David M. Panicek, MD • Constantine Gatsonis, PhD[2] • Daniel I. Rosenthal, MD
Leanne L. Seeger, MD • Andrew G. Huvos, MD • Sheila G. Moore, MD[3]
Daryl J. Caudry, MS • William E. Palmer, MD • Barbara J. McNeil, MD, PhD

CT and MR Imaging in the Local Staging of Primary Malignant Musculoskeletal Neoplasms: Report of the Radiology Diagnostic Oncology Group[1]

PURPOSE: To assess the relative accuracies of computed tomography (CT) and magnetic resonance (MR) imaging in the local staging of primary malignant bone and soft-tissue tumors.

MATERIALS AND METHODS: At four institutions, 367 eligible patients (aged 6–89 years) with malignant bone or soft-tissue neoplasms in selected anatomic sites were enrolled. Patients underwent both CT and MR imaging within 4 weeks before surgery. In each patient, CT scans were interpreted independently by two radiologists and MR images by two other radiologists at the enrolling institution. The CT and MR images were then interpreted together by two of those radiologists and subsequently reread at the other institutions. Imaging and histopathologic findings were compared and were supplemented when needed with surgical findings. Receiver operating characteristic curve analysis and descriptive statistical analysis were performed.

RESULTS: Cases were analyzable in 316 patients: 183 had primary bone tumors; 133 had primary soft-tissue tumors. There was no statistically significant difference between CT and MR imaging in determining tumor involvement of muscle, bone, joints, or neurovascular structures. The combined interpretation of CT and MR images did not statistically significantly improve accuracy. Interreader variability was similar for both modalities.

CONCLUSION: CT and MR imaging are equally accurate in the local staging of malignant bone and soft-tissue neoplasms in the specific anatomic sites studied.

Approximately 6,000 new cases of soft-tissue sarcomas and 2,000 new cases of bone sarcoma are diagnosed each year in the United States (1). Before the 1970s, optimal treatment of these (typically large) lesions often was achieved by amputating the affected limb. Subsequent advances in preoperative assessment, neoadjuvant therapy, and surgical techniques have allowed limb-sparing (limb-salvage) operations to be performed in the large majority of such cases, with at least equivalent patient survival rates and improved functional results (2–9).

Successful planning of an individual patient's therapy requires the precise and accurate delineation of the local extent of neoplasm in bones, muscles, joints, blood vessels, and nerves. Magnetic resonance (MR) imaging has been embraced by many as superior to computed tomography (CT) for this purpose, typically on the basis of retrospective analyses of small series of cases within single institutions; in some studies, CT was performed without intravenous contrast material. Apparent advantages of MR imaging include the ability to obtain images in multiple planes, improved contrast between soft-tissue masses and normal tissues, clearer delineation of the extent of intramedullary bone involvement, and identification of the relationship between a tumor mass and major neurovascular structures without the use of intravascular contrast material. Although MR images often provide strikingly more contrast resolution than CT images, the effect of this difference or of the other purported advantages of MR imaging has yet to be proved to result in improved local staging of musculoskeletal neoplasms.

The Radiology Diagnostic Oncology Group (RDOG) (10) was formed in 1987 to perform multi-institutional comparative studies of relevant imaging modalities in the staging of various cancers (eg, of the lung, colon, prostate, pancreas, and head and neck), typically by using a paired study design in which each patient undergoes all of the imaging tests with standard protocols. This RDOG study was undertaken to determine the relative accuracies of CT and MR imaging for local staging of primary malignant musculoskeletal tumors before surgical resection.

Index terms: Bone neoplasms, staging, 40.32 • Computed tomography (CT), comparative studies, 40.1211 • Magnetic resonance (MR), comparative studies, 40.1214 • Receiver operating characteristic (ROC) curve • Soft tissues, neoplasms, 40.32

Abbreviations: RDOG = Radiology Diagnostic Oncology Group, ROC = receiver operating characteristic, SE = spin echo.

Radiology 1997; 202:237–246

[1] From the Departments of Radiology (D.M.P.) and Pathology (A.G.H.), Memorial Sloan-Kettering Cancer Center, 1275 York Ave, New York, NY 10021; the Department of Health Care Policy, Harvard Medical School, Boston, Mass (C.G., D.J.C., B.J.M.); the Department of Radiology, Massachusetts General Hospital, Boston (D.I.R., W.E.P.); the Department of Radiological Sciences, University of California, Los Angeles (L.L.S.); and the Department of Radiology, Stanford University Hospital, Palo Alto, Calif (S.G.M.). From the 1995 RSNA scientific assembly. Supported by National Institutes of Health, National Cancer Institute grant U01 CA54046. Received July 9, 1996; revision requested August 16; revision received September 17; accepted September 18. **Address reprint requests to** D.M.P.
[2] Current address: Center for Statistical Science, Brown University, Providence, RI.
[3] Current address: Department of Imaging, Cedars-Sinai Medical Center, Los Angeles, Calif.

MATERIALS AND METHODS

Four participating institutions enrolled patients in this study: Memorial Sloan-Kettering Cancer Center (New York, NY); Massachusetts General Hospital (Boston); University of California, Los Angeles; and Stanford University Hospital (Palo Alto, Calif). Potential candidates for this protocol were brought to the attention of the principal investigators or their research assistants by the medical oncologists or surgeons responsible for their care. An initial evaluation form was completed for an eligible candidate on the basis of the inclusion and exclusion criteria described below. If a patient met those criteria and agreed to participate in the study after the nature of the procedures had been fully explained, the patient's signature on a standard informed consent form was required before enrollment. The protocol and consent form were approved by the institutional review board of each participating institution. Each participating patient was then enrolled by telephone at the American College of Radiology (office in Philadelphia, Pa).

Patient Inclusion Criteria

To be eligible for enrollment, a patient had to have a proved or strongly suspected primary malignant neoplasm arising from bone or nonvisceral soft-tissue structures in the arm (above the elbow), shoulder, pelvis, hip, thigh, knee, or calf. Patients with neoplasms that involved other areas of the musculoskeletal system were not enrolled because the number of patients anticipated to have tumors in those sites was small, which would have led to insufficient data for meaningful analysis. Patients with fibromatosis or desmoid tumor were also deemed eligible for the protocol because these lesions are considered by some to represent low-grade malignancy (fibrosarcoma) and often are treated as such. Patients had to be at least 6 years of age so that the routine need for sedation could be avoided. A patient may have received neoadjuvant chemotherapy, radiation therapy, or both before the imaging, but at least 90% of that therapy had to be completed before the imaging to prevent appreciable treatment-related changes from occurring in the interval between imaging and subsequent surgery.

A patient had to be a surgical candidate, because the standard of reference in this study is the histopathologic examination of the specimen obtained at surgery supplemented (eg, if gross tumor knowingly was not resected at surgery) with the findings at surgery. Patients with distant metastatic disease from their primary musculoskeletal neoplasms were eligible for the study if the primary neoplasm was to be resected. A patient had to be able to undergo both CT scanning with intravenous administration of iodinated contrast material and MR imaging.

Patient Exclusion Criteria

Patients were ineligible for this study if they had undergone previous resection of the neoplasm or incisional biopsy with removal of the majority of the tumor. Patients with only a small amount of residual disease or with recurrent disease after previous resection were not enrolled.

Patients with a round cell musculoskeletal neoplasm (eg, lymphoma, leukemia, multiple myeloma, Ewing sarcoma, embryonal rhabdomyosarcoma) or a metastasis from a nonmusculoskeletal primary tumor were not enrolled in the study. Such tumors may behave differently than other primary musculoskeletal sarcomas, and en bloc resection specimens often are not obtained.

Patients were not eligible for the study if they had an additional extensive primary process in the bone or soft tissues (such as Paget disease or neurofibromatosis) in the area of the musculoskeletal neoplasm. Such disease markedly distorts the normal anatomic relationships and imaging features. An underlying, less distorting benign lesion such as osteochondroma was not excluded. The presence of a pathologic fracture that resulted in gross displacement or angulation precluded enrollment in the study, because the resultant hemorrhage and edema could greatly obscure relevant detail.

Patients with contraindications to intravenous contrast material or MR imaging were not eligible for the study. Pregnant women were not enrolled in this study, because their imaging work-up must be individualized.

CT Scanning Protocol

Most patients underwent scanning with nonhelical CT scanners (GE 9800; GE Medical Systems, Milwaukee, Wis); other state-of-the-art CT scanners occasionally were used if those scanners were not available at the time of the examination. In most cases, the patient was supine during scanning. Owing to the presence of tumors, some patients found the supine position uncomfortable or impossible to assume; such patients were in the prone or, rarely, lateral decubitus position during scanning. Patients with musculoskeletal neoplasms of the pelvis that also potentially involved pelvic viscera underwent scanning 3–4 hours after ingesting 750 mL of dilute oral contrast material.

A localizing CT digital radiograph was obtained for determining the appropriate region to be scanned. The exact region was individualized to include the whole tumor and entire associated major bone. For tumors of the shoulder or arm, the patient usually underwent scanning with the arms at the side. The scan diameter was based on the size of the body region being scanned and was made as small as practical.

The CT sections first were obtained without the administration of intravenous contrast material by using 10-mm collimation to obtain contiguous axial sections through the whole lesion and entire associated major bone. Subsequently, CT sections were obtained through the whole tumor, beginning 60 seconds after the initiation of the intravenous administration of 150 mL of 60% iodinated contrast material delivered by means of power injector at 1 mL/sec. The dose for a child was reduced proportionately to the child's weight (2 mL/kg). The collimation and table increments used to obtain the contrast material–enhanced CT sections were 5 mm if the tumor was smaller than 10 cm (as estimated from physical inspection of the patient and from the unenhanced CT images) or 10 mm if the tumor was larger than 10 cm. Initially, in cases of possible joint invasion, contiguous 3-mm CT sections were obtained through the affected joint. However, this practice was discontinued early in the study because of a perceived lack of clinical usefulness and the increased time and radiation dose required.

CT scans of soft-tissue tumors were reconstructed by using the standard algorithm, and scans of bone tumors were also reconstructed by using the bone algorithm. The CT sections were photographed by using window width and level settings that best allowed evaluation of soft-tissue structures (eg, window width, +500 HU; window level, +50 HU) and bones (eg, window width, +2,000 HU; window level, +350 HU). The exact settings were individualized for each patient on each scanner. At least one set of images was targeted to the affected body part.

MR Imaging Protocol

The MR examinations were performed with 1.5-T units (GE Medical Systems). Most patients were supine with their arms at their sides and with the appropriate body part as close as possible to the center of the magnet during imaging.

A rapid, low-resolution localization series was obtained to define the region to be imaged, which included the entire tumor and associated major bone. Then, by using the body coil, T1-weighted spin-echo (SE) images of the entire bone were obtained in the coronal, sagittal, or both coronal and sagittal planes. Oblique axis imaging was performed if the body part being imaged could not be positioned parallel to the imager couch. The following parameters were used: a repetition time of 300–600 msec and an echo time of 10–20 msec (300–600/10–20), 5-mm-thick sections, a 1-mm intersection gap, 192–256 phase-encoding steps, and two signals acquired.

By using a local coil (or body coil for pelvis or hip lesions), T1-weighted SE (300–600/10–20) axial images that included the entire lesion were then obtained with 192–256 phase-encoding steps and two signals acquired. Sections were 5 mm thick with a 1-mm intersection gap if the lesion was smaller than 10 cm (as estimated from physical inspection of the patient and the

coronal or sagittal MR images) or 8–10 mm thick with a 1.5-mm intersection gap if the lesion was larger than 10 cm. Proton-density– and T2-weighted SE (2,000–2,500/20, 80) axial images of identical thicknesses were obtained with 128 phase-encoding steps and two signals acquired.

In the early phases of the study, in cases of possible joint invasion, 3-mm-thick axial proton-density– and T2-weighted SE images (2,000–2,500/20, 80) were obtained through the joint with a 1-mm intersection gap, 192 phase-encoding steps, and two signals acquired. As noted above for CT, this practice was discontinued because of a perceived lack of clinical usefulness. For all MR imaging sequences, the smallest field of view was used that could encompass the region to be imaged while allowing a reasonable number of sections to be obtained and an adequate signal-to-noise ratio.

Several special software options were used to decrease artifacts, including superior and inferior spatial presaturation pulses and the no-phase-wrap and no-frequency-wrap options. Fast SE images were not obtained and fat saturation pulses were not used because those were not yet available to us when the trial began. Patients did not receive gadolinium-based intravenous contrast material as part of the protocol.

Each MR section was photographed by using window width and level settings that best allowed evaluation of soft tissues and bones.

Quality Control

A quality control committee composed of two radiologists (D.M.P., W.E.P.) periodically reviewed all images from the four institutions throughout the study. The committee checked for image quality and adherence to study protocols. Those images that were deemed to have deviated substantially from the protocol parameters or that were of poor technical quality were designated as inevaluatable and were excluded from the final data analysis.

Patient Population

Three hundred sixty-seven patients were enrolled in the study (213 male, 154 female; mean age, 40 years; age range, 6–89 years).

Fifty-one patients were excluded from the final data analysis for various reasons: 22 because the final histopathologic diagnosis was benign, 11 for lack of both imaging and histopathologic data, four for lack of histopathologic data, and one because imaging was not performed. Eight were excluded because they did not undergo surgery (because the patient was deemed inoperable [$n = 2$], the patient refused surgery [$n = 2$], the disease was deemed unresectable [$n = 1$], or other reasons [$n = 3$]). One patient was excluded because the imaging was performed more than 4 weeks before surgery. Also, in 17 patients CT and in 21 patients MR imaging had deviated substantially from the imaging protocol or images were of unacceptable technical quality according to the quality control committee; those unacceptable imaging studies were not used in the data analysis. (Both CT and MR images were unacceptable in four patients.)

Overall, 296 patients had acceptable CT scans, 291 had acceptable MR images, 316 had acceptable CT or MR images, and 276 had acceptable CT and MR images. Of the 316 patients whose images were analyzable, 176 were male and 140 were female patients; their mean age was 39 years (median, 37 years; range, 6–88 years). The mean age of the 183 patients with primary bone tumors and analyzable images was 31 years (median, 25 years; range, 6–78 years), and the mean age of the 133 patients with primary soft-tissue tumors and analyzable images was 50 years (median, 50 years; range, 6–88 years). A total of 70 patients were aged 6–18 years (mean, 14 years; median, 15 years).

Interpretation of CT and MR Images

Each institution identified a team of four faculty radiologists who participated in this study. All readers were interpreters of both CT and MR images, except for one reader at one institution who interpreted only CT images. Many but not all readers were musculoskeletal radiologists. Two readers were selected (by a randomization procedure administered by the American College of Radiology) to independently read the CT scans obtained in each patient enrolled at their institution, and two others to independently read the MR images. Each reader had access to information about the histopathologic type of the primary tumor (when known) but no information about the clinical stage or the findings of the other imaging modality.

Each CT and MR image was analyzed (by using standard radiologic criteria) for specific features that are relevant to the local staging of musculoskeletal neoplasms: origin of tumor in bone versus soft tissue; size and location of lesion; presence and length of intramedullary bone tumor; involvement of specific bones, muscles, nerves, and blood vessels; intraarticular extension; satellite lesions in soft tissue; and bony skip lesions. The radiologists were instructed to score each bone, muscle, and joint for the presence or absence of tumor by using a sliding five-point scale (0 = normal, 1 = probably normal, 2 = indeterminate, 3 = probably abnormal, 4 = definitely abnormal) and to assess each nerve and vessel by using a three-point scale (yes, no, indeterminate). Involvement of blood vessels and nerves was considered present if the structure was encased or invaded by tumor.

After the initial readings were completed for each modality, a separate "joint reading" was performed to determine whether information from one imaging modality (eg, CT) improved the true-positive and true-negative assessments of the other (eg, MR imaging). In this session, one of the two CT scan readers and one of the two MR image readers of a given case together evaluated both studies, assessed his or her original findings in view of the results of the other modality, and then completed a joint reading form that focused on the key assessments made during the initial reading for the modality.

To assess interreader and interinstitutional variability, the images of cases from a given institution were reread by readers at the other participating institutions. The rereadings consisted of an abbreviated version of the key assessments made during the initial readings of the cases. The rereading was accomplished by sending images to the various institutions during the course of the study; this was based on the availability of those images at the American College of Radiology (office in Philadelphia, Pa). Readers at one of the institutions were unable to reread a sufficient number of such cases to allow inclusion of that institution in the assessment of variability; CT and MR images were reread at three of the other institutions (120, 153, or 180 pairs of examinations at each institution). The images of all cases could not be reread owing to time and personnel constraints.

Surgical Proof

Choice of surgical procedures was not altered by using this protocol. Preoperative CT and MR findings were available to the surgeon (in conjunction with other clinical factors) in the planning of each patient's surgical procedure. At the end of an operation, the surgeon completed the surgical data form, detailing the type of procedure and any known areas of gross tumor left in the patient. The surgeon also tagged the resection specimen and alerted the pathologist to the meaning of the various tags to aid in appropriate orientation of the specimen during histopathologic examination.

Histopathologic Examination

Findings at histopathologic examination of the surgical specimen constituted the standard of reference against which the imaging findings were assessed. The pathologist described and processed the resected specimens routinely, aided by the specimen tags provided by the surgeon for proper orientation of the specimen and identification of relevant anatomic structures. The anatomic structures present were described as normal tissue, abnormal tissue without tumor present, or abnormal tissue with tumor present.

For bone tumors, a cross-section of the proximal margin of bone was cut with a band saw. A longitudinal plane for sectioning, which usually gives the most information, was selected to demonstrate the extension of tumor into adjacent soft tissue (if present), and a longitudinal section (approximately 5 mm thick) parallel to the first was cut with the band saw and

submitted for histopathologic examination after decalcification.

The three principal dimensions of the tumor were determined. Muscles, joints, and any other bones present in the specimen were assessed for presence of tumor. Areas proximal and distal to the main tumor mass were inspected for satellite tumor nodules. Major blood vessels were opened and examined, and fragments of any thrombus seen were removed and submitted for microscopic examination. Major nerves, when present, were assessed for encasement or invasion by tumor. Multiple sections of the tumor and of the various resection margins were studied by means of microscopic examination.

All sarcomas were classified according to histopathologic type and grade of malignancy (low-grade or high-grade designation). The amount of necrosis within the tumor was estimated.

No practical method could be devised to assess interinstitutional variability in the histopathologic assessment of the tumors in this study. However, at the outset all participating pathologists were instructed by the lead pathologist (A.G.H.) in a standard histopathologic examination for this protocol.

Data Analysis

The complete set of data elements in each patient enrolled in the study were detailed clinical, anatomic, and imaging data collected on standard forms at the following: initial (clinical) evaluation, first reader CT evaluation, second reader CT evaluation, first reader MR imaging evaluation, second reader MR imaging evaluation, joint CT and MR imaging reading, interinstitutional CT reading, interinstitutional MR reading, surgery, and histopathologic analysis. The final surgery and pathology reports, as well as the CT and MR images, were submitted for each patient. The data forms were collated and entered into a database by the American College of Radiology (office in Philadelphia, Pa). Data analysis was performed at the Department of Health Care Policy, Harvard Medical School, Boston, Mass.

The CT and MR imaging determinations of lesion size were each compared with that of histopathologic analysis, as well as with each other. The Wilcoxon signed rank test (11) was used to test the hypothesis that there was no difference in the estimates of tumor length provided at CT, MR imaging, and histopathologic analysis. For the purpose of descriptive statistics, imaging scores of 0, 1, and 2 were considered negative; 3 and 4 were considered positive. Similarly, ratings of "no" and "indeterminate" were considered negative; "yes" was considered positive. The histopathologic category of abnormal tissue with no tumor present was combined with the normal tissue category for comparison against imaging scores, because the radiologists were instructed to score structures only on the basis of the suspected presence or absence of tumor.

Because of the lack of precision in the anatomic description of bone parts (such as metaphysis and diaphysis), a matching algorithm was developed to allow comparison between imaging and histopathologic descriptions. Anatomic regions of each bone were classified as neighboring (ie, contiguous with) or not neighboring (ie, not contiguous with) each of the other portions of that bone. For example, the lesser trochanter of the femur is a neighbor of the intertrochanteric region but not of the femoral head. A match between imaging and histopathologic analysis was considered to occur if both agreed that no tumor was present in a bone or if tumor was rated as present in one or more identical, neighboring, or both identical and neighboring regions of a bone. A mismatch was considered to occur if imaging and histopathologic findings disagreed on whether any tumor was present in a specific bone, or if the lesion in bone predicted at imaging was not in the identical or neighboring region as that of tumor found in that bone at histopathologic examination.

Agreement between imaging and pathologic determinations of lesion length (12) indirectly corroborates that the lesion assessed was correctly localized. In addition, the location of the lesion shown at imaging directs the surgeon to resect that exact area.

Muscles were assessed individually on the data forms but were then grouped as follows during data analysis: arm or shoulder (deltoid, trapezius, pectoralis major and minor, serratus anterior, teres major and minor, latissimus dorsi, rhomboideus major and minor, levator scapulae, supraspinatus, infraspinatus, subscapularis, biceps, brachialis, brachioradialis, coracobrachialis, and triceps), pelvis or hip (gluteus minimus, medius, and maximus; psoas; iliacus; iliopsoas; piriformis; obturator internus and externus; gemellus; and quadratus femoris), thigh or knee (tensor fascia latae; rectus femoris; vastus medialis, lateralis, and intermedius; sartorius; gracilis; pectineus; adductor; biceps femoris; semitendinosus; and semimembranosus), and calf (tibialis anterior, extensor hallucis longus, extensor digitorum longus, peroneus longus and brevis, gastrocnemius, soleus, plantaris, popliteus, flexor digitorum longus, tibialis posterior, and flexor hallucis longus). Grouping was performed (*a*) to produce sufficient numbers of observations per group to allow meaningful statistical analysis and (*b*) because a detailed comparison of CT scans and MR images for each specific muscle likely would be of little radiologic or clinical interest.

Receiver operating characteristic (ROC) curves were constructed for all readers combined for involvement of periosteum, cortex, and medullary cavity of bones, as well as for muscles grouped according to anatomic regions. Because of the small number of cases in which joints or major nerves or vessels were involved by tumor at histopathologic analysis, ROC curves were not constructed for those findings. Instead, sensitivity, specificity, positive and negative predictive values, and accuracy were calculated. The McNemar test was used to compare the sensitivities and specificities of CT and MR imaging for those items not assessed with ROC curves (11, pp 268–270). The areas under the ROC curves were estimated by using the Wilcoxon statistic (13). A nonparametric approach (14) was used to compare areas under correlated ROC curves; the Bonferroni correction was used to control for multiple comparisons within each group (15).

Interreader and interinstitutional variabilities in the assessment of imaging studies were measured by comparing the ROC curves for tumor involvement of bone and of muscle for each of the readers and by listing the ranges of areas under those curves.

Table 1
Histologic Diagnoses of Primary Tumors in 316 Analyzable Cases

Diagnosis	Primary Bone Tumor (n = 183)	Primary Soft-Tissue Tumor (n = 133)
Osteosarcoma	121	6
Chondrosarcoma	41	5
Malignant fibrous histiocytoma	9	36
Liposarcoma	0	35
Synovial sarcoma	0	15
Leiomyosarcoma	3	10
Fibrosarcoma	2	5
Rhabdomyosarcoma	1	1
Hemangiopericytoma	1	1
Angiosarcoma	1	1
Anaplastic sarcoma	1	3
Neurosarcoma	0	5
Alveolar soft part sarcoma	0	4
Epithelioid sarcoma	0	2
Other	3	4

RESULTS

Bone Tumors

The final histopathologic diagnoses in the 183 primary bone tumors are listed in Table 1. The lesions were determined to be high grade in 147 patients (80%), low grade in 34 (19%), and unknown in two (1%).

Before presurgical imaging, 21 patients received preoperative radiation therapy, 112 received chemotherapy, and 11 received both. Twenty-one patients underwent amputation: forequarter (n = 2), hindquarter (n = 6), above knee (n = 10), or below knee (n = 3). In four patients, the surgeon stated that the entire tumor was not removed at surgery.

Osseous lesion location.—The primary bone tumors in the 183 patients were located in the shoulder or arm

Table 2
Primary Bone Tumors: Agreement between Assessments of Length of Intramedullary Tumor

Comparison	Agreement (%)		Absolute Value of Difference (cm)		Difference (cm)		Mean Difference (cm) ± Standard Deviation
	Tumor ≤2 cm	Tumor ≤5 cm	Median	Range	Median	Range	
CT versus pathology	67 (94 of 141)	89 (125 of 141)	1.5	0–11.0	0.5	−6.0–11.0	1.1 ± 3.1*
MR imaging versus pathology	69 (88 of 127)	88 (112 of 127)	1.5	0–12.9	0.2	−12.9–11.0	0.9 ± 3.3*
CT versus MR imaging	72 (91 of 126)	89 (112 of 126)	1.3	0–10.9	0.0	−10.7–10.9	0.2 ± 3.3†

Note.—Tumor length was greater at CT than at pathologic analysis in 58% (82 of 141) of patients and greater at pathologic analysis than at CT in 32% (45 of 141) of patients. Tumor length was greater at MR imaging than at pathologic analysis in 53% (67 of 127) of patients and greater at pathologic analysis than at MR imaging in 35% (44 of 127) of patients. Tumor length was greater at CT than at MR imaging in 49% (62 of 120) of patients and greater at MR imaging than at CT in 40% (51 of 126) of patients.

* $P < .001$ (Wilcoxon signed rank test).

† $P = .42$ (Wilcoxon signed rank test).

($n = 31$), pelvis or hip ($n = 26$), thigh or knee ($n = 82$), or calf ($n = 37$); or the location was unspecified ($n = 7$).

Osseous lesion size.—The primary intramedullary component of the lesions ranged from 1.0 cm to 32.0 cm (mean, 8.9 cm) in greatest dimension at pathologic examination. Agreements of intramedullary lesion length assessments between CT, MR imaging, and pathologic analysis are listed in Table 2 and are based on data from the primary reading performed at the patient's institution. The CT and MR imaging measurements of the intramedullary tumor length each differed significantly from the measurements obtained at pathologic analysis ($P < .001$ for both comparisons [Wilcoxon signed rank test]); however, there was no significant difference between mean CT and MR imaging measurements ($P = .42$). The length of the intramedullary tumor tended to be overestimated with both CT and MR imaging compared with pathologic measurement.

With data from the primary reading at the patient's institution and from the rereadings performed at the other institutions, the median difference between the CT and MR imaging measurements of length of intramedullary neoplasm was 0.15 cm (range, −9.3–8.3 cm); the mean difference was 0.10 cm ± 2.4 (± standard deviation) ($P = .71$).

Anatomic extent of bone tumor.—An associated soft-tissue mass was present in 114 cases. Twenty-six cases of intraarticular extension were demonstrated at histopathologic examination. At histopathologic examination, tumor was found to involve major vessels in six cases and major nerves in three cases. Skip lesions (within bone) were also infrequent; they were seen in seven cases at histopathologic examination.

The observed sensitivity, specificity, accuracy, and positive and negative predictive values for bone, joint, muscle, vessel, and nerve involvement and for the presence of bony skip lesions at CT and MR imaging are presented in Table 3. The sensitivities and accuracies of CT and of MR imaging for bone involvement generally were high, with lower specificities. For both modalities, sensitivities and specificities for joint involvement were moderately high, whereas sensitivities for skip lesions and for nerve or vessel encasement or invasion were low.

The results of ROC analysis for bone and muscle involvement are listed in Table 4; only those bones and muscle groups with at least 40 observations are included. Overall, there was no statistically significant difference between CT and MR imaging for the assessment of bone and muscle involvement. The two readings for each modality did not show consistently statistically significant differences, and the joint readings did not statistically significantly change the observed areas under the ROC curves.

Soft-Tissue Tumors

The final histopathologic diagnoses of the primary soft-tissue tumors in 133 patients are listed in Table 1. The lesions were determined to be high grade in 102 patients (77%), low grade in 29 (22%), and of unknown grade in two (1%).

Fifty patients received radiation therapy before presurgical imaging, 34 received chemotherapy, and 24 received both. Eight patients underwent amputation: hindquarter ($n = 2$), above knee ($n = 3$), and below knee ($n = 3$). In two patients, the surgeon stated that the entire tumor was not removed at surgery.

Soft-tissue lesion location.—The primary soft-tissue tumors in the 133 patients were located in the shoulder or arm ($n = 20$), pelvis or hip ($n = 17$), thigh or knee ($n = 73$), or calf ($n = 21$); or the location was unspecified ($n = 2$). Lesions were located deep to the deep fascia in 117 patients and were superficial in 13 patients; the location was unknown in three patients.

Soft-tissue lesion size.—The maximum dimension of the primary soft-tissue mass ranged from 1.2 cm to 40.0 cm (mean, 11.6 cm) at pathologic examination. Agreements of maximum lesion dimension assessments between CT, MR imaging, and pathologic analysis are listed in Table 5 and are based on data from the primary reading performed at the patient's institution. The CT and MR imaging measurements of the maximum dimension of tumor were significantly different from the measurements obtained at pathologic analysis ($P < .001$ and $P = .002$ [Wilcoxon signed rank test]), as well as significantly different from each other ($P = .02$). The maximum dimension of the tumor tended to be overestimated with both CT and MR imaging compared with pathologic measurement.

By using data from readings at the patient's institution and from the rereadings performed at the other institutions, the median difference between the CT and MR imaging measurements of the maximum dimension of the soft-tissue masses was 0.5 cm (range, −17.3–12.0 cm); the mean difference was 0.9 cm ± 3.4 ($P = .001$).

Anatomic extent of soft-tissue tumor.—At histopathologic examination, tumor was found to involve bone in 12

Table 3
Primary Bone Tumors: Descriptive Statistics for Bone, Joint, Muscle, Vessel, and Nerve Involvement and for Skip Lesions

	CT					MR Imaging				
Tumor Location	Sensitivity (%)*	Specificity (%)†	Accuracy (%)	PPV (%)	NPV (%)	Sensitivity (%)*	Specificity (%)†	Accuracy (%)	PPV (%)	NPV (%)
Humerus										
Periosteum	89 (19)	25 (4)	78	85	33	100 (19)	40 (5)	88	86	100
Cortex	89 (19)	25 (4)	78	85	33	94 (18)	33 (6)	79	81	67
Medullary cavity	95 (19)	75 (4)	91	95	75	94 (18)	50 (6)	83	85	75
Pelvis										
Periosteum	100 (24)	98 (45)	99	96	100	88 (25)	89 (19)	89	92	85
Cortex	100 (26)	100 (43)	100	100	100	89 (27)	100 (17)	93	100	85
Medullary cavity	96 (24)	100 (45)	99	100	98	96 (25)	100 (19)	98	100	95
Femur										
Periosteum	96 (57)	64 (39)	83	80	93	98 (52)	50 (36)	78	74	95
Cortex	97 (66)	70 (30)	89	88	91	100 (62)	56 (25)	87	85	100
Medullary cavity	96 (68)	75 (28)	90	90	88	94 (62)	68 (25)	86	88	81
Tibia										
Periosteum	100 (24)	73 (26)	86	77	100	100 (23)	77 (22)	89	82	100
Cortex	100 (28)	86 (22)	94	90	100	96 (26)	89 (19)	93	93	94
Medullary cavity	96 (28)	96 (23)	96	96	96	92 (25)	90 (21)	91	92	90
Fibula										
Periosteum	88 (8)	95 (19)	93	88	95	100 (7)	79 (14)	86	70	100
Cortex	100 (8)	89 (19)	93	80	100	100 (7)	86 (14)	90	78	100
Medullary cavity	100 (9)	100 (18)	100	100	100	88 (8)	100 (13)	95	100	93
Skip lesions	0 (7)‡	97 (151)‡	93	0	95	14 (7)‡	96 (139)‡	92	14	96
Intraarticular extension	67 (24)‡	81 (135)‡	79	39	93	70 (23)‡	80 (124)‡	78	39	93
Muscles										
Arm or shoulder	93 (14)	50 (16)	70	62	89	83 (12)	47 (17)	62	53	80
Pelvis or hip	95 (19)	84 (76)	86	60	98	100 (19)	67 (36)	78	61	100
Thigh or knee	67 (24)	66 (93)	66	33	88	63 (24)	58 (83)	59	30	84
Calf	75 (16)	75 (52)	75	48	91	71 (14)	81 (42)	79	56	89
Vessels	33 (6)‡	95 (164)‡	92	18	97	33 (6)‡	93 (151)‡	91	17	97
Nerves	33 (3)‡	95 (158)‡	94	11	99	50 (2)‡	93 (148)‡	92	08	99

Note.—NPV = negative predictive value, PPV = positive predictive value.
* Numbers in parentheses are true-positives + false-negatives. Differs from † in some instances because of excluded patients.
† Numbers in parentheses are true-negatives + false-positives. Differs from * in some instances because of excluded patients.
‡ $P > .05$ (McNemar test).

cases, major nerves in nine cases, and major vessels in six cases. Three cases of intraarticular extension were demonstrated at histopathologic examination.

The observed sensitivity, specificity, accuracy, and positive and negative predictive values for muscle, bone, joint, vessel, and nerve involvement and for the presence of satellite lesions in soft tissues at CT and MR imaging are presented in Table 6. Sensitivities, specificities, and accuracies of CT and of MR imaging for bone involvement and joint invasion were high, with slightly lower specificities. Sensitivities for vessel encasement or invasion were moderately good (and better than those for nerve involvement), with high specificities, for both imaging modalities. Although the specificities of CT and MR imaging for vessel and nerve involvement reached statistical significance ($P = .02$ and $P = .04$, respectively), the power of these findings is limited by the small number of observations on which they are based. Both CT and MR imaging were insensitive for the detection of satellite lesions in soft tissues, but the specificities were high.

The results of ROC analysis for muscle involvement are listed in Table 7; only those muscle groups with at least 40 observations are included. Overall, there was no statistically significant difference between CT and MR imaging for the assessment of muscle involvement. The two readings for each modality did not show consistently statistically significant differences, and the joint readings did not statistically significantly change the observed areas under the ROC curves.

Interreader and Interinstitutional Variability

The ranges of the areas under the ROC curves for readers from the three institutions that were included in the assessment of variability are presented in Table 8. The ranges were similar for both CT and MR imaging. A more detailed analysis of interreader and interinstitutional variability will be presented in a subsequent report.

DISCUSSION

The findings of this study do not support the prevailing wisdom that MR imaging is better than CT for the local staging of musculoskeletal neoplasms (16–24). Although the margins of musculoskeletal lesions often are more conspicuous on MR images than on CT scans because of the higher contrast with surrounding structures, our findings indicate that high-quality CT scans (including images obtained with intravenous contrast material enhancement) provide comparable information with regard to the overall local extent of these tumors. The prevailing wisdom may reflect the lower image quality attained with older CT scanners and the failure to use intravenous contrast material.

It is possible that other important, but less easily quantifiable, information is gleaned by the surgeon from MR images, particularly those obtained in nonaxial planes, or that MR imaging increases the surgeon's confidence in the preoperative staging data, which results in a better patient

Table 4
Primary Bone Tumors: ROC Analyses of Bone and Muscle Involvement with Tumor

Tumor Location	CT		MR Imaging	
	First Reader	Joint Reading	First Reader	Joint Reading
Pelvis				
Periosteum				
A_z	0.99	0.99	0.89	0.89
95% CI	0.95–1.00	0.95–1.00	0.77–1.00	0.77–1.00
Prevalence (%)	35 (69)	36 (59)	57 (44)	55 (38)
Cortex				
A_z	1.00	1.00	0.94	0.96
95% CI	1.00–1.00	1.00–1.00	0.85–1.00	0.87–1.00
Prevalence (%)	38 (69)	39 (59)	61 (44)	61 (38)
Medullary cavity				
A_z	1.00	1.00	0.98	0.95
95% CI	1.00–1.00	1.00–1.00	0.93–1.00	0.87–1.00
Prevalence (%)	35 (69)	36 (67)	57 (44)	65 (37)
Femur				
Periosteum				
A_z	0.83	0.80	0.76	0.80
95% CI	0.75–0.91	0.70–0.90	0.66–0.86	0.70–0.90
Prevalence (%)	59 (96)	56 (78)	59 (88)	56 (77)
Cortex				
A_z	0.83	0.82	0.82	0.86
95% CI	0.75–0.91	0.73–0.91	0.73–0.90	0.78–0.94
Prevalence (%)	69 (96)	68 (78)	71 (87)	69 (77)
Medullary cavity				
A_z	0.87	0.87	0.82	0.88
95% CI	0.80–0.94	0.80–0.95	0.74–0.91	0.80–0.95
Prevalence (%)	71 (96)	71 (95)	71 (87)	65 (94)
Tibia				
Periosteum				
A_z	0.89	0.88	0.90	0.91
95% CI	0.78–1.00	0.75–1.00	0.80–1.00	0.80–1.00
Prevalence (%)	48 (50)	50 (34)	51 (45)	51 (35)
Cortex				
A_z	0.93	0.93	0.95	0.93
95% CI	0.85–1.00	0.84–1.00	0.87–1.00	0.84–1.00
Prevalence (%)	56 (50)	56 (34)	58 (45)	57 (35)
Medullary cavity				
A_z	0.96	0.94	0.91	0.88
95% CI	0.89–1.00	0.84–1.00	0.81–1.00	0.76–1.00
Prevalence (%)	55 (51)	56 (52)	54 (46)	57 (46)
Muscles				
Pelvis or hip				
A_z	0.90	0.88	0.84	0.81
95% CI	0.81–1.00	0.77–1.00	0.70–0.97	0.66–0.97
Prevalence (%)	20 (95)	20 (80)	35 (55)	36 (45)
Thigh or knee				
A_z	0.73	0.72	0.67	0.65
95% CI	0.62–0.85	0.58–0.85	0.54–0.79	0.50–0.80
Prevalence (%)	21 (117)	19 (96)	22 (107)	18 (92)
Calf				
A_z	0.77	0.79	0.79	0.83
95% CI	0.63–0.90	0.63–0.94	0.66–0.93	0.67–0.98
Prevalence (%)	24 (68)	23 (48)	25 (56)	23 (44)

Note.—A_z = area under ROC curve, CI = confidence interval. All P values were greater than .05 (DeLong method). Numbers in parentheses are the numbers of observations.

outcome; however, this study was not designed to address these issues.

The CT and MR findings reported to the surgeon introduce an element of "work-up bias" by influencing, to at least some degree, the surgical approach. At a minimum, the surgeon generally excises areas suspected to represent tumor on the images. Such bias is inevitable, because it is impossible (and unethical) to withhold such information from the surgeon. However, the surgical procedure performed is itself independent of the predictions of the preoperative imaging tests, because the procedure is continually modified on the basis of the evolution of findings and events during surgery.

Most structures deemed normal by the radiologist will not be excised at surgery and are thus unavailable for histopathologic examination. This potential verification bias cannot be corrected by means of follow-up imaging in the context of this study, because patients with malignant musculoskeletal neoplasms often receive adjuvant (postoperative) chemotherapy, radiation therapy, or both chemotherapy and radiation therapy. The absence of tumor in a structure at follow-up imaging therefore is not proof that the tumor was not present in that region before surgery and subsequent therapy. Also, local recurrences of malignant musculoskeletal tumors are common, and it is not possible to distinguish a local recurrence that results from growth of microscopic foci of tumor left behind at surgery and gross tumor that was actually present (but not evident) at the preoperative imaging study. For these reasons, the surgeon's assessment that no gross tumor was left behind at surgery was considered as a secondary standard of reference when structures were imaged but not excised.

Shortcomings of the primary standard of reference (ie, histopathologic examination) must be noted. Even pathologists who devote much of their professional effort to studying musculoskeletal neoplasms can have great difficulty determining the exact identities of individual muscles, nerves, and blood vessels included in a surgical specimen. The precise orientation of the specimen may be unclear, especially after sectioning obscures the normal anatomic landmarks, and only small portions of muscles, nerves, and blood vessels may be included in the specimen. Moreover, the presence of a large tumor mass can markedly distort or mask normal anatomic relationships.

To overcome these difficulties, pathologists must rely heavily on the anatomic information provided by the surgeon. However, in some cases, the tumor may completely obliterate the normal regional anatomy for both the surgeon and the pathologist. Although this may be problematic in an anatomy-based study such as this, the standard histopathologic examinations performed here reflect the highest level of clinical practice achievable at this time.

It is at least theoretically possible that CT, MR imaging, or both CT and MR imaging are more precise than histopathologic examination in the local staging of musculoskeletal neoplasms. These (nondestructive) imaging methods allow large numbers of sections to be obtained in as many planes as desired, which shows the entire lesion in detail and within the overall anatomic context. In contrast, the pathologist is limited by practical considerations in the number of tumor sections that can be obtained and analyzed (especially in large lesions);

Table 5
Soft-Tissue Tumors: Agreement between Assessments of Maximum Dimension

Comparison	Agreement (%)		Absolute Value of Difference (cm)		Difference (cm)		Mean Difference (cm) ± Standard Deviation
	Tumor ≤2 cm	Tumor ≤5 cm	Median	Range	Median	Range	
CT versus pathology	54 (63 of 116)	83 (96 of 116)	2.0	0–19	1.0	−13–19	2.0 ± 4.6*
MR imaging versus pathology	59 (70 of 119)	87 (103 of 119)	2.0	0–18	0.5	−9.5–18	1.1 ± 3.7†
CT versus MR imaging	58 (66 of 113)	86 (97 of 113)	1.5	0–20.5	0.5	−12–20.5	1.0 ± 4.4‡

Note.—Maximum dimension was greater at CT than at pathologic analysis in 66% (76 of 116) of patients and greater at pathologic analysis than at CT in 28% (32 of 116) of patients. Maximum dimension was greater at MR imaging than at pathologic analysis in 62% (74 of 119) of patients and greater at pathologic analysis than at MR imaging in 33% (39 of 119) of patients. Maximum dimension was greater at CT than at MR imaging in 55% (62 of 113) of patients and greater at MR imaging than at CT in 34% (38 of 113) of patients.
* $P < .001$ (Wilcoxon signed rank test).
† $P = .002$ (Wilcoxon signed rank test).
‡ $P = .02$ (Wilcoxon signed rank test).

Table 6
Primary Soft-Tissue Tumors: Descriptive Statistics for Muscle, Bone, Joint, Vessel, and Nerve Involvement and Presence of Satellite Lesions

Tumor Location	CT					MR Imaging				
	Sensitivity*	Specificity†	Accuracy	PPV	NPV	Sensitivity*	Specificity†	Accuracy	PPV	NPV
Muscles										
Arm or shoulder	100 (14)	67 (3)	94	93	100	92 (13)	50 (4)	82	86	67
Pelvis or hip	88 (8)	76 (72)	78	29	98	89 (9)	77 (56)	78	38	98
Thigh or knee	96 (51)	49 (35)	77	73	89	96 (54)	38 (37)	73	69	88
Calf	87 (15)	74 (19)	79	72	88	73 (15)	77 (13)	75	79	71
Bones										
Periosteum	90 (10)	80 (60)	81	43	98	90 (10)	82 (60)	83	45	98
Cortex	90 (10)	83 (60)	84	47	98	90 (10)	88 (60)	89	56	98
Medullary cavity	100 (6)	91 (64)	91	50	100	100 (6)	89 (64)	90	46	100
Intraarticular extension	100 (2)‡	98 (113)‡	98	50	100	100 (3)‡	97 (104)‡	97	50	100
Vessels	67 (6)‡	91 (116)§	89	27	98	33 (6)‡	84 (119)§	82	10	96
Nerves	38 (8)‡	92 (109)‖	88	25	95	11 (9)‡	85 (110)‖	79	06	92
Satellite lesions	14 (7)‡	98 (112)‡	93	33	95	29 (7)‡	97 (113)‡	93	40	96

Note.—NPV = negative predictive value, PPV = positive predictive value.
* Numbers in parentheses are true-positives + false-negatives. Differs from † in some instances because of excluded patients.
† Numbers in parentheses are true-negatives + false-positives. Differs from * in some instances because of excluded patients.
‡ $P > .05$ (McNemar test).
§ $P = .02$ (McNemar Test).
‖ $P = .04$ (McNemar Test).

the failure to section a tumor-bearing portion of a surgical specimen can cause a false-positive imaging result. Currently, no other reliable standard of reference exists to prove whether these imaging studies are better than histopathologic examination in the local staging of tumor.

The participating pathologists were not asked to distinguish between microscopic and macroscopic foci of tumor. Thus, this study cannot determine what proportion of the apparently false-negative imaging assessments was due to the presence of only microscopic foci of tumor.

The size and shape of some soft-tissue tumor masses can change after surgical resection, which leads to discrepancies in the assessment of maximum dimension with imaging and pathologic examination. For example, a large mass may be elongated between muscles in situ but may assume a more rounded configuration after resection. Similarly, the cystic component of a resected soft-tissue mass may rupture or leak fluid before it is measured in the pathology laboratory, which results in a smaller measurement at pathologic examination than at imaging. Discrepancies in measurements of lesion size also may be partly due to differences in the tumor axes selected for measurement, despite standard instructions. These factors may have accounted for the greater discrepancies between imaging and pathologic assessments of soft-tissue tumor size as compared with the assessments of intramedullary tumor length. Because of the complex configurations of many tumors, it was not possible to provide instructions in anticipation of all possible circumstances.

The prevalence of skip lesions in bone has been reported to be as high as 25% in patients with osteosarcoma (25), but others have found skip lesions to be uncommon (26). In this study, it is notable that skip lesions were seen at histopathologic examination in only seven (3.8%) of the 183 patients with primary bone tumors and that the sensitivity of imaging for skip lesions was extremely low. However, because the sensitivity was based on only seven true-positive cases, the result must be regarded as tentative pending assessment of a larger number of patients with skip lesions.

Tumor encasement or direct invasion of major blood vessels or nerves was similarly uncommon in this study (in 3.3% or 1.1%, respectively, of the

Table 7
Primary Soft-Tissue Tumors: ROC Analyses of Muscle Involvement

Tumor Location	CT		MR Imaging	
	First Reader	Joint Reading	First Reader	Joint Reading
Pelvis or hip				
A_z	0.88	0.91	0.88	0.90
95% CI	0.72–1.00	0.74–1.00	0.72–1.00	0.73–1.00
Prevalence (%)	10 (80)	10 (70)	14 (65)	14 (56)
Thigh or knee				
A_z	0.72	0.73	0.71	0.78
95% CI	0.62–0.83	0.62–0.84	0.60–0.81	0.68–0.89
Prevalence (%)	59 (86)	59 (76)	59 (91)	58 (79)

Note.—A_z = area under ROC curve; CI = confidence interval. All P values were greater than .05 (DeLong method). Numbers in parentheses are the numbers of observations.

Table 8
Interreader Variability: Ranges of Areas under ROC Curves for Readers at Three Institutions

Tumor Location	Primary Bone Tumor		Primary Soft-Tissue Tumor	
	CT	MR Imaging	CT	MR Imaging
Bones				
Cortex	0.81–0.94	0.77–0.96	...	...
Medullary cavity	0.80–1.00	0.79–0.95	...	...
Muscles	0.62–0.83	0.59–0.81	0.61–0.85	0.53–0.81

patients with bone tumors and in 4.5% or 6.8%, respectively, of the patients with soft-tissue tumors). In view of the difficulties inherent in distinguishing mere contact and displacement from actual encasement or invasion of neurovascular structures at imaging, this low prevalence of actual encasement or invasion will yield false-negative and false-positive interpretations, which result in lower imaging accuracy in clinical practice unless obvious gross tumor encasement is demonstrated.

The readers were given the unenhanced and contrast-enhanced CT images together for interpretation. No attempt was made to compare those images during the study. However, a secondary project in which these cases are being used is in progress to determine whether the unenhanced images are beneficial.

The particular imaging techniques used during this 4-year study did not include some newer MR imaging pulse sequences and imaging options. For example, the fast SE MR imaging sequence produces T2-weighted images in less time than required for conventional T2-weighted sequences, and fat-selective suppression pulses are now available (27). Also, fast gradient-echo sequences can be used to obtain dynamic contrast-enhanced T1-weighted images. However, it is not clear whether further accentuation of the contrast between tumor and normal tissue will improve the ability to distinguish between contact and invasion. MR angiography could be used to produce more detailed images of blood vessels located near a tumor. Similarly, helical (spiral) technology now allows high-quality multiplanar reformations to be produced with CT, which might improve the acceptability of CT images to referring clinicians and possibly the ability to depict tumorous encasement of blood vessels with CT.

The distinction between soft-tissue tumor mass and adjacent edema or reactive changes in muscle can be difficult at CT and MR imaging. Dynamic contrast-enhanced MR imaging has been reported to facilitate that distinction (28–30), although gadolinium-based contrast material administration was not helpful in the definition of tumor margins of osteosarcoma at nondynamic MR imaging in a different study (31). No MR imaging contrast material was used in our study. Short inversion time inversion-recovery imaging is more sensitive to the presence of edema but may lead to an overestimation of tumor extent (32). Moreover, until recent modifications of the pulse sequence were made available, short inversion time inversion-recovery imaging required long amounts of time to produce small numbers of images. Again, it is not clear whether these newer MR imaging techniques improve the ability to assess the local stage of a musculoskeletal neoplasm.

Another limitation of the study is that a multitude of histopathologic types of tumors were separated into only two categories (soft-tissue and bone primary lesions), despite the different imaging features and biologic behavior of some of those tumors (eg, malignant fibrous histiocytoma vs well-differentiated liposarcoma). Further stratification would have led to small numbers of observations in a multitude of categories, which would have precluded meaningful statistical analysis.

Many of the patients received radiation therapy, chemotherapy, or both before definitive surgical resection. In such cases, both the CT and MR imaging examinations for this study were performed after such therapy was completed to allow comparison of the imaging findings with the results of subsequent histopathologic examination. The pretherapy imaging findings in those cases, although important in planning the patient's initial therapy, were not directly assessed in our study. Nevertheless, surgeons rely primarily on posttherapy imaging to guide the subsequent definitive surgical procedure; thus, our study did reflect actual clinical practice.

Overall, our results are generalizable to many radiology practices. The distribution of histopathologic types of tumors seen in this study reflects the overall prevalences of the various malignant musculoskeletal tumors. The CT and MR imaging equipment, imaging techniques, and methods of histopathologic examination used are widely available. The readers in this study largely reflect the faculty that might be encountered in academic centers where many musculoskeletal neoplasms are evaluated and treated.

The results of this multi-institutional collaborative study show that CT and MR imaging provide comparable information relevant to preoperative local staging of primary malignant musculoskeletal neoplasms located in the anatomic sites studied. No objective benefit was shown for a combined reading of both studies. Interreader variability was similar for both modalities. Factors such as relative costs and availability of these imaging modalities, ability of a given patient to tolerate intravenous contrast material for CT scanning or to undergo MR imaging, and physician preferences will influence whether CT or MR imaging is performed in an individual patient. ■

Acknowledgments: The authors thank the following individuals for their important contributions to this study: Thomas Caldwell, Nancy Connor, Brenda Harrison, Cynthia B. Olson, MBA, MHS, Elaine Pacers, and JoAnn Stetz, RN, RTT, from the American College of Radiology, Philadelphia, Pa; John Tsimikas, PhD, from Harvard Medical School, Boston, Mass; Felix Chew, MD, Damian Dupuy, MD, Susan V. Kattapuram, MD, Andrew Rosenberg, MD, Mark Gebhardt, MD, Henry J. Mankin, MD, John Ready, MD, Dempsey Springfield, MD, and research assistants Mary Jane O'Neil and Michael Rosol from Massachusetts General Hospital, Boston; James F. Caravelli, MD, Robert T. Heelan, MD, Susan Hilton, MD, James M. Woodruff, MD, Patrick J. Boland, MD, Mary Sue Brady, MD, Murray F. Brennan, MD, Daniel Coit, MD, Martin Karpeh, MD, John H. Healey, MD, Joseph M. Lane, MD, and research assistant Esther Choy from Memorial Sloan-Kettering Cancer Center, New York, NY; Gabrielle Bergman, MD, Gary M. Glazer, MD, Robert Herfkens, MD, Gerald Berry, MD, Richard Kempson, MD, Donald Nagel, MD, Lawrence Rinsky, MD, Leo Semkin, MD, James Gamble, MD, Stuart Goodman, MD, and research assistant Brian Martin from Stanford University Hospital, Palo Alto, Calif; Amilcare Gentili, MD, Richard H. Gold, MD, Lawrence Yao, MD, Yao-Shi Fu, MD, Jeffrey J. Eckardt, MD, Frederick R. Eilber, MD, and research assistant Mary Ann Burns, CRT, from University of California, Los Angeles. We also thank the many others, including our patients and technologists, who contributed to this study.

References

1. Boring CC, Squires TS, Tong T, Montgomery S. Cancer statistics, 1994. CA Cancer J Clin 1994; 44:7–26.
2. Shiu MH, Brennan MF. Surgical management of soft tissue sarcoma. Philadelphia, Pa: Lea & Febiger, 1989.
3. Brennan MF. Management of extremity soft-tissue sarcoma. Am J Surg 1989; 158: 71–78.
4. Enneking WF, Spanier SS, Goodman MA. The surgical staging of musculoskeletal sarcoma. J Bone Joint Surg [Am] 1980; 62: 1027–1030.
5. Enneking WF, Spanier SS, Malawer MM. The effect of the anatomic setting on the results of surgical procedures for soft parts sarcoma of the thigh. Cancer 1981; 47:1005–1022.
6. Enneking WF. Musculoskeletal tumor society: staging of musculoskeletal neoplasms. Skeletal Radiol 1985; 13:183–194.
7. Pettersson H, Springfield DS, Enneking WF. Radiologic management of musculoskeletal tumors. Heidelberg, Germany: Springer-Verlag, 1987.
8. McDonald DJ. Limb-salvage surgery for treatment of sarcomas of the extremities. AJR 1994; 163:509–513.
9. Smith DK, Parsons TW. Re: limb-salvage surgery for treatment of sarcomas of the extremities. AJR 1994; 163:514–516.
10. Gatsonis C, McNeil BJ. Collaborative evaluations of diagnostic tests: experience of the radiology diagnostic oncology group. Radiology 1990; 175:571–575.
11. Lehmann E. Nonparametrics: statistical methods based on ranks. Oakland, Calif: Holden Day, 1975; 123–132, 268–270.
12. Gillespy T III, Manfrini M, Ruggieri P, Spanier SS, Pettersson H, Springfield DS. Staging of intraosseous extent of osteosarcoma: correlation of preoperative CT and MR imaging with pathologic macroslides. Radiology 1988; 167:765–767.
13. Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristic curve. Radiology 1982; 143: 29–36.
14. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics 1988; 44:837–845.
15. Fleiss JL. The design and analysis of clinical experiments. New York, NY: Wiley, 1986; 103.
16. Weekes RG, Berquist TH, McLeod RA, Zimmer WD. Magnetic resonance imaging of soft-tissue tumors: comparison with computed tomography. Magn Reson Imaging 1985; 3:345–352.
17. Petasnick JP, Turner DA, Charters JR, Gitelis S, Zacharias CE. Soft-tissue masses of the locomotor system: comparison of MR imaging with CT. Radiology 1986; 160:125–133.
18. Aisen AM, Martel W, Braunstein EM, McMillin KI, Phillips WA, Kling TF. MRI and CT evaluation of primary bone and soft-tissue tumors. AJR 1986; 146:749–756.
19. Pettersson H, Gillespy T III, Hamlin DJ, et al. Primary musculoskeletal tumors: examination with MR imaging compared with conventional modalities. Radiology 1987; 164:237–241.
20. Chang AE, Matory YL, Dwyer AJ, et al. Magnetic resonance imaging versus computed tomography in the evaluation of soft tissue tumors of the extremities. Ann Surg 1987; 205:340–348.
21. Bland KI, McCoy DM, Kinard RE, Copeland EM III. Application of magnetic resonance imaging and computerized tomography as an adjunct to the surgical management of soft tissue sarcomas. Ann Surg 1987; 205:473–481.
22. Demas BE, Heelan RT, Lane J, Marcove R, Hajdu S, Brennan MF. Soft-tissue sarcomas of the extremities: comparison of MR and CT in determining the extent of disease. AJR 1988; 150:615–620.
23. Bloem JL, Taminiau AHM, Eulderink F, Hermans J, Pauwels EKJ. Radiologic staging of primary bone sarcoma: MR imaging, scintigraphy, angiography, and CT correlated with pathologic examination. Radiology 1988; 169:805–810.
24. Manaster BJ, Ensign MF. Imaging of musculoskeletal tumors. Semin Oncol 1991; 18:140–149.
25. Enneking WF, Kagan A. Skip metastases in osteosarcoma. Cancer 1975; 36:2192–2205.
26. Huvos AG. Osteogenic sarcoma. In: Huvos AG. Bone tumors. 2nd ed. Philadelphia, Pa: Saunders, 1991; 119.
27. Mirowitz SA. Fast scanning and fat-suppression MR imaging of musculoskeletal disorders. AJR 1993; 161:1147–1157.
28. Erlemann R, Reiser MF, Peters PE, et al. Musculoskeletal neoplasms: static and dynamic Gd-DTPA-enhanced MR imaging. Radiology 1989; 171:767–773.
29. Hanna SL, Fletcher BD, Parham DM, Bugg MF. Muscle edema in musculoskeletal tumors: MR imaging characteristics and clinical significance. JMRI 1991; 1:441–449.
30. Lang P, Honda G, Roberts T, et al. Musculoskeletal neoplasm: perineoplastic edema versus tumor on dynamic postcontrast MR images with spatial mapping of instantaneous enhancement rates. Radiology 1995; 197:831–839.
31. Seeger LL, Widoff BE, Bassett LW, Rosen G, Eckardt JJ. Preoperative evaluation of osteosarcoma: value of gadopentetate dimeglumine-enhanced MR imaging. AJR 1991; 157:347–351.
32. Shuman WP, Patten RM, Baron RL, Liddell RM, Conrad EU, Richardson ML. Comparison of STIR and spin-echo MR imaging at 1.5 T in 45 suspected extremity tumors: lesion conspicuity and extent. Radiology 1991; 179:247–252.