REVIEW ARTICLE

RADIOLOGY IN THE DIAGNOSIS AND MANAGEMENT OF BONE TUMOURS

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The range of radiological investigations available for the diagnosis and the assessment of tumours of the skeleton has increased rapidly over the last decade. This increasingly sophisticated technology is available at a time when perceptions of the mortality and morbidity of these tumours have been altering rapidly. Most clinicians see few primary bone tumours in their working lives, and some are not yet familiar with modern imaging modalities. This article explores the value and limitations of these modalities in the investigation and management of bone tumours.

PLAIN RADIOGRAPHY
Conventional x-ray films are usually the initial method of detection and localisation of a tumour. There have been no new developments in the technology of plain films other than continued improvement in resolution balanced by the wish to minimise radiation dosage. Although some subdivisions of the descriptions of various tumours have been made, there has been no major advance in the understanding of changes seen on plain film.

The digital manipulation of images may help with tissue characterisation or edge enhancement, though experience with xerography suggests that edge enhancement, whilst useful in detecting some features of the soft tissues, tends to degrade the overall quality of the diagnostic image. These digital techniques are still under development and are not widely available.

For the assessment of a lesion on plain film an adequate range of exposures is essential so that, on the one hand, soft-tissue extensions can be detected and, on the other, intra-osseous lesions are adequately penetrated to reveal, for example, lesional calcification. Although, by convention, a pair of films at right angles is sufficient, additional "round the clock" projections, possibly using a skull unit, may reveal for the first time periosteal new bone formation or a soft-tissue mass.

Plain films can provide basic information from which a differential diagnosis may be produced and the answer found to several basic questions.

Is the lesion solitary or multiple? Multiple lesions are more likely to represent metastasis or a systemic disorder such as histiocytosis. On the other hand, a solitary metastasis most often arises from tumours of thyroid, kidney or bronchus.

What type of bone is involved? Most metastases present in the axial skeleton. Osteoid osteoma rarely arises in bone of membrane origin.

Where is the lesion in bone? Fibrous cortical defect and non-ossifying fibroma are cortical in location whereas chondroblastoma is apophysial or epiphysial. Giant-cell tumour is typically subarticular in the mature skeleton.

Are the margins of the lesion well or ill defined? A slow-growing tumour usually has a short zone of transition with normal bone; aggressive lesions are more permeative.

Is there a bony reaction? The more indolent the lesion, the greater the chance that some sclerosis will occur.

Does the lesion contain calcification? The "ground glass" quality of fibrous dysplasia, and the "popcorn" calcification of chondroid tissue are useful signs.

The differential diagnosis in most cases can be narrowed in this way to two or three possibilities, and in many instances plain films can provide enough information for biopsy and management. Few peripheral osteoid osteomas, uncomplicated osteochondromas or fibrous cortical lesions will require further imaging. Plain films can, however, provide only limited data on intra-osseous or extra-osseous tumour extension and relatively inefficient detection of distant metastases, particularly those in the lungs. Further investigations are then mandatory, since blind biopsy should no longer have a major role in the management of the patient.

ISOTOPE SCINTIGRAPHY

Scintigraphic examination of the skeleton has become widely available as part of the increasing use of radio-pharmaceuticals. Most radiographic departments have at least a gamma camera. A computer to help handle the acquired data is useful but not essential.
Bone scanning is one of the more simple, relatively cheap investigations and involves only a small radiation hazard. It requires little notice since the active nuclide can be eluted in the department and converted to the pharmaceutical by the use of a commercially available kit. Diphosphonates labelled with technetium-99m are most often used in dosages of 500 to 600 mBq.

Most clinicians accept that scintigraphy is efficient in the detection of bony metastasis (Figs 1 and 2), more secondary deposits being detected at an earlier stage than by radiography. The few exceptions to this include myeloma, histiocytosis and the metastases from some pelvic and urogenital primary tumours. Occasionally the skeleton may be uniformly avid for the radiopharmaceutical, so that an apparently normal "super scan" is obtained (Figs 3 and 4). This may be caused by diffuse metastasis (particularly from a prostatic tumour), Paget's disease, hyperparathyroidism and myelosclerosis. This pitfall can be avoided, provided that the scan is interpreted in the light of the known features of a plain film examination. Indeed, it is always essential to interpret the more sophisticated investigations with reference to the clinical features and the appearance of the plain films (Figs 5 and 6).
An early and a late bone scan image from a patient with osteomyelitis of the thumb demonstrates a marked abnormality in the blood pool phase (Fig. 7) with non-specific, diffuse changes on the later image. The plain radiograph shows an ill-defined soft-tissue swelling with some bone destruction consistent with osteomyelitis, which in this case was due to a human bite.

The blood pool phase of a bone scan demonstrates markedly abnormal activity at the end of one great toe. Radiographs show a soft-tissue mass with a pressure defect of bone due to a soft-tissue haemangioma.

A bone scan demonstrating a focus of abnormally increased activity just distal to the greater trochanter which on a plain radiograph is shown to be due to a bone island. A blood pool scan (not illustrated) was normal.
The earlier reported descriptions of scintigraphic findings in primary bone tumours have often been limited to the delayed or bony phase of the examination. A bone scan has at least two phases, commonly described as the early or blood pool phase and the delayed or bony phase (Figs 7, 8 and 9). Blood pool phase activity derives mainly from extracellular fluid in the perivascular space; consequently any cause of increased local perfusion will be revealed as increased activity on the scan (Figs 10, 11 and 12). Increased adsorption of radiopharmaceutical onto hydroxyapatite, together with other ill-understood mechanisms, results in abnormal activity on the delayed scan. This concept of the dual phases of a bone scan is relevant in the differential between, for example, an osteoid osteoma and a bone island. Both show increased activity in the delayed phase, but osteoid osteoma is characterised by an intense focus of increased perfusion in the early phase (Figs 13, 14 and 15) whereas no such increase is observed in scans of a bone island (Figs 16 and 17). Similarly an inflammatory lesion characteristically has a markedly abnormal perfusion phase but the delayed phase may vary, particularly early in the evolution of the disease as shown in Figures 7, 8 and 9.

What then are the benefits of skeletal scintigraphy in the management of primary tumours?

Is there a tumour? Scintigraphy is a convenient and safe method of looking for an occult lesion of bone when plain films have been thought to be normal. The classical example is a small osteoid osteoma arising in cancellous bone (see Figs 13, 14 and 15). Other painful lesions of bone, such as stress fractures, may be demonstrated when plain films have not helped.

Is skeletal scintigraphy tumour specific? No combination of scintigraphic features is characteristic of any given tumour. Nonetheless, some statement about the tissue type may be made. The centre of a lipoma or simple cyst is most unlikely to be active on a bone scan since both are practically avascular and neither binds hydroxyapatite.

Does scintigraphy demonstrate the intra-osseous extent of a tumour? Much better delineation may be obtained by skeletal scintigraphy than by plain films (Figs 18 and 19). However, in some cases, for example in osteosarcoma, a falsely extended pattern of activity may suggest involvement beyond the actual histological limits (Chew and Hudson 1982). This extended pattern reflects the oedema and inflammation in bone adjacent to the tumour and is arguably therefore the true extent of the lesion if not of the tumour cells.

Does scintigraphy demonstrate an extra-osseous lesion? This depends on the relative vascularity of the lesion and whether it is avid for radiopharmaceutical as is the case, for example, in bone-forming tumours such as osteosarcoma. By contrast, in malignant round-cell tumours the mass itself is largely photopenic (that is, "cold") and skeletal scintigraphy is not then a reliable indicator of soft-tissue involvement.

Fig. 18
An amputation specimen of the distal femur containing an osteosarcoma. The level of bone section was well above the level of the top of the photograph. The pre-operative bone scan shows increased activity corresponding to the chondroblastic and osteoblastic sections of the tumour, with slightly reduced activity in the haemorrhagic, telangiectatic part. Activity appears also to be diffusely increased in the knee. This was seen at operation not to be involved by tumour and activity was presumably due to disuse osteoporosis. Extension of tumour into the epiphysis is confirmed.

Fig. 19

Does it demonstrate pulmonary metastasis? Sometimes the metastasis of a bone or cartilage-forming tumour may be detected by its activity on a bone scan (Figs 20 and 21). This is not, however, reliable for most sarcomas, and even osteosarcomas may give false-negative results if the metastasis is very deep within the lung, is not viable after successful chemotherapy or is not of a predominantly bone-forming type. Consequently pulmonary metastasis is not constantly diagnosed by skeletal scintigraphy. Similarly metastases in other soft tissues, particularly intracerebral ones, may be overlooked. Subsequent skeletal metastasis is, however, reliably detected.

Does the bone scan demonstrate local recurrence? This again depends on whether or not the tumour is associated with increased vascularity or the production of calcification or ossification. Certainly in patients with
This patient has had a prosthetic replacement of the upper humerus for osteosarcoma. Recurrent tumour in remaining lymph nodes is demonstrated by the abnormal increase in activity.

A patient with severe low back pain and normal radiographs is shown to have an intense focus of abnormal scintigraphic activity on the right side at the L4 level (this is a posterior scan). A subsequent CT scan demonstrates an osteoid osteoma in the inferior part of the right pars interarticularis of the L4 vertebra.

An osteosarcoma of the sacrum is demonstrated. Note the soft-tissue extension both ventrally into the pelvis and dorsally into subcutaneous tissues. The neural canal is obliterated by tumour.

On a lateral radiograph a soft-tissue mass is lying anterior to the sacrum. A CT scan demonstrates the typical features of a chordoma, a large symmetrical soft-tissue mass extending anteriorly.

A defect, unequivocally in the cortex, confirms the diagnosis of a fibrous cortical defect in the upper tibia. CT scans of both thighs showing an extensive fatty tumour on the right. This would be entirely consistent with a lipoma, but the excised specimen contained unequivocal liposarcoma.

Part of the body of L4 vertebra is replaced by well defined multiple radiolucent defects consistent with a diagnosis of haemangiomma.
osteosarcoma this is a most useful imaging facility (Fig. 22).

Occasionally other radiopharmaceuticals may prove useful in the assessment of a tumour. Gallium-67 citrate has been recommended, particularly for the detection of lymphomas and some sarcomas (Kirchner and Simon 1984). In most circumstances, for bony lesions, there is no evidence that this is better than, or a substitute for, scintigraphy with ⁹⁹mTc-diphosphonate. However, for lymph node disease or soft-tissue tumours gallium-67 can be helpful. On rare occasions a tumour-specific agent may be diagnostic, as is iodine-125 in thyroid metastasis.

**TOMOGRAPHY AND COMPUTERISED TOMOGRAPHY**

Computerised tomography has become available in most countries with privileged health care. When it is widely available it has virtually supplanted routine tomography. Its importance comes from several exciting features. The CT scan demonstrates axial anatomy while giving discrimination between tissue types and planes. Further computer manipulation permits visualisation of other planes. Consequently it is possible, within the limitations of the resolution of the apparatus, to demonstrate clearly the relationship of a tumour to adjacent structures. Moreover, contrast medium can be introduced; intravenous injection, for example, allows localisation of the great vessels in relation to a tumour and permits assessment of the vascularity of a lesion by enhancement of delayed images. In addition to these features, a CT scan reveals the same basic radiological signs as plain films.

It is reasonable to ask specific questions concerning computerised tomography. **Can it detect the presence of tumour?** Occasionally a tumour may be localised solely by CT, although its presence may have been suspected either clinically or by scintigraphy (Figs 23 and 24). It has been suggested that about 4% of primary tumours are detected by this means.

**Does it improve the assessment of tumours?** The value of CT lies in its ability to delineate tumours in inaccessible sites, for example in the pelvis and the sacrum (Figs 25, 26 and 27). The axial projection makes it possible to localise a lesion in or adjacent to bone more accurately (Fig. 28).

**Does it provide tissue-specific information?** CT can demonstrate fat (Fig. 29) and calcification more readily than plain films since it demonstrates tissue absorption of radiation in a grey-scale range. Hence it has an ability to discriminate between tissue types, but it does not demonstrate whether or not such fat or calcification is benign or malignant (Fig. 29). Very rarely does it produce an image that is diagnostically characteristic (Fig. 30).

**Does it demonstrate the intra-osseous extent?** A CT scan may demonstrate extension of tumour either by subtle changes in the absorption coefficient of bone marrow (Fig. 31) or by the presence of calcification or ossification within the medullary canal (Figs 32 and 33) which cannot be appreciated on the plain films. The combination of CT and bone scintigraphy provides the best estimate of the extent of intra-osseous spread when a less than radical operation is being planned.

**Does it demonstrate extra-osseous extent?** There is no doubt that a CT scan is the most accurate means of defining extra-osseous spread, since it best shows soft-tissue planes (Figs 34 and 35). The margins of a lesion on a CT scan may give information about its relative encapsulation though this should not be trusted completely.

**Does it detect metastases?** CT scans or whole-lung tomography can demonstrate more pulmonary metastases at an earlier stage than plain films of the chest (Fig. 36). The relative advantages of conventional whole-lung tomography and CT assessment of the lung are not yet clearly defined.
A malignant round-cell tumour (later confirmed as Ewing's sarcoma) is shown by radiography to involve a lower rib. The CT scan demonstrates the anatomy much better. It shows a very large soft-tissue mass, which is disproportionate to the bony involvement. This is typical of malignant round-cell tumour.

Pulmonary metastases from osteosarcoma. One lesion, shown by calcification (arrow), has resulted in an encysted effusion on the right. A second metastasis is also seen in the right lower lobe.

Radiograph showing a pathological rib fracture. It was later found to be due to histiocytosis. The CT scan shows diffuse interstitial opacification throughout the lung fields also due to histiocytosis.

Angiographs of the calf in two patients demonstrate very similar patterns. In one (Fig. 39) this is due to myositis ossificans and in the other (Figs 40 and 41) the lesion is an alveolar rhabdomyosarcoma. Both show an intense tumour blush and abnormal vessels. One is benign, the other malignant and there are no discriminatory features.

A large secondary chondrosarcoma arises from the left pubis. The arteriogram shows only displacement of major vessels with no abnormal vascularity, an appearance typical of low-grade chondrosarcoma.

Subtraction angiograms in a case of Brodie’s abscess show only a slight increase in normal branches on the arterial phase (left) and a ring of periosteal veins on the delayed image (arrows).
A CT scan occasionally provides serendipitous information. A good example is the demonstration of pulmonary infiltration in a patient with histiocytosis when a CT scan was made to assess a rib lesion (Figs 37 and 38). It has been suggested that as often as once in 14 instances some unique, extra, and relevant information may be gained from CT that had not been shown on previously plain films. In at least three-quarters of cases CT provides a better assessment of the form, the extent and the relationships of a tumour.

**VASCULAR STUDIES**

The use of arteriography has waxed and waned since the initial enthusiasm at its introduction some years ago. To some extent it has fallen into disrepute because it has failed to provide an absolute criterion, or combination of criteria, for malignancy or for useful tumour specificity (Figs 39, 40 and 41). No characteristic feature of malignancy has been found. Whilst the appearance of tumour vessels and encasement may be very suggestive of a malignant lesion, both features may be seen in benign conditions, particularly in fibromatosis and in myositis ossificans. Furthermore, many of the uses of arteriography have been supplanted by CT or scintigraphy.

Arteriography can still provide some specific information and is useful when other modalities are not available. It should not be used in isolation but always as part of a planned series of examinations designed to refine the diagnosis in a specific case.

**Is the lesion vascular or avascular?** Arteriography can help. For example, the vascular pattern of one cartilage-containing tumour, a low-grade chondrosarcoma, is largely hypovascular or avascular (Fig. 42). On the other hand, a chondroblastic osteosarcoma is highly vascular.

**Is the lesion infective or neoplastic?** Infection is typically shown by an increased number of normal arteries with obvious engorgement of periosteal veins on the delayed phase of the angiogram (Figs 43 and 44).

**Intra-osseous and extra-osseous extent** also may be demonstrated (Figs 45, 46 and 47). These findings correlate well with CT but are no better than that achieved by the combination of CT and skeletal scintigraphy. The blood pool phase of a bone scan is itself adequate to demonstrate the hypervascularity of a tumour (Figs 48 and 49).

Arteriography, and indeed venography, have a place when the relationship between a tumour and a large vessel is being assessed with a view to prosthetic replacement or en bloc resection. Arteriography demonstrates the relationships between vessels and tumour masses better than any other modality (Figs 50 and 51). A correlation may also exist in some tumours between the degree of malignancy and the extent of abnormality of the vascular pattern demonstrated by arteriography. This seems to be valid for parosteal osteosarcomas and for the range of histiocytic and fibrous tumours (Yaghmai 1977).
Finally an evolving, but not yet fully assessed, therapeutic role for angiography is seen in embolisation of tumours either before or instead of operation. Highly vascular lesions such as aneurysmal bone cysts respond beneficially to this treatment.

**FURTHER INVESTIGATIONS**

Rarely will further imaging investigations be needed. Lymphography may be required for the assessment of lymphomas, although CT, splenectomy and laparotomy for staging may provide equivalent information. New modalities of imaging are becoming available in some centres. These include emission computerised axial tomography (ECAT) and magnetic resonance imaging (MRI). Their roles have not yet been fully assessed and the considerable cost of MRI will certainly limit its availability for some time.

**DISCUSSION**

In many instances it may be reasonable to argue that further radiological examination is unnecessary once adequate plain films have been taken. An obvious osteoid osteoma or fibrous cortical defect does not require further imaging although localisation at the operation may be needed for the osteoma. A logical approach to the use of radiology for less clear-cut lesions will shorten and clarify the differential diagnosis.

An example is shown in Figures 52 to 55, where an expansile lytic lesion is seen in the distal femur of an adolescent. The differential diagnosis on the plain film would include aneurysmal bone cyst, fibrous dysplasia, cartilage tumour and atypical simple bone cyst. The clinical features did not help. Scintigraphy, having proved the lesion to be solitary, shows it to be avascular with increased activity around its margins (Figs 53 and

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**Fig. 53**

An atypical simple bone cyst of the distal femur. From left to right: the plain film appearances; the blood pool phase of a bone scan, demonstrating increased perfusion around the margins of the lesion but not within it; the delayed phase scan, again showing increased activity around the margins of the lesion but not within it; and a CT scan which confirms the expansile nature of the lesion, its well-defined margins and no internal calcification.

**Fig. 56**

Plain film of a primary chondroosarcoma arising in the roof of the acetabulum. A CT scan demonstrates that the tumour has extended from bone into soft tissues at the insertion of gluteus medius. Biopsy through this muscle (arrow) avoided contamination of the wound before a subsequent radical excision.
This virtually excludes aneurysmal bone cyst which is almost always hypervascular. The absence of increased activity within the lesion on the delayed phase bone scan is strongly against fibrous dysplasia, which is usually very active in relation to the formation of histologically visible fibre bone. A CT scan then demonstrated the tumour matrix to be of soft-tissue density with no evidence of calcification (Fig. 55). By exclusion, an unusual simple bone cyst is the most obvious diagnosis, and this was later proven histologically.

It may be asked why a precise diagnosis is needed before biopsy. Some hazards of biopsy have been reported, including frank misdiagnosis with a significant effect on the result of treatment (Mankin, Lange and Spanier 1982). In any given tumour it cannot be known whether the histological features will be straightforward. After a biopsy, the scintigraphic, CT and angiographic characteristics may be irreversibly altered. The obtaining of adequate data before biopsy helps cope with this eventuality.

Biopsy samples may be unrepresentative. For example, a biopsy including cartilage matrix from a chondroblastic osteosarcoma, may be misinterpreted as a chondrosarcoma. Wound contamination by tumour cells may be avoided by a more logical biopsy approach made possible by the full anatomical delineation of the lesion (Figs 56 and 57). Blind biopsy is not appropriate when consideration is being given to limb-sparing operations such as local resection or prosthetic replacement. Both of these procedures are dependent upon full and accurate radiological demonstration of the extent of the tumour.

Radiological imaging has an increasing role in the follow-up of patients after operations of this type since the patients are living longer and more aggressive treatment is being advised for such complications as pulmonary metastasis. In these patients the accurate delineation of the number and the position of metastases in the lungs is needed before local resection can be undertaken.

The increasing range of radiological investigations which are now available have already had a significant impact on the diagnosis and the management of primary bone tumours. Close co-operation between orthopaedic surgeon, radiologist and oncologist will help to make use of these methods to their optimal efficiency.

The author gratefully acknowledges the help of his colleagues in the Bristol Bone Tumour Registry and the use of their material, Mrs Anne Brown for her secretarial assistance and the Medical Photographic Department of the University of Bristol for the photographic prints.

REFERENCES


