Radiosurgery for Metastatic Spinal Tumors: Follow-Up MR Findings


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BACKGROUND AND PURPOSE: We reported the MR findings of spinal metastatic lesions after SRS according to the volumetric changes (in press). However, in the case of osteoblastic metastatic lesions, tumor volume usually doesn’t change during remission. In this study, we retrospectively analyzed pre- and post-SRS CT and MR imaging findings of locally controlled osteoblastic spinal metastatic lesions besides volumetric changes.

MATERIALS AND METHODS: Among 113 spinal metastatic lesions in 72 patients, 10 lesions were osteoblastic. CT and MR images were reviewed to identify 4 parameters: 1) changes in tumor volume, 2) changes in CT attenuation, 3) changes in T2 signal intensities and 4) changes in degrees of contrast enhancement.

RESULTS: Tumor volume was unchanged in 9 lesions and increased in 1 lesion. CT attenuation increased in 7 lesions and T2 signal intensities were heterogeneous with dark signal foci within the tumor in 3 of 7 lesions and with dark and bright signal foci within the tumor in 4 of 7 lesions. In 3 lesions where CT attenuation decreased, T2 signal intensity became heterogeneous with dark and bright foci in 2 of 3 lesions and T2 signal intensity became normalized in 1 lesion. The degree of contrast enhancement decreased in 8 lesions but 2 lesions showed persistent contrast enhancement.

CONCLUSIONS: Further progression of sclerotic changes was a more common finding than loss of sclerotic foci. Main MR imaging features of osteoblastic lesions after treatment were development of dark with or without bright signal foci, with decrease in contrast enhancement.

ABBREVIATIONS: EBRT = external beam radiation therapy; SRS = stereotactic radiosurgery.
diosurgery at our hospital. All patients had a histologic diagnosis of malignant neoplasm and had either synchronous or metachronous metastasis to the spine. Diagnosis of spinal metastasis was established by typical MR and CT imaging findings, such as paravertebral soft tissue mass, osteolytic or osteoblastic changes, and involvement of posterior elements. Of the 180 lesions, 80 were not subject to follow-up MR imaging after radiosurgery and were excluded from the analyses. Patients who received previous conventional radiation therapy \((n = 4)\) or underwent open surgery \((n = 14)\) or vertebroplasty \((n = 3)\) were also excluded. Thus, 44 patients \((29 \text{ men and 15 women})\) with 79 tumors were enrolled in this study. Patient age ranged from 28 to 80 years \((\text{mean } 58.5 \text{ years})\). The 79 spinal metastatic tumors were located in the cervical \((5 \text{ lesions } [6.3\%])\), thoracic \((35 \text{ lesions } [44.3\%])\), lumbar \((32 \text{ lesions } [40.5\%])\), and sacral \((7 \text{ lesions } [8.9\%])\) spine. Mean follow-up time was 7.07 months \((\text{range } 1–29 \text{ months})\).

### Radiosurgery Technique

The radiosurgical procedure consisted of 1) image acquisition, 2) stereotactic localization and patient setup, and 3) radiosurgical planning and treatment. For imaging, high-resolution thin-section MR images were obtained \((\text{with a } 1.5T \text{ Symphony; Siemens Medical Systems, Erlangen, Germany})\). All examinations included both T1-weighted \((\text{TR}, 400–700 \text{ ms}; \text{TE}, 12 \text{ ms})\) and T2-weighted images \((\text{TR}, 3000–5000 \text{ ms}; \text{TE}, 108 \text{ ms})\) sequences. Before the administration of contrast, imaging of the involved spinal segment \((\text{ie}, \text{cervical, thoracic, and/or lumbar})\) was performed with T1- and T2-weighted imaging in the sagittal \((512 \times 256 \text{ matrix with a NEX of } 2)\) and axial \((320 \times 256 \text{ matrix with a NEX of } 4)\) planes. Sagittal imaging was performed with 3-mm sections and a section gap of 1 mm; axial imaging was performed with 2-mm sections, with no gap and no angles. Intravenous gadolinium was given to all patients \((0.1 \text{ mmol/kg})\). The spine was imaged in the axial and sagittal planes after contrast with TSE T1-weighted sequences. Before CT images were obtained for radiosurgical planning, the patient was brought to a simulating room to prepare the setup of his or her positioning and immobilization in conjunction with the stereotactic devices.

For the stereotactic localization and procedure, the patient was placed in a vacuum bag on an ExacTrac body tray \((\text{Brainlab, Feldkirchen, Germany})\) and immobilized with an aquaplastic mask device. Before the CT scan was performed, the external fiducial markers were affixed to the anterior iliac spine, the skin of the anterior chest wall, and the mask frame. The fiducial skin markers were placed in relation to the locations of the lesions. Then the patient was sent to the CT room under the stereotactic localizer and frame.

The patients were scanned on a 4-detector row CT scanner \((\text{Volume Zoom; Siemens Medical Systems})\). Contrast-enhanced CT images were obtained throughout the range defined by the fiducial markers and stereotactic localizer. The scanning parameters were 110 mAs, 120–140 kVp, FOV 50 cm, collimation 2.5 mm, section thickness 3 mm, and increment 2 mm.

The DICOM data of the MR and CT images were transferred to workstations for radiosurgical planning. To obtain high-resolution spatial information and accurate stereotactic images, the MR images were fused, at each vertebral segment, onto the CT images \((\text{which included the stereotactic devices})\) by using the segmentation image fusion method.\(^8\)

Radiosurgical teams including a medical physicist and neurosurgeons defined the tumor volume to be irradiated. They then provided optimal dosimetric planning and prescribed a radiation dose and fraction size, which depended on the tumor histology, location, proximity to critical structures, and clinical status. The average dose-fractionation scheme was \(53.5 \pm 8.4 \text{ Gy in } 1–6 \text{ fractions}\). Finally, the patient was repositioned with the stereotactic frame and irradiated under image-guided navigation with an infrared tracking system.

### Follow-Up MR Imaging Evaluation

Follow-up MR images were performed with the same parameters as the pretreatment MR images and were retrospectively and independently evaluated by 2 neuroradiologists. These evaluations focused on 1) changes in tumor volume, 2) changes in T2 signal intensity, and 3) changes in contrast enhancement patterns. The tumor volume was measured by performing manual segmentation by using multiple image sections on TSE T1-weighted axial images, with consideration of TSE T1, TSE T2, and contrast-enhanced TSE T1-weighted axial and sagittal images. Volume calculation was then performed by incorporating the data obtained from each of the multiple sections with the assistance of 3D software \((\text{Rapida; Infinitt, Seoul, Korea})\). All MR images were analyzed in a consensus reading by 2 neuroradiologists \((Y.H. \text{ and B.L., with } 13 \text{ and } 4 \text{ years of experience in spine imaging, respectively})\). Tumor volume was measured independently by the same neuroradiologists and the mean value was used.

The pre- and posttreatment volume ratios and volumetric changes were used to categorize the tumors as decreased in volume \((\text{group } 1)\), unchanged in volume \((\text{group } 2)\), and increased in volume \((\text{group } 3)\). If the ratio of volumetric changes was within \(10\%\) \((\text{the ratio range } 0.9–1.1)\), the lesions were regarded as unchanged in volume.

T2 signal intensity changes of the tumors were categorized into 4 types: type 1 \((\text{no changes})\), type 2 \((\text{increase in T2 signal intensity})\), type 3 \((\text{increase in T2 signal intensity intermixed with dark signal intensity})\), and type 4 \((\text{totally dark signal intensity})\) \((\text{Table } 1; \text{Fig } 1)\). Enhancement patterns were divided into 2 groups: no change in contrast enhancement and decrease of contrast enhancement with or without nonenhancing foci.

The clinically recommended follow-up schedule was to perform MR imaging during the first 3 months and every 3 months thereafter. Whenever patients had any neurologic signs or aggravation of symptoms, they were asked to come to our institute and additional MR imaging was obtained when needed. The last MR images were used as a comparison with pretreatment images.

### Table 1: Definitions of 3 groups for volume changes and 4 types of T2 signal changes

<table>
<thead>
<tr>
<th>Changes</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tumor Volume</td>
<td>Decreased</td>
<td>Unchanged</td>
<td>Increased</td>
</tr>
<tr>
<td>T2 Signal Intensity</td>
<td>Type 1</td>
<td>Type 2</td>
<td>Type 3</td>
</tr>
<tr>
<td></td>
<td>No change</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td></td>
<td>pattern</td>
<td>in T2</td>
<td>signal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>intensity</td>
<td>intensity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>intermixed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>with dark</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>signal</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>intensity</td>
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Results

Changes in Tumor Volume

The volumetric changes of each group are summarized in Table 2. The mean initial pretreatment tumor volume was 40,006 mm³ (range 510 – 423,401 mm³). Among the 79 lesions, 32 (40.5%) decreased in volume (group 1), 39 (49.4%) remained unchanged (group 2), and 8 (10.1%) increased in volume (group 3). Thus, 73 (group 1 + group 2 [89.9%]) of 79 lesions were stable or decreased in size and were thus considered locally controlled.

The mean follow-up periods for groups 1, 2, and 3, were 6.69 months (range 1–27 months), 6.54 months (range 1–29 months), and 5.5 months (range 1–11 months), respectively.

Changes in T2 Signal Intensity and Contrast Enhancement Patterns

Table 3 summarizes the changes in T2 signal intensity and contrast enhancement patterns. In group 1, the most common findings were increased T2 signal intensity intermixed with dark signal intensity (type 3), and 28 (87.5%) of the total 32 lesions were seen with this pattern (Fig 2). The signal intensity on T2-weighted images increased homogeneously in 2 lesions (6.25%; type 2) and changed to dark (type 4) in the other 2 lesions (6.25%). Contrast enhancement decreased and nonenhancing foci developed in 31 lesions (96.9%). Only 1 lesion (3.1%) showed persistent homogeneous enhancement and this lesion was of type 3.

In group 2, the most common findings were also type 3 (36/39, 92.3%). The other 3 lesions were categorized into type 1 (2/39, 5.1%) and type 2 (1/39, 2.6%), and contrast enhancement persisted in these 3 lesions.

In group 3 (8 lesions), 2 (25.0%) type 4 lesions changed to homogeneous dark signal intensity without contrast enhancement (Fig 3). In 2 lesions (25%), there were no significant interval changes in T2 signal intensity and the degree of contrast enhancement and categorized type 1 (Fig 4). In 4 type 3 lesions, contrast enhancement decreased and the initial tumor volume also decreased, but local recurrences developed at the margins of the lesions and the total volume of the tumors increased (Fig 5).

We also classified metastatic lesions into osteolytic, mixed, and osteoblastic based on the CT images used for stereotactic localization. Among the 79 lesions, 60 lesions were osteolytic, 14 mixed, and 5 osteoblastic. Four of 5 lesions showed type 3 patterns, and 1 lesion showed type 4 pattern. Four type 3 lesions were unchanged in volume, but 1 type 4 lesion, in the area of the T1 signal intensity changes, was increased and categorized in group 3. Contrast enhancements were decreased in all osteoblastic lesions.

Discussion

The development of advanced image-guided techniques has made possible the delivery of large doses of radiation to very tightly defined targets. These techniques have increased the chance of local control of spinal metastatic tumors, with SRS emerging as a new treatment option. Several studies on the efficacy of SRS for spinal metastatic tumors have been reported recently.6-17 Although MR imaging is the best tool to evaluate the status of metastatic spinal tumors, many results about treatment efficacy are confined to clinical data such as

Table 2: Volumetric changes of each group

<table>
<thead>
<tr>
<th>Group</th>
<th>Pretreatment Volume (mm³)</th>
<th>Posttreatment Volume (mm³)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (n = 32)</td>
<td>64,742.39 (1274–423,401)</td>
<td>42,750.41 (441–257,075)</td>
<td>0.65 (0.08–0.88)</td>
</tr>
<tr>
<td>2 (n = 39)</td>
<td>19,906.46 (510–112,890)</td>
<td>19,337.26 (515–120,200)</td>
<td>0.98 (0.9–1.08)</td>
</tr>
<tr>
<td>3 (n = 8)</td>
<td>33,051.75 (1292–136,909)</td>
<td>54,334.00 (1357–169,066)</td>
<td>1.60 (1.17–2.82)</td>
</tr>
</tbody>
</table>
Some reports have included measurements of tumor volume by MR imaging but have not provided detailed MR imaging findings. The life span of affected patients is limited, in most cases, by systemic disease. As a result, patients and clinicians tend to focus on systemic problems rather than spinal metastases, unless the latter is causing pain or neurologic deficits. Thus, follow-up MR imaging is often not performed after the initial treatment of spinal metastases because it is not considered a priority or because the patient’s condition is too poor or unstable. However, an accurate follow-up evaluation of a spinal metastatic tumor may benefit clinical management, as one can detect tumor recurrences or compressive deformities and then administer an appropriate treatment, such as boost radiation therapy.

In our study, variable signal intensity changes and enhancement patterns were observed, and the most common findings were increased T2 signal intensity, combined with dark signal intensity changes (type 3), and stable or decreased tumor volume (groups 1 and 2). These were considered indicative of local tumor control. Pollen and Shlaer described osteoblastic response on plain radiographs after successful treatment, including chemotherapy of metastatic cancer of the prostate. Others also reported that development of a sclerotic rim at the periphery of the tumors, followed by centripetal...

<table>
<thead>
<tr>
<th>Group 1 (n = 32)</th>
<th>Group 2 (n = 39)</th>
<th>Group 3 (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contrast Enhancement</td>
<td>Contrast Enhancement</td>
<td>Contrast Enhancement</td>
</tr>
<tr>
<td>Decreased</td>
<td>Persistent</td>
<td>Decreased</td>
</tr>
<tr>
<td>Type 1 (n = 4)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Type 2 (n = 3)</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Type 3 (n = 68)</td>
<td>27</td>
<td>1</td>
</tr>
<tr>
<td>Type 4 (n = 4)</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

**Fig 2.** Initial and 27-month follow-up MR and CT images in 52-year-old man with lung cancer. (A and B) T2 signal intensities of metastatic lesion in L3 body and right pedicle increased and intermixed with dark signal intensity on T2-weighted axial and sagittal images. (C) Sclerotic changes are seen on follow-up CT image.

**Fig 3.** Expanded appearance with progressed sclerotic change. Initial and 11-month follow-up MR and CT images in 47-year-old woman with breast cancer. (A) Signal intensity of metastatic lesion changed to dark signal intensity and area of signal intensity changes seemed to be increased on T2-weighted axial image. (B) Contrast enhancement was not seen on contrast-enhanced T1 axial images. (C) On CT image, sclerotic changes progressed at the periphery of the lesion.
Heterogeneous T2 dark signal intensity with expanded appearance. This result is not different from the result of entire lesions, but the number of cases is very small and further additional evaluations about osteoblastic lesions will be needed.

There were several limitations in this study. First, our study was retrospective. We agreed on the fact that preplanned sequential MR imaging follow-up studies are helpful to manage clinical symptoms or control tumor progression, but practically, follow-up MR imaging has been ordered based on clinical change. Patients with spinal metastatic lesions often had a poor general condition such that follow-up imaging was often not performed due to systemic disease. As a result, the follow-up period varied from 1 to 29 months and evaluations were performed at different intervals. We evaluated only the last MR image. This would be the second limitation, and a serial evaluation would be more helpful to observe the pattern of changes after treatment. Third, a variety of different tumors were treated. But in our study, the response and imaging appearance could not be evaluated in each type of tumor because the numbers of each tumor were so small. Fourth, we were not able to compare the radiologic analysis with clinical parameters and radiologic-pathologic correlation was not performed.

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Conclusions
The most common MR imaging findings after stereotactic radiosurgery of spinal metastatic tumors were increased T2 signal intensity intermixed with T2 dark signal intensity, suggesting sclerotic changes, and decreased contrast enhancement. When T2 signal intensity shows no changes, or increased signal intensity without dark signal intensities, close follow-up is recommended. Patterns of tumor growth were classified as indicative of either 1) volume increase without changes of signal intensity and contrast enhancement, or 2) initial local control, but growth, at the periphery of the tumor during follow-up. Although volumetric changes of the metastatic tumors after SRS is the best marker for response, correlation with T2 signal intensity changes and contrast enhancement patterns can give additional information for the current status of spinal metastatic lesions after treatment. 

References