The Role of Imaging in the Evaluation of Suspected Bone Lesions

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Introduction

Cancer is widely recognized as one of the most devastating diagnoses in medicine. Worldwide, there was an estimated incidence of 24.5 million cancer cases, a number that is increasing year by year. (31560378) Society has invested heavily in better understanding and treating cancer, significantly increasing the lifespan of patients with malignancy.[1]

The natural course of many cancers, even with treatment, is to metastasize, and bone is the third most common site.[1] The most common carcinomas to metastasize to bone include lung, breast, prostate, renal, and thyroid; multiple myeloma also commonly affects the skeletal system. In general, metastases indicate advanced disease and are an independent risk factor for early death in cancer patients.[2] The likelihood of developing metastatic disease depends on the histologic grade of the tumor, response to treatment, and patient demographic factors. Osseous metastases can destroy the local architecture of bone, which can eventually lead to loss of cortical integrity. These lesions often result in significant morbidity for the patient and can require operative fixation. A pathologic fracture, a fracture through an osseous metastatic lesion, is associated with high morbidity and potentially loss of the patient's functional independence. Thus, metastatic lesions necessitate early diagnosis and treatment to prevent ambulatory dysfunction and further functional decline.

Primary bone tumors can be either benign or malignant. Benign bone tumors, such as osteoblastomas and non-ossifying fibromas, are a heterogenous group of tumors that can often be mistaken for malignant tumors to the untrained eye. While their true incidence is unknown, it is estimated that they are present in 30-40% of children.[3] Sarcomas, or primary malignancies of the musculoskeletal system, are much less common, with an estimated incidence of 3,910 cases per year in the United States.[4] Even with modern chemotherapy, sarcomas carry a poor prognosis, with 5-year survival ranging from 38.5% to 91.7% with an average 5-year survival of 58.9%.[5] Early diagnosis and complete resection are necessary to mitigate morbidity and mortality.

Role of Imaging in Workup of Osseous Lesions

As in other areas of orthopaedic surgery, imaging is paramount to successful diagnosis, treatment planning, and prognostication. Most primary and metastatic bone tumors can be initially detected on plain radiographs (X-rays). X-rays are diagnostic in many conditions, especially certain benign lesions and metastases in patients with other known osseous disease. Advanced imaging, such as computed tomography (CT) can be used to provide more detail about the bone involvement, particularly in metastatic disease of the pelvis. Magnetic resonance imaging (MRI) is necessary for diagnosis and surgical planning in primary bone tumors.

Plain Radiography

After a history and physical examination, X-ray is the next step in evaluating a bone lesion. In certain bone lesions, the radiographic appearance is pathognomonic, i.e., unique enough to confidently make a diagnosis without additional diagnostic tests. Such entities include unicameral bone cyst, non-ossifying fibroma, and fibrous dysplasia. Furthermore, the interpreting physician can use lesion characteristics, such as the pattern of bone loss, surrounding sclerosis, periosteal reaction, and matrix formation, to determine whether a lesion appears benign or malignant. For example, lytic lesions with a well-defined border and a sclerotic rim are slow-growing and often benign, whereas lytic lesions with a moth-eaten appearance and ill-defined borders are more likely to be malignant. Similarly, periosteal reaction can indicate an aggressive process; malignant lesions often demonstrate a laminated reaction with visible Sharpey's fibers, often also known as a "sunburst" pattern. Bone lesions with an associated soft tissue mass can raise the periosteum and lead to formation of a Codman's triangle. The matrix, or substance within an osseous lesion, can be used for diagnostic purposes. Patterns of stippling or "rings-and-arcs" formations, as seen in chondroid matrix, are common in enchondromas and chondrosarcomas; a dense but fluffy (or "cloud-like" appearance), indicating osteoid matrix, is seen in bone-forming lesions such as osteosarcomas (see Tables 1 and 2), and a "ground glass" appearance, with absent trabeculae, characterizes fibrous dysplasia.

Computed Tomography

If plain radiographs do not provide sufficient detail of the osseous anatomy, CT scans may be helpful to better evaluate the lesion. CT is the preferred imaging modality for assessing bone defects and cortical integrity, particularly in the scapula, spine, pelvis, ribs, and chest wall. It can help determine the need for intervention (radiation, percutaneous cement injection, or open surgical stabilization) for pelvic metastases by characterizing the available bone stock. It can also be diagnostic for certain lesions, in particular osteoid osteoma, where it can visualize the pathognomonic central, lytic nidus representing a vascular structure surrounded by sclerosis and cortical thickening.

CT is also useful in cancer staging. In a patient presenting with osseous metastases and unknown primary, CT of the chest, abdomen, and pelvis can identify the origin. For a new diagnosis of sarcoma, CT of the chest is indicated to rule out metastases, which most commonly occur in the lungs. Following initial treatment, surveillance CT is often used to monitor for disease progression.

Table 1. Imaging characteristics of benign and malignant lesions of bone by age

Age	Well-defined Lytic Lesion	Ill-defined Lytic Lesion	Sclerotic Lesion
0-10	Eosinophilic granuloma Unicameral bone cyst	Eosinophilic granuloma Ewing's Sarcoma Leukemia Lymphoma	Osteosarcoma
10-20	Non-ossifying fibroma Fibrous Dysplasia Osteofibrous Dysplasia Eosinophilic granuloma Unicameral bone cyst Aneurysmal bone cyst Chrondroblastoma Chondromyxoid fibroma	Ewing's Sarcoma Eosinophilic granuloma Osteosarcoma	Osteosarcoma Fibrous Dysplasia Eosinophilic granuloma Osteoid osteoma Osteoblastoma
20-40	Giant cell tumor Enchondroma Chondrosarcoma Brown Tumor Osteoblastoma	Giant cell tumor Malignany fibrous histiocytoma	Enchondroma Osteoma Bone island Parosteal osteosarcoma Healed prior lytic lesions
40+	Metastases Multiple myeloma Geode	Metastases Multiple myeloma Chondrosarcoma	Metastases Bone island

Table 2. Common Benign versus Malignant Tumors by Site

Site	Benign	Malignant
Diaphysis	Fibrous Dysplasia Enchondroma Osteofibrous dysplasia	Adamantinoma Ewing's Sarcoma Periosteal osteosarcoma Lymphoma
Metaphysis	Non-ossifying fibroma Aneurysmal bone cyst Unicameral bone cyst Enchondroma Osteoid Osteoma Osteoblastoma	Osteosarcoma Malignant fibrous histiocytoma Lymphoma
Epiphysis	Chondroblastoma Giant cell tumor Osteomyelitis	Chondrosarcoma
Multiple	Eosinophilic granuloma Fibrous dysplasia Hemangioendothelioma Enchondroma Osteochondroma Osteochondroma Non-ossifying fibroma Multiple hereditary exostoses Ollier's Syndrome Maffucci's Syndrome Jaffe-Companacci Syndrome Paget's Disease Hyperparathyroidism Bone infarcts	Leukemia Lymphoma Metastatic disease Multiple Myeloma

Magnetic Resonance Imaging

MRI is the diagnostic method of choice when locally staging musculoskeletal tumors due to its high resolution and ability to differentiate between tissue types based on proton density signatures. The high spatial resolution of MRI allows it to best identify soft tissue involvement and the tumor's anatomic relationship to important structures such as nerves and arteries. Different MRI sequences are available to better identify different tumor components. T1 weighted sequences provide the best view of anatomy, with water represented as low intensity, muscle as intermediate intensity, and fat as high intensity. T2 weighted sequences allow for better identification of pathology, including edema surrounding a tumor, with fluid detected as high signal intensity. Since fat is also represented with a high signal intensity on T2 sequences, tumors with a high fatty component (e.g. liposarcomas) or adjacent to areas of high fat density can be visualized using fat suppressed (FS) T2 weighted sequences. It is important to recognize that large areas of edema can be seen in both benign and metastatic lesions. While MRI is particularly useful in the diagnosis of primary bone lesions and operative planning, it is rarely indicated for metastatic lesions; in these situations, X-ray or CT is often all that is required for operative planning.

Figure 1. Lytic lesion located in the femoral diaphysis. Not shown is the lateral film indicating the lesion was within the anterior femoral cortex.

Cases Demonstrating Judicious Imaging Use

Case 1

A 74-year-old female presented to the orthopaedic oncology clinic as a referral from radiation oncology for evaluating of right thigh pain. Past medical history significant for stage IV non-small cell lung carcinoma status post multiple rounds of radiotherapy and chemotherapy. X-ray demonstrated a well-circumscribed lytic lesion within the anterior cortex of the femoral diaphysis, worrisome for an impending pathologic fracture (Figure 1). No further imaging was needed to determine the diagnosis or treatment plan, and the patient successfully underwent intramedullary nail fixation.

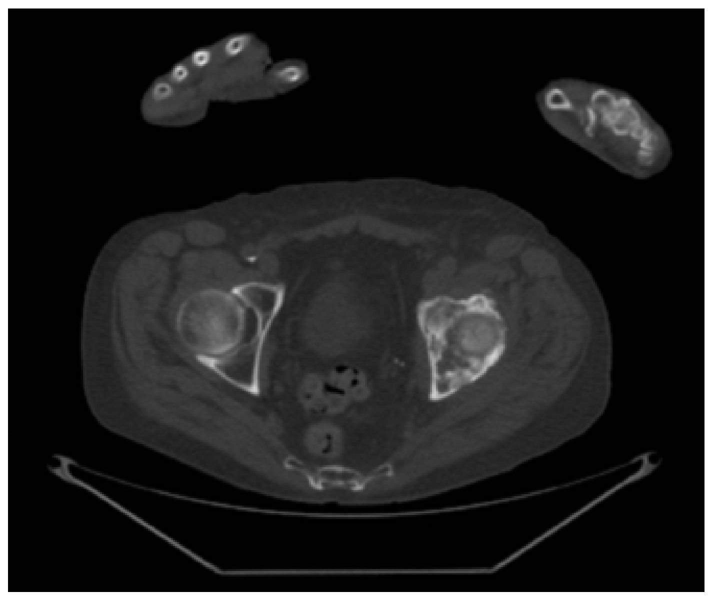

Figure 2. Destructive lesion of the left ilium extending down to the superior aspect of the left acetabulum. CT imaging indicated given the complex anatomy of the pelvis and possible percutaneous palliative treatment options.

Case 2

An 84-year-old male presented to the orthopaedic oncology clinic with hip pain of 3 months duration that started while playing golf. His medical history includes multiple myeloma with osseous involvement, currently on pembrolizumab. X-ray demonstrated a known iliac lytic lesion with new extension into the superior acetabulum. Given the patient's lesion location in the pelvis, a CT scan was obtained to visualize the bone in more detail (Figure 2). This CT demonstrated an intact acetabulum with enough residual bone to attempt percutaneous stabilization with cement injection rather than open pelvic reconstruction.

Case 3

A 59-year-old male was referred for new diagnosis of a biopsy-proven dedifferentiated bone sarcoma of his right pelvis. MRI was ordered to determine the precise extent and location of the tumor, as well as proximity to critical surrounding structures. Based on the results, the surgical team determined that an internal hemipelvectomy would be necessary to achieve wide resection. (Figure 3).

Conclusion

Primary and metastatic bone lesions represent a significant morbidity and mortality, necessitating expedient and accurate diagnosis while avoiding subjecting the patient to unnecessary

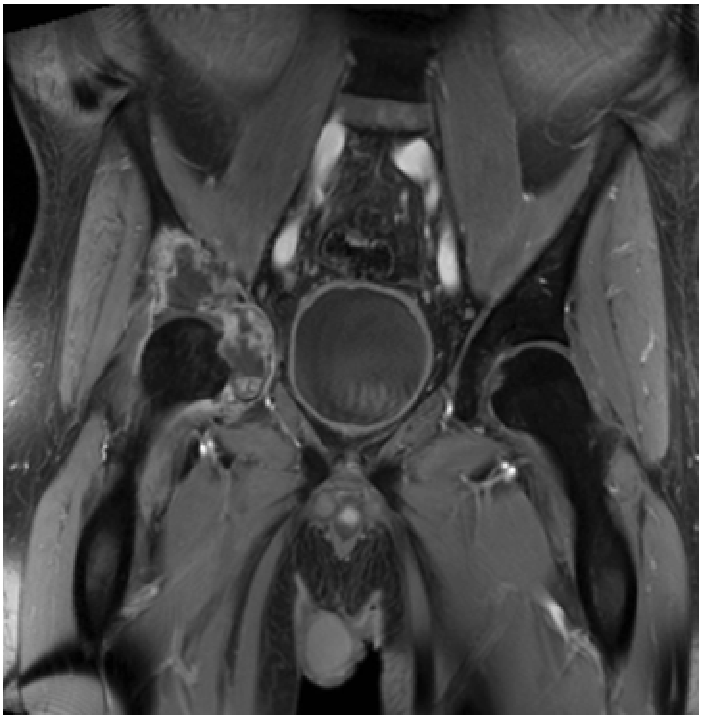

Figure 3. Post contrast fat suppressed T1 MRI with locally aggressive sarcoma within the right pelvis. Note that fluid is dark on a T1 sequence, but contrast shortens tissue relaxation times and thus increases signal, as seen in the edema and vascularity surrounding the right pelvic lesion.

tests. XR is routinely used in initial workup, and CT may be useful to provide further detail of osseous destruction. MRI is typically reserved when necessary for diagnosis and treatment planning of primary bone lesions.

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