Accuracy of MR Imaging in Diagnosis of Bone Invasion by Soft Tissue Sarcomas: Experience at NCI, Cairo, Egypt

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Abstract

Purpose: To evaluate the Magnetic Resonance (MR) imaging signs and overall accuracy of MR imaging for detection of osseous invasion by soft-tissue sarcomas.

Material and Methods: Preoperative MR images of 41 osseous sites in patients diagnosed and treated at the National Cancer Institute (NCI), Cairo University, (2005-2011) for soft tissue sarcomas who underwent surgical bone resection or amputation were assessed retrospectively for signs of osseous invasion. MRI signs assessed included osseous abutment by tumor, cortical destruction, and cortical and medullary signal intensity change on T1- and T2-weighted images. Imaging findings were correlated with histopathological findings.

Results: Fifteen sites (36.5%) showed osseous invasion histologically. Tumor abutted bone at 26 lesion sites (63.5%). Maximal diameter of osseous abutment and extent of circumferential abutment did not significantly affect osseous invasion. On T1- and T2-weighted images, 13 lesion sites showed cortical signal intensity change (sensitivity, 100%; specificity, 86.7%) and 11 lesion sites showed cortical destruction (sensitivity, 73.3%; specificity, 96.2%). Eleven lesion sites showed decreased medullary T1 signal intensity (sensitivity, 100%; specificity, 96.7%), and 11 lesion sites showed increased medullary T2 signal intensity (sensitivity, 100%; specificity, 96.7%). MR imaging had an overall sensitivity of 86.7%, specificity of 100%, PPV of 100%, and NPV of 93%. Total accuracy was 95% for detection of osseous invasion.

Conclusion: Cortical and medullary signal intensity change and cortical destruction on T1- and T2-weighted MR images were sensitive and specific for osseous invasion by soft tissue sarcomas and can be used reliably for preoperative assessment.

Key Words: Sarcoma — Soft tissue sarcoma — Bone invasion — MR imaging.

Introduction

SOFT-TISSUE sarcomas are rare tumors that can affect any age, gender, and anatomic subsite. They have unique growth features, tending to extend within compartments and along fascial planes on a path of least resistance. The extremities are the site of 50% of soft-tissue sarcomas, with 80% of those occurring in the lower extremities ill.

Local control and survival vary according to the anatomic site, largely because resection is less feasible and radiation therapy less easily administered in some regions. In patients undergoing curative treatment, outcome is best for extremity soft-tissue sarcomas and worst for retroperitoneal sarcomas and those arising adjacent to critical non expendable anatomy. Management of soft-tissue sarcomas provides a paradigm of the multidisciplinary approach for the optimization of local control, function preservation, and limb salvage [2].

Osseous invasion by soft-tissue sarcoma is uncommon, with a frequency of 9% (12 of 133 cases) reported in one study. Nevertheless, to effectively treat soft-tissue sarcoma in patients in whom osseous invasion cannot be excluded on the basis of preoperative imaging, the surgeon may have to resect part of the adjacent bone en bloc with the tumor if osseous invasion is directly apparent or if the tumor closely approximates the cortical surface. Studies have suggested that pathologic evidence of osseous invasion is associated with a shortened survival following diagnosis [3].

Accurate radiologic assessment of the extent of the soft-tissue sarcoma provides critical anatomic information for planning both the surgical approach and the treatment field for the adjuvant radiation therapy. MRI is the imaging modality that is most frequently used not only for preoperative evaluation of tumor size but also for the mapping of the anatomical extension of soft tissue sarcoma [4].
Our aim in this retrospective study was to assess the overall accuracy of MR imaging and of specific MR imaging signs for the detection of osseous invasion in soft-tissue sarcoma, with histopathologic analysis used as the standard of reference.

**Patients and Methods**

Our study group comprised all patients with available preoperative MR images who underwent surgical resection between January 2005 and October 2011 for soft-tissue sarcoma at the National Cancer Institute, Cairo University. The study group included 38 patients (21 men, 17 women) with age range from 17-56 years. For all patients, the decision to resect bone had been made either preoperatively, because MR images indicated osseous invasion by the tumor, or intraoperatively, because the tumor appeared to abut the bone so closely that subperiosteal resection might result in failure to remove all malignant cells (Table 1).

**Imaging and image evaluation:**

MR imaging of all patients was performed with a 1.5 Tesla imager (Achieva; Philips Medical Systems). T1- and T2-weighted images were obtained in the transverse plane and at least one longitudinal plane (coronal or sagittal) by using either a surface coil or a body coil. For T1-weighted imaging, a conventional spin-echo pulse sequence was used (repetition time msec/echo time msec, 400-680/8-16); for T2-weighted imaging, a fast spin-echo pulse sequence was used (3,500-5,867/80-105; echo train length, eight). The matrix size, section thickness, and field of view varied according to the anatomic location and size of each lesion.

All images were evaluated retrospectively and by consensus of two readers who were blinded to clinical and histopathologic findings and who reviewed the images together. After the anatomic location of each lesion was identified, the images were assessed as follows:

- A determination of osseous abutment by the tumor was made on the basis of evidence on T1-weighted images of a loss of normal soft-tissue interface between the tumor mass and the adjacent cortex. Osseous abutment was considered absent if a completely normal tissue interface was observed between the tumor and adjacent bone. If no osseous abutment was evident on T1-weighted images, T2-weighted images of the same patient were evaluated to determine whether peritumoral edema or reactive change was present that extended to the cortical surface. Peritumoral edema and reactive change were identified on T2-weighted images as regions of increased soft-tissue signal intensity with ill-defined margins and without mass effect or distortion of the soft-tissue interface without corresponding abnormality on T1-weighted images.

- If osseous abutment was present, its extent was determined by measuring its maximal diameter on MR images. Additionally, in lesions involving long bones, the maximal extent of circumferential abutment was evaluated as less than 25%, 25%-50%, or more than 50% of the total circumference of the adjacent bone.

- Cortical signal intensity change was defined as increased signal intensity in the normally hypointense cortical bone adjacent to the tumor. Cortical signal intensity change was assessed on both transverse and longitudinal images to avoid false-positive diagnoses resulting from partial volume averaging along obliquely imaged cortical margins, as well as to assist in the identification of nutrient vessels.

- Cortical destruction was defined as a defect in the cortical bone adjacent to the tumor. All images on which cortical destruction was identified also showed cortical signal intensity change, whereas not all images that showed cortical signal intensity change also indicated cortical destruction, because some signal intensity changes were due to malignant cell infiltration of the cortex without obvious cortical erosion or destruction.

- Medullary signal intensity change on T1-weighted images was defined as focal replacement of the normally high signal intensity of bone marrow by low signal intensity in the medulla adjacent to the tumor.

- Medullary signal intensity change on T2-weighted images was defined as focal replacement of the normal bone marrow signal intensity (which may be intermediate or low, depending on whether fat suppression was used) by high signal intensity in the medulla adjacent to the tumor.

**Surgery and histologic analysis:**

The mean time interval between MR imaging and surgical resection was 34 days (range, 2-112 days), but for four of 38 patients the delay was greater than 8 weeks. Seventeen (44.7%) of 38 patients received adjuvant preoperative chemoradiation therapy (Table 1).

All osseous tissue resected from the tumor sites were subjected to histologic analysis for evidence of tumor invasion of the cortex and medulla. Resected osseous tissue specimens were evaluated visually. Bone was sampled at the sites in closest
proximity to the tumor and at sites of apparent abnormality on specimen radiographs. The bone was decalcified and embedded in paraffin. Slices with a thickness of 5μm were cut, stained with hematoxylin-eosin, and examined with light microscopy. Bone was considered to be involved when tumor cells were seen in the cortex or the medulla. Bone was considered not to be involved when tumor cells were seen in the periosteum but not in the cortex or medulla, or when subperiosteal new bone formation was apparent in which no tumor cells were present.

Statistical analysis:

Statistical analysis was performed by using histopathologic findings in surgically resected bone as the standard of reference. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated separately for the presence of osseous abutment, cortical and medullary signal intensity change, and cortical destruction.

Again using histopathologic findings as the standard of reference, the overall performance of MR imaging was assessed for the detection of osseous invasion on the basis of any finding of cortical destruction or cortical and/or medullary signal intensity change, and cortical destruction.

Results

Pathologic findings:

Forty-one osseous sites were identified on images of the 38 patients. Three patients underwent resection of two separate osseous sites. One patient with fibrosarcoma of the foot with calcaneous and talus are resected and examined. One patient with a synovial sarcoma of the femur and tibia which were examined pathologically. The other patient with a malignant fibrous histiocytoma of the leg underwent resection of the tibia and fibula. Each resection was counted as a separate osseous site. In each of the remaining 35 patients, only one osseous site was evaluated.

The anatomic locations of the sites were as follows: Lower extremity in 28 of the 38 patients (73.7%), upper extremity in 6 patients (15.8%), and pelvic girdle in 4 patients (10.5%) (Table 1).

The lesions were identified at histologic analysis as synovial sarcoma in 12 of 41 sites (29.2%), fibrosarcoma in 10 of 41 (24.4%), malignant fibrous histiocytoma in seven of 41 (17.1%), leiomyosarcoma in four of 41 (9.8%), liposarcoma three of 41 (7.3%), embryonal rhabdomyosarcoma in two of 41 (4.9%), and pleomorphic sarcoma in three of 41 (7.3%) (Table 2).

Table (2): Histologic findings of osseous invasion in soft tissue sarcomas.

<table>
<thead>
<tr>
<th>Histologic type</th>
<th>No. of osseous sites</th>
<th>No. of sites with cortical invasion</th>
<th>No. of sites with medullary invasion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synovial sarcoma</td>
<td>12</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Fibrosarcoma</td>
<td>10</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Malignant fibrous histiocytoma</td>
<td>7</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Leiomyosarcoma</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Liposarcoma</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Embryonal rhabdomyosarcoma</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pleomorphic sarcoma</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>41</td>
<td>15</td>
<td>11</td>
</tr>
</tbody>
</table>

All sites with histologic medullary invasion also showed histologic evidence of cortical invasion.

Histologically proved neoplastic osseous invasion had occurred in 15 (36.5%) of the 41 osseous sites; involvement of the cortex alone was evident in four sites, and involvement of both the cortex and medulla was seen in eleven (Tables 1,2). No evidence of either cortical or medullary involvement was found at histologic evaluation of tissue samples from the other 26 sites.
Osseous abutment:

Twenty-six (63.5%) of the 41 osseous sites showed osseous abutment at pathology (Case 1). MRI detected abutment in 28 sites. The T2-weighted images depicted peritumoral edema or reactive change extending to the adjacent cortex in 2 of these 28 osseous sites. At histologic examination, however, no malignant cells were seen in either the cortex or the medulla in any of the two sites. Also, MR imaging showed two cases with abnormal cortical signal intensity. Histologic evidence of osseous invasion was not present and abutment only is concluded.

Table (3): Effectiveness of MR imaging for the detection of osseous invasion.

<table>
<thead>
<tr>
<th>MR findings</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>PPV (%)</th>
<th>NPV (%)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical signal intensity changes</td>
<td>100% (11/11)</td>
<td>86.7% (13/15)</td>
<td>84.6% (11/13)</td>
<td>100% (13/13)</td>
<td>92.3% (24/26)</td>
</tr>
<tr>
<td>Cortical destruction</td>
<td>73.3% (11/15)</td>
<td>96.2% (25/26)</td>
<td>91.7% (11/12)</td>
<td>86.2% (25/29)</td>
<td>87.8% (36/41)</td>
</tr>
<tr>
<td>Medullary signal intensity changes</td>
<td>100% (11/11)</td>
<td>96.7% (29/30)</td>
<td>91.7% (11/12)</td>
<td>100% (29/29)</td>
<td>97.6% (40/41)</td>
</tr>
<tr>
<td>Overall accuracy</td>
<td>86.7% (13/15)</td>
<td>100% (26/26)</td>
<td>100% (13/13)</td>
<td>93% (26/28)</td>
<td>95% (39/41)</td>
</tr>
</tbody>
</table>

Case (1): Male patient 32 years old with pathologically proven pleomorphic sarcoma and local recurrence. (a,b); Axial T1-weighted images, (c,d); Axial T2-weighted images, (e,f); Axial post-gadolinium T1-weighted images with fat suppression. The mass is seen to abut the periosteum with no underlying cortical bone or medullary invasion (g); Pathology after excision.
Cortical signal intensity change and cortical destruction:

Alteration in cortical signal intensity was found on MR images of 13 osseous sites (Case 2). At each of these sites, increased cortical signal intensity was evident both on T1-weighted and T2-weighted images. All 11 sites in which cortical involvement was histologically proved were characterized by cortical signal intensity change on MR images. There were two false-positive findings of cortical involvement based on cortical signal intensity change. In both cases, analysis of histologic specimens disclosed reactive remodeling without intracortical malignant cells. In one case, the site evaluated had been subjected to preoperative radiation therapy. T1-weighted images and T2-weighted images of this lesion site also showed medullary signal intensity changes. The other site in which a false-positive finding was made had not been subjected to radiation therapy and did not show any alteration in medullary signal intensity. Cortical signal intensity change seen both on T1-weighted and T2-weighted images had an overall sensitivity of 100%, specificity of 86.7%, PPV of 84.6%, NPV of 100%, and total accuracy of 92.3% for detection of cortical involvement.

Case (2): Male patient 22 years old with pathologically proven monophasic synovial sarcoma. (a,b); Axial T1-weighted, and T2-weighted. (c,d) post-gadolinium T1-weighted fat suppression images. (e,f); Coronal post-gadolinium T1-weighted fat suppression images. The axial images show lateral femoral condyle cortical thickening, irregularity, and postcontrast area of enhancement (arrows). The coronal images show knee joint lateral capsule and lateral collateral ligament invasion. (g,h); pathology with H&E, and cytoK staining of the resected bone.
Case (3): Female patient 23 years old with pathologically proven fibrosarcoma with multiple excisions. (a,b); Coronal T1-weighted images, (c); Sagittal STIR image, (d,e); Coronal post-gadolinium T1-weighted image (d) with fat suppression (e). The calcaneus bone shows area of marrow infiltration adjacent to the soft tissue residual mass. Below knee amputation confirmed bone infiltration (f): Pathology of the specimen after excision.
Histologic analysis confirmed osseous invasion in 11 lesion sites in which evidence of cortical destruction was found on MR images. The false-positive site showed changes in both cortical and medullary signal intensities on MR images, and this site also had been subjected to radiation therapy subsequent to MR imaging and prior to resection. Four sites were considered false-negative for osseous invasion because no cortical destruction was evident on MR images but cortical involvement was established at histologic analysis. MR findings of cortical destruction had a sensitivity of 73.3%, specificity of 96.2%, PPV of 91.7%, NPV of 86.2%, and total accuracy of 87.8% for the detection of cortical involvement.

Medullary signal intensity change:

Medullary signal intensity change on T1-weighted images and T2-weighted images were correlated with histologic findings of medullary involvement and of osseous invasion as a whole (both medullary and cortical involvement). In the eleven sites in which intramedullary invasion was histologically proved (Case 3), coexisting cortical involvement was also confirmed histologically, reflective of direct tumor extension through the cortex into the medulla.

On T1-weighted images of 11 sites, a focal area of decreased medullary signal intensity was observed at the location of each lesion. On T2-weighted images of the same 11 sites, a corresponding focal area of increased medullary signal intensity was observed. In one site, findings of medullary involvement based on medullary signal intensity change on T1-weighted images were false-positive (sensitivity, 100%; specificity, 96.7%; PPV, 91.7%; NPV, 100%; total accuracy, 97.6%). In this site, histologic analysis confirmed only cortical involvement with focal replacement of adjacent marrow by means of fibrosis and necrosis. This lesion had been subjected to radiation therapy subsequent to MR imaging and prior to resection.

Overall accuracy of MR imaging signs:

Fifteen (25%) of the 41 sites were considered positive for osseous invasion on the basis of observation of at least one of the following: Cortical signal intensity change on T1-weighted or T2-weighted images, cortical destruction, or medullary signal intensity change on T1-weighted or T2-weighted images. Two false-negative findings and only three false-positive findings of osseous invasion were made on the basis of combination of these MR imaging signs (sensitivity, 86.7%; specificity, 100%; PPV, 100%; NPV, 93%; accuracy, 95%) (Table 3).

Discussion

Soft-tissue sarcomas are rare tumors that can affect any age, gender, and anatomic subsite. They have unique growth features, tending to extend within compartments and along fascial planes on a path of least resistance. The extremities are the site of 50% of soft-tissue sarcomas, with 80% of those occurring in the lower extremities [ii].

Local control and survival vary according to the anatomic site, largely because resection is less feasible and radiation therapy less easily administered in some regions. In patients undergoing curative treatment, outcome is best for extremity soft-tissue sarcomas and worst for retroperitoneal sarcomas and those arising adjacent to critical non expendable anatomy. Management of soft-tissue sarcomas provides a paradigm of the multi-disciplinary approach for the optimization of local control, function preservation, and limb salvage [2].

Osseous invasion by soft-tissue sarcoma is uncommon, with a frequency of 9% (12 of 133 cases) reported in one study. Nevertheless, to effectively treat soft-tissue sarcoma in patients in whom osseous invasion cannot be excluded on the basis of preoperative imaging, the surgeon may have to resect part of the adjacent bone en bloc with the tumor if osseous invasion is directly apparent or if the tumor closely approximates the cortical surface. Studies have suggested that pathologic evidence of osseous invasion is associated with a shortened survival following diagnosis [3].

Accurate radiologic assessment of the extent of the soft-tissue sarcoma provides critical anatomic information for planning both the surgical approach and the treatment field for the adjuvant radiation therapy. MRI is the imaging modality that is most frequently used not only for preoperative evaluation of tumor size but also for the mapping of the anatomical extension of STS [4].

MR imaging is ideally suited to the imaging of soft-tissue masses owing to its excellent soft-tissue contrast, multiplanar capabilities, and lack of ionizing radiation. It is invaluable for local staging and surgical planning and can play a role in diagnosis of soft-tissue sarcomas. The technical factors relating to MR imaging, which include positioning, radiofrequency coil selection, and the pulse sequences chosen, are critical to proper imaging of soft-tissue sarcomas.

A radiofrequency coil should be selected to provide adequate coverage of the lesion. Surface coils offer high signal-to-noise ratio, high resolu-
tion, and good off-center fat suppression and are used for the hand, wrist, and foot. Body coils cover a large field of view and are useful to localize soft-tissue lesions relative to an anatomic landmark such as a joint for surgical and radiation therapy planning [2].

MR imaging pulse sequences for soft-tissue sarcomas include a large-field-of-view localizer, which allows quick assessment of the lesion location and size and facilitates planning for the rest of the imaging planes. Orthogonal plane imaging is then performed with axial sequences and longitudinal plane sequences, which can be either coronal or sagittal depending on the lesion location. These planes should include both the proximal and distal extent of the lesion as well as any peritumoral edema to define the full extent of the tumor [2].

Utilizing MRI, lesions should be evaluated in at least 2 different orthogonal planes with conventional T1-weighted and T2-weighted spin-echo MRI pulse sequences. Gradient echo may be a useful sequence for the identification of hemosiderin. A short tau inversion recovery (STIR) sequence can also be a helpful adjunct, as it produces fat suppression and further enhances signal intensity of abnormal tissue. It is especially helpful for the detection of subnormal abnormalities. Fat suppression on T1-weighted imaging allows separation of contrast enhancement and paramagnetic substances from fat. Fat suppression on T2WI increases signal-to-background intensity differences for high signal lesions within fatty soft tissue and bone marrow [3].

Intravenous contrast is useful in finding a demarcation between tumor and muscle/edema. It also provides information about tumor vascularity and can distinguish solid from cystic lesions [5]. It is also valuable in the assessment of postoperative recurrence and in fibromatoses. Gadolinium contrast material can help guide selection of a more viable area of the tumor to target for biopsy [41].

Use of T1-weighted fat-suppressed contrast enhanced imaging can improve lesion detection, tissue characterization, and determination of tumor extent. STIR technique entails an alternative MRI sequence that suppresses the signal intensity of fat and the additive effects of T1 and T2 mechanisms on tissue signal intensity. STIR imaging is commonly used to detect bone marrow lesions because it is sensitive in the detection of tumor, edema, and infection in bone marrow. Fast STIR imaging is superior to T1-weighted fat-suppressed contrast-enhanced imaging in the evaluation of all bone marrow components, and the two techniques have comparable results in the evaluation of surrounding soft tissue components [61].

Local evaluation of soft-tissue sarcomas is based on the location of the lesion, the lesion size, the amount of peritumoral edema, the compartmental extent of the mass, neurovascular involvement, and extension to the underlying bone or adjacent joint. Involvement of bone by soft-tissue sarcoma has been shown to correlate with a higher frequency of disease-related death. MR imaging has good sensitivity and specificity for the detection of osseous invasion, as evidenced by changes in cortical and medullary signal intensity [7].

In the preoperative setting, the gross tumor volume is typically represented by the radiologically defined tumor, but the acceptable volume margin remains problematic, depending on the results of the prior biopsy, the anatomic containment of the lesion, and the imaging characteristics of the lesion, including high T2 signal change evident on MR images beyond the overt tumor. This finding is thought to be due to increased water content and has therefore been labeled "peritumoral edema." However, it is not clear whether this MR imaging finding is actually the result of tissue edema, corresponding to the reactive zone noted earlier, or microscopic disease. Evidence from one study performed by White et al., suggests that tumor cells may reside in this area of high T2 signal, and it has been their policy to consider this region within the radiation therapy target volume [8].

The goal of surgery is a wide excisional margin, which is defined as 2cm of skin, fat, or muscle, to resect the adjacent microscopic disease. Fascia is an excellent barrier to tumor spread, such that mm of fascia can still be considered a wide margin. The reactive zone of edema surrounding the tumor, which can often extend quite far from the mass, is considered to contain microscopic disease [9]. For this reason, marginal excision is not adequate if surgery is the only treatment. Radiation therapy is necessary to address residual microscopic disease within the reactive zone of edema.

It is critical to determine if the tumor is superficial to the fascia. Although a small superficial lesion can usually be managed with surgery alone, there are several exceptions to this rule. For example, superficial lesions with edema or that appear infiltrative or multinodular generally require surgery and radiation therapy due to extensive microscopic disease.

Superficial tumors adjacent to bone often require combined management with radiation and
surgery. Although histologic bone involvement occurs in less than 5% of soft-tissue sarcomas, it is an independent poor prognostic factor, associated with an increased risk of metastases, amputation, and decreased survival [11].

Elias et al., [3] is the only reported group to investigate the effectiveness of MR imaging for the detection of osseous invasion in soft-tissue sarcoma and have reported sensitivity of 100%, specificity of 93%, and accuracy of 95%. In a study of 133 patients with soft-tissue sarcoma, in 12 of whom histologic findings indicated osseous invasion, investigators found that CT and MR imaging had similar sensitivities, specificities, and accuracies for the detection of osseous invasion in soft-tissue sarcoma [4]. The imaging signs that were considered to indicate osseous invasion on CT or MR images were not specified in these reports of clinical studies.

We defined osseous abutment by the tumor as loss of a normal soft-tissue interface between the tumor mass and osseous cortex on T1-weighted images. The cases without osseous abutment are not included in our study, for each case in which T1-weighted images showed no osseous abutment, T2-weighted images were evaluated for peritumoral edema and reactive change extending to the cortical surface. It can be difficult to differentiate between tumor tissue and peritumoral edema or reactive change, but features favoring the latter include areas of increased signal intensity in soft tissue on T2-weighted images, with ill-defined margins, no mass effect, no distortion of the soft-tissue interface, and no corresponding signal intensity change on T1-weighted images. Peritumoral edema or reactive change may indicate a vascular or inflammatory response with or without tumor cell infiltration. The reactive zone around a sarcoma commonly is removed en bloc with the tumor during limb salvage surgery [12]. Furthermore, radiation therapy may contribute to peritumoral changes of increased signal intensity on T2-weighted images as seen in false-positive results of two cases by MR imaging [13].

Cortical signal intensity change both on T1-weighted and T2-weighted images correlated strongly with histologic evidence of cortical involvement. All 11 lesions found at histologic analysis also showed cortical signal intensity changes on T1- or T2-weighted MR images (sensitivity, 100%; NPV, 100%). There were two false-positive findings based on cortical signal intensity changes observed on T1- or T2-weighted images (specificity, 86.7%; PPV, 84.6%). Cortical destruction was observed in 11 sites, with one false-negative finding (sensitivity, 73.3%; NPV, 86.2%) and 4 false-positive finding (specificity, 96.2%; PPV, 91.7%). Cortical destruction may be less sensitive than cortical signal intensity change for detection of cortical involvement, because tumor cells can permeate the cortex (creating cortical signal intensity change) without causing appreciable cortical destruction. Conversely, cortical destruction would be expected to be more specific because reactive change alone is unlikely to cause cortical structural remodeling.

Focal decrease in medullary signal intensity on T1-weighted images and focal increase in medullary signal intensity on T2-weighted images strongly correlated with histologic evidence of medullary involvement. All 11 sites found to have medullary involvement at histologic analysis (all with coexistent cortical involvement) were characterized by decreased medullary signal intensity on T1-weighted images and increased medullary signal intensity on T2-weighted images (sensitivity, 100%; NPV, 100%).

There were one false-positive findings of medullary involvement on the basis of decreased medullary signal intensity on T1-weighted and T2-weighted images (specificity, 96.7%; PPV, 91.7%). Concerning tumors with intramedullary involvement, that increased signal intensity on T2-weighted images lacks specificity (because it may be due to peritumoral edema, as well as osseous invasion) and can lead to overestimation of tumor size and extent. For this reason, T1-weighted images are more accurate for the assessment of intramedullary involvement NI.

In all sites with false-positive findings based on cortical or medullary signal intensity changes on T1- or T2-weighted images, reactive change was found at histologic analysis. All lesions with false-positive findings based on altered intramedullary signal intensity seen on T1- or T2-weighted images had been subjected to preoperative radiation therapy. In these lesions, tumor cells that were present initially in the medulla may have been eliminated by irradiation, leaving behind only reparative tissue. Irradiation also can induce morphologic changes in bone marrow that may affect medullary signal intensity on MR images [15] and thus lead to false-positive findings of osseous invasion.

Another potential source of discrepancies between imaging findings and histologic findings with respect to osseous invasion are various limi-
tations inherent in the process of histologic examination. The pathologist is dependent on the surgical description of specimen orientation, and normal anatomic landmarks may be obscured by resection. Moreover, because not all resected bone is subjected to histologic assessment, osseous invasion may be recognized on MR images and theoretically missed at histologic examination [4].

There are potential pitfalls also in the interpretation of the MR imaging signs of osseous invasion. Difficulties may arise in the assessment of osseous abutment by the tumor at sites of muscle or tendon insertion into bone. At such sites, the absence of the soft-tissue interface normally seen between the muscle or the tendon and the bone could be misinterpreted as tumor abutment, because muscle and tumor may have similar signal intensities on T1-weighted images. Next, normal nutrient vessels or islands of hematopoietic marrow may cause focal cortical or medullary signal intensity change on MR images, which could be confused with tumor-related changes. Finally, partial volume averaging may cause the cortical border to appear ill defined on images, leading to a false-positive finding of cortical destruction. This tends to occur especially on transverse images of the tubular long bones, at sites of metadiaphyseal flaring, because the cortex is thin and obliquely oriented to the imaging plane. Correlation of transverse images with longitudinal images is important to avoid this pitfall [5].

The results of our study indicate that the overall accuracy of MR imaging for the detection of osseous invasion by soft-tissue sarcoma is high with findings of cortical or medullary signal intensity change or cortical destruction on T1- and T2-weighted images (Table 3). Our study, however, had several limitations. Due to the relatively few cases of histologically proved osseous invasion, caution must be exercised in interpreting the absolute statistical values obtained for each MR imaging sign. The relatively small numbers reflect the known resistance of bone to invasion by soft-tissue sarcoma. In addition, selection bias may have been introduced by our inclusion in this study only of subjects in whom bone was resected at surgery. We did not examine images of subjects with soft-tissue sarcoma who did not undergo bone resection, because any imaging findings could not be correlated with histopathologic findings. This accounts for the apparent high rate (36.5%) of osseous invasion of soft-tissue sarcoma in our study subjects. Nevertheless, we did find an overall NPV of 93% for MR assessment of osseous invasion, and this NPV should be lower for the general population of soft-tissue sarcoma patients, including those who did not undergo bone resection, since they are even less likely to have osseous invasion than were our study subjects.

The delay between MR imaging and surgical resection, and the use of radiation therapy in the interim in some cases, are further potential limitations. These factors may account for some of the discrepancies between imaging findings and histologic findings. The delay between MR imaging and surgical resection in some patients might be expected to have caused an increase in the number of false-negative findings in our study; patients without osseous invasion at MR imaging could have developed osseous invasion by the time of resection.

Conclusion:

Cortical and medullary signal intensity changes and cortical destruction observed on T1- and T2-weighted MR images are highly sensitive and highly specific signs of osseous invasion by soft-tissue sarcoma, when compared with findings at histopathologic evaluation. Increasing maximal diameter and increasing circumference of osseous abutment by the tumor did not result in a statistically significant increase in the likelihood of osseous invasion.

References


