Clinical Oncology

Bone and Soft Tissue Tumor Imaging: An Overview
Marcus Pianta, MBBS MMed FRANZCR; Mark Lourensz; Nicholas Trost, MBBS FRANZCR
MRI Department, St Vincent’s Hospital, Fitzroy, Victoria, Australia

Why?
Imaging of bone and soft tissue tumors has progressed in line with technological developments in medical imaging equipment. Particularly with modern computed tomography (CT) and magnetic resonance imaging (MRI) scanners, multiplanar imaging is significantly quicker, more practical and of higher resolution than 10 years ago. As a benefit, it is now possible to very accurately define a suspected bone or soft tissue tumor in terms of its involvement of the surrounding small neurovascular structures, breaching of fascial planes, deposits at distal sites and likely underlying histology (Fig. 1). Simultaneously, oncologic orthopedic surgical techniques have developed and progressed from limb amputation to many tumors now being resected in line with ‘limb sparing surgery’ [1]. This involves generally wide surgical margins around the entire tumor and adjuvant chemotherapy and/or radiotherapy in order to preserve the patient’s limb and as much function as possible.

At our institution, all patients suspected of having a primary bone or soft tissue sarcoma are comprehensively imaged, discussed in a multi-disciplinary team meeting and most undergo pre-treatment percutaneous biopsy. Imaging is crucial to determine a preliminary diagnosis and prognosis, develop a treatment plan and prepare the approach for biopsy, surgery and chemo/radiotherapy. It is also essential in post-treatment progress monitoring and in assessing for tumor recurrence and complications such as pathological fractures or infection.

How?
Whilst plain radiographs, ultrasound and CT are usually the initial investigations for ‘lumps and bumps’, soft tissue extent is most comprehensively assessed with MRI, which is best performed at the institution where the oncological treating team is based and where the surgery will be performed. Positron emission tomography (PET) and Thallium scans are also useful to assess for metabolic activity in a lesion, especially for targeting a percutaneous biopsy to yield an optimum diagnostic result and when determining treatment response. Whilst MRI yields excellent soft tissue contrast, the correct scan parameters and sequences are required to maximize the imaging outcome. At our institution the lesion is imaged in 3 orthogonal planes at high resolution with a combination of T1, T2-weighted, short TI/tau inversion recovery (STIR) and contrast-enhanced sequences [2]. Our routine protocol targeted to the lesion comprises T1 without fat saturation in all 3 planes, T2 fat-saturated in the axial plane, STIR in a longitudinal plane and post-gadolinium fat-saturated T1 in the axial and longitudinal planes. The longitudinal plane (usually sagittal or coronal) for the STIR and post-gadolinium sequences is chosen to be perpendicular to the lie of the lesion so that it is imaged within the central slices of the acquisition e.g. a quadriceps mass will be longitudinally imaged in the sagittal plane (Fig. 2), and an adductor compartment mass in the coronal plane (Fig. 3).

T1-weighted imaging best demonstrates the anatomy involved. Most solid com-
Clinical Oncology

T1 fat-saturated post-contrast images show a Ewing’s sarcoma replacing the proximal femoral medulla. There is bone destruction and a large, enhancing soft tissue component.

T2-weighted sequences show a giant cell tumor of the tibia, windowed to demonstrate the fluid-fluid levels. There is also low signal peripherally and throughout consistent with a combination of fibrous tissue and hemosiderin.

DWI and ADC map show restricted diffusion of a right groin lesion. When demonstrated, a high grade soft tissue sarcoma or lymphoma should be suspected.

Comprehensive imaging of a patient with a tumor includes whole-body thallium scan and PET to evaluate metabolic activity and multiplicity (Fig. 7) and CT of the thorax to assess for the presence of pulmonary metastasis (Fig. 8). Finally, biopsy is performed in accordance with the clinical context.

Component of tumors are of intermediate T1 signal similar to muscle. Pathological foci of fat, melanin, protein, methemoglobin, some calcifications and contrast can be seen with high T1 signal. T2-weighted images are generally useful for determining fluid components, where bright signal corresponds with increased free water protons as seen in edema and fluid collections such as cysts and necrosis. Fluid layering, or ‘fluid-fluid levels’ may be seen in aneurysmal bone cysts, giant cell tumors of bone (Fig. 4), telangiectatic osteosarcoma, cystic degeneration, infection and hematomas. Whilst most solid tumors are of intermediate T2 signal, some specific pathological types may demonstrate high T2 signal such as cartilaginous and myxoid tumors, chordomas and nerve sheath tumors. Tumors with lower T2 signal compared to muscle may include those of high fibrous content and giant cell tumor of the tendon sheath.

STIR sequences help highlight pathology by suppressing fat and allowing bright fluid signal in tumors and edema to be more conspicuous.

T1 post gadolinium contrast administration with fat saturation is also employed to better outline abnormal enhancement of a lesion or tumor by suppressing the surrounding T1-bright fat (Fig. 5). The pattern of enhancement can indicate vascular permeability or necrosis, and help differentiate tumor (rapid enhancement) compared to reactive edema or post-radiotherapy changes (more gradual enhancement) [3].

Fat saturation imaging is often suboptimal in the presence of a ferromagnetic prosthesis that causes local field inhomogeneities and susceptibility artifact [4]. In such cases, T1 pre and post contrast imaging is employed without fat saturation. Occasionally, a gradient echo sequence will be added to highlight differences in magnetic susceptibility for cases particularly suspected of containing calcification or blood products, such as pigmented villonodular synovitis, synovial chondromatosis or hemorrhagic metastasis. Whilst we do not routinely use diffusion-weighted imaging (DWI), solid components of higher-grade and poorly responsive sarcomas can demonstrate a low apparent diffusion coefficient (ADC) and low/restricted diffusion (high diffusion-weighted signal) (Fig. 6). The clinical context needs to be carefully noted [5] however, as an abscess can result in a similar appearance.

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Bone lesions that cause aggressive periostal reaction or destroy cortex, medulla and comprise a surrounding soft tissue mass should be considered malignant. Such a process can be seen with primary tumors such as Ewing’s sarcoma (Fig. 5), or with osteochondromas that have undergone malignant change to chondrosarcomas. In this case, the often well organized foci of high T2 signal that reflect cartilage remnants will be more disorganized throughout a large soft tissue mass. In comparison, synovial cell sarcoma, which usually occurs around a joint can comprise multiple foci of low T2 signal in keeping with calcifications.

In the appropriate clinical setting, a different diagnosis for such an aggressive appearing lesion should include acute osteomyelitis.

Multiple lesions raise the possibility of a malignant tumor, including if seen within the lungs, which may be visible at the edge of the MRI Field whilst imaging the shoulder or pelvis. Skip lesions within the same bone or limb should also be sought. Growth along neurovascular planes or into joints is also highly suggestive of a malignant lesion and indicates a poorer prognosis, including increased complexity of surgery. A location for biopsy is best evaluated in reference to the T1 and post contrast imaging where vividly enhancing regions of tumor, suggesting viability, may yield more success with a pathology diagnosis [8]. Non-enhancing regions of tumor can reflect internal lesion necrosis or cystic-appearing tumor components such as myxoid, which will demonstrate very high T2-weighted signal (Fig. 12). These findings can be correlated on PET or Thallium imaging, where increased tracer uptake is suggestive of viable tumor, and lack of uptake often correlates with lack of contrast enhancement on MRI. Post-radiotherapy changes may result in increased tumor size due to necrosis and hemorrhage, although a good response will also correlate with reduced or absent lesion enhancement (Fig. 13). Caution with non-enhancing cystic-appearing lesions is required if there is any increased T1 internal signal and irregular, thickened enhancing capsule that may indicate the planned surgical approach so that minimal tissue planes are contaminated and the biopsy tract can be excised.

In addition to the targeted imaging of the primary lesion, further STIR and post gadolinium fat-saturated T1 sagittal and coronal sequences with a wide field of view are acquired through the entire limb (Fig. 9) to evaluate for skip lesions. This saves time required in the scanner, for example axial scans through the entire limb are not required, whilst maintaining acceptable sensitivity for evaluating for skip pathology. In cases where the lower limb is involved, thick axial and coronal images are also acquired through the pelvis and lower lumbar spine to exclude skip lesions, metastases and lymphadenopathy – all of which affect prognosis and management planning (Fig. 10).

**Reporting**

It is important to foster a close relationship with the entire treating team of a patient with a soft tissue tumor - whether benign or malignant. In this way, a feedback loop can be developed so that difficult cases are flagged early, and there is open and frequent communication amongst physicians, including the surgeons, radiologists and pathologists. When reporting, there are several key points that should be made clear to the referring physician in order to help strategically patients, particularly those at risk of aggressive or poorly responsive tumors. Deep compartment and larger sized soft tissue tumors should be considered aggressive [4] until proven otherwise (usually with biopsy). Poor definition and invasion of multiple compartments suggests malignancy, whereas confinement to a single muscular compartment with a well-defined capsule suggests a less aggressive, or even benign lesion. Peri-lesional increased T2 signal can indicate tumor spread or edema for which contrast enhancement can help differentiate, as well as determine cystic, solid and mixed components of lesions [7] (Fig. 11).
abscess formation – either super-infection of an underlying lesion, or as a result of intervention e.g. biopsy or surgery. Concluding the report should be concise and offer a brief differential if required. When appropriate, percutaneous biopsy can be recommended and specialist referral suggested. Concerning findings should be communicated at the time of reporting such as unexpected and new metastasis, post-operative complications (wound dehiscence, compressive hematomata) or pathological fractures.

Final thoughts
Tumor imaging can be daunting, given the relatively high stakes involved with a missed diagnosis or mis-diagnosis resulting in unnecessary further investigations, biopsies or even surgeries which can include excision of the biopsy tract to avoid recurrence in the tract due to tumor seeding. When imaging post-operatively, the surgical approach should be known and so efficiency is required to maintain diagnostic image quality. Whilst there are some indicative features of tumors that correlate with certain components or likelihood of aggressiveness, ultimately biopsy is required to confirm tissue diagnosis prior to surgical planning, particularly in cases of potential tumor recurrence.

Conclusion
Imaging of bone and soft tissue tumors can be very rewarding with a team approach, including use and continued development of reproducible imaging protocols and knowledge of what the referring physicians need to know. Open and frequent communication amongst the treating team is essential, with discussion regarding biopsy approaches and inter-physician feedback paramount to improving patient outcomes.

MRI sequencing of large primary tumors and metastasis can be time-consuming and so efficiency is required to maintain diagnostic image quality. Whilst there are some indicative features of tumors that correlate with certain components or likelihood of aggressiveness, ultimately biopsy is required to confirm tissue diagnosis prior to surgical planning, particularly in cases of potential tumor recurrence.

Pre and post radiotherapy: The initial T1 post contrast-enhanced scan (13A) demonstrates a large soft tissue, enhancing mass in the antral compartment of the right thigh which is smaller and shows markedly reduced enhancement following radiotherapy (13B), in keeping with tumor necrosis and a good response.

References

Contact
Marcus Pianta, MBBS MMed FRANZCR
MRI Department
St Vincent’s Hospital
41 Victoria Pde
Fitzroy, Vic
Australia 3065
marcus.pianta@svhm.org.au