied system is the Cyberknife [12,16], which sets the standard for spinal and body stereotactic radiosurgery. Over the past few years a variety of new technologies have become available for the delivery of high dose conformal radiation to spinal lesions [8–11], but no studies have compared those systems.

Our report documents the safety and applicability of the Synergy-S system for the treatment of spinal tumors at all spinal levels. The uniqueness of the Synergy-S system is

the use of an on-board CBCT that provides high resolution imaging of bony structures for accurate target localization [10,18] which, together with the non-invasive body fixating techniques described, obviate the need to use invasive or non-invasive fiducials required in other systems such as the Cyberknife or Novalis [9,12]. The Synergy-S system, which is extensively used for treatment of intracranial tumors, has only recently been evaluated for spinal tumors [8,10] and data on its efficacy are still scarce. Our results demonstrate that response to treatment, in terms of both palliation of pain and local tumor control, was good and was achieved in 80% and 87.5% of patients, respectively. Other series have reported on palliation of pain in 43–86% of patients [8,12,16,19,20] and local tumor control in 84–95% [8,12,14,20,21].

We used radiation doses of 1200–2200 cGy in a single fraction or 1500–3500 cGy in five fractions. These doses were selected based on current literature, depending on tumor histology and location [4,12,20–22]. The reason for using fractionation was epidural extension of the tumor with radiological spinal cord compression. According to our experience and the literature, the major dose-limiting factor is the spinal cord. Although no strict guidelines yet exist for spinal radiosurgery most groups use 10 Gy to 10% of the spinal cord volume as the cutoff value [4]. We were able to achieve excellent conformality, with a steep falloff gradient of the target dose sparing the radiosensitive neural structures in the spinal canal. As a result we were able to deliver the prescribed treatment dosages to the tumor without any radiation-induced complications in our cohort, including eight patients who were treated after previously failed conventional radiotherapy [Table 1].

We did not encounter any technical difficulties in treating any spinal segment. In addition, although no head-to-head comparison was performed, our initial data show that the planning and treatment times compare favorably with other systems reported in the literature [10,15,23]. Because most treatments are delivered in the ambulatory setting this is of importance for both the clinician and the patient.

To conclude, our preliminary results show that the Synergy-S system enabled delivery of high dose radiation treatment to localized targets in an efficient and safe manner while maintaining non-invasive fixation and reproducible correct identification of the target.

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"I can is a million times more powerful than IQ"

Anonymous