An Atlas of Planar and SPECT Bone Scans

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This book is dedicated to Coral, Jan and our children

Preface

Bone scanning is an important diagnostic technique, which can profitably be applied to almost all aspects of skeletal pathology, and this atlas will prove to be an invaluable aid to those whose work centres around the investigation of the skeleton. The over 900 illustrations represent the work of two busy hospital departments, both with large patient populations but, nevertheless, with often quite different clinical practices.

The book has been carefully structured to facilitate problem solving. We have also distilled our own experience into compact and accessible 'Teaching points', which are found extensively throughout the text.

By combining his knowledge of nuclear medicine with the case material and analyses presented in this atlas, the practitioner should be able to make optimal interpretations of planar and SPECT bone scan images. As particular emphasis has been placed on clinical application, those working in specialties such as orthopaedics, oncology, rheumatology and endocrinology will find much of interest and direct practical relevance.

Acknowledgments

It would have been impossible to produce a nuclear medicine atlas of planar and SPECT bone scans without the assistance of our colleagues and support, if not sympathy, from our families.

While many individuals have played a role in the creation of this atlas the contributions of several are particularly notable.

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The bone scan is the most frequently performed nuclear medicine imaging procedure. In current clinical practice, it is often used as a high sensitivity screening test, which in most clinical situations outperforms conventional X-ray for the detection of skeletal pathology. At other times, the bone scan is valuable as a functional test of bone metabolism that complements the anatomical detail available from conventional X-ray, computed tomography (CT) or magnetic resonance imaging (MRI).

The continuous growth in bone scanning since the introduction of technetium-99m (^{99m}Tc) labelled tracers more than 10 years ago has progressed alongside improvements in imaging techniques. Each new generation of gamma cameras has provided the nuclear medicine practitioner with improved bone scan images. The recent introduction of single photon emission computed tomography (SPECT) enhances the bone scan by providing cross-sectional anatomical detail and image contrast that previously was unavailable. Equally important to the recent growth in bone scanning have been the newer clinical applications, not only in oncology but also in orthopaedics, sports medicine and rheumatology.

This atlas considers in detail adult bone scanning with ^{99m}Tc-labelled diphosphonates, and includes a limited selection of paediatric bone scans as well. The mechanisms of tracer uptake and techniques for both planar and SPECT bone scanning are first described. This chapter is followed by a carefully structured presentation of normal bone scans, normal variants, artefacts and pitfalls, frequently encountered scan 'patterns', an extensive collection of scans showing bone abnormalities due to a wide variety of malignant and benign skeletal pathology, and miscellaneous extraskeletal bone scan findings. Other nuclear medicine techniques, such as gallium-67 scanning, and other imaging modalities, for example conventional X-ray, CT and MRI are considered in passing only as they relate to the bone scan cases presented.

Mechanisms of tracer uptake

Bone scanning is almost exclusively performed using ^{99m}Tc-labelled diphosphonate (Figure 1.1) which shows exquisite sensitivity for skeletal abnormality. The technique has the limitation that scan appearances may be non-specific; however, in many clinical situations recognizable patterns of scan abnormality are seen which often suggest a specific diagnosis.

The mechanism of tracer uptake on to bone is not fully understood but it is believed that diphosphonate is adsorbed on to the surface of bone, with particular affinity for sites of new bone formation (Figures 1.2, 1.3). It is thought that diphosphonate uptake on bone primarily reflects osteoblastic activity but is also dependent on skeletal vascularity. Thus bone scan images provide a functional display of skeletal activity. As functional change in bone occurs earlier than gross structural change, the bone scan will often detect abnormalities before they are seen on an X-ray. Any diphosphonate which is not taken up by bone is excreted via the urinary tract, and in a normal study the kidneys are clearly visualized on the bone scan; indeed there are many examples of renal pathology which have been detected for the first time on the bone scan.

It is also recognized that, on occasion, there may be uptake of ^{99m}Tc diphosphonate at non-skeletal sites. There have been many situations reported where this can occur, but it is believed that in all cases the common factor is the presence of local microcalcification.

Chemical structure of diphosphonates

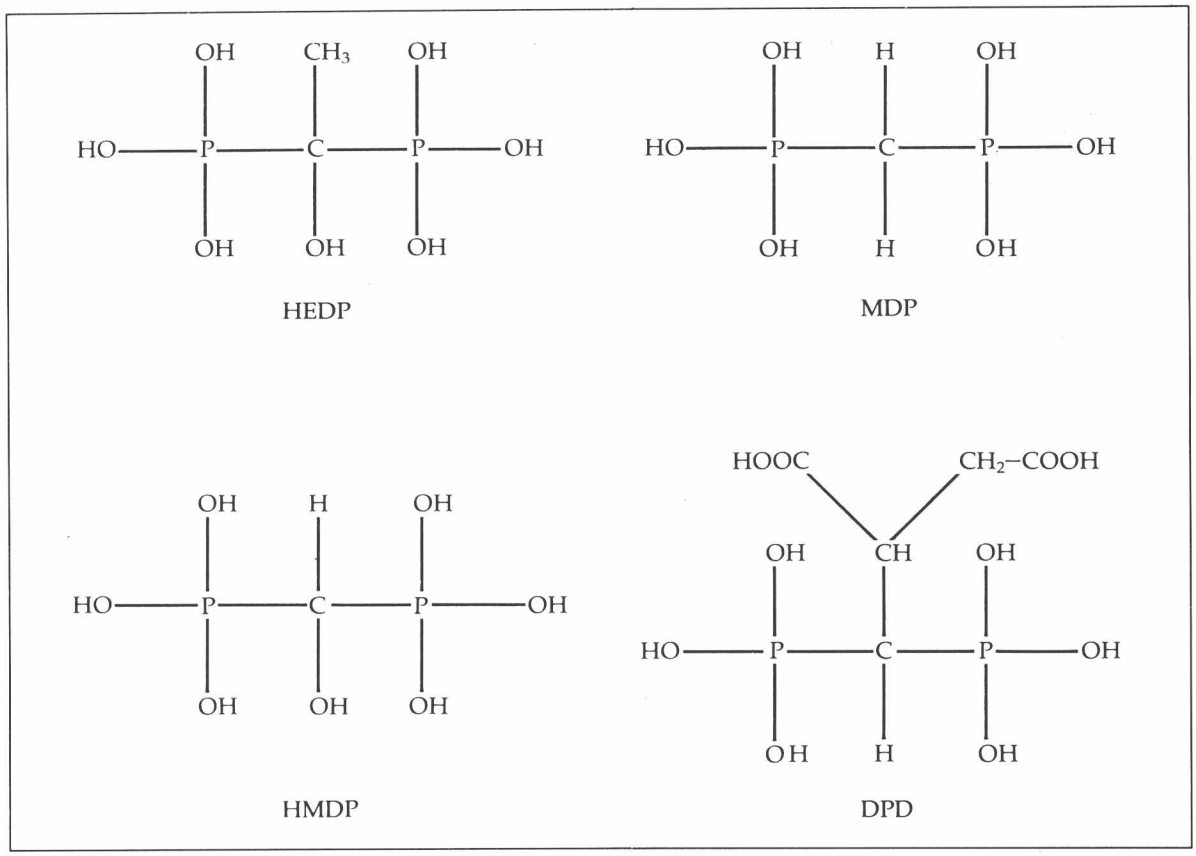


Figure 1.1

Chemical structure of diphosphonate compounds used for bone scanning. At the present time MDP is the most widely used agent. HEDP, hydroxyethylidene diphosphonate; MDP, methylene diphosphonate; HMDP, hydroxymethylene diphosphonate; DPD, dicarboxypropane diphosphonate.

Mechanism of diphosphonate uptake on bone

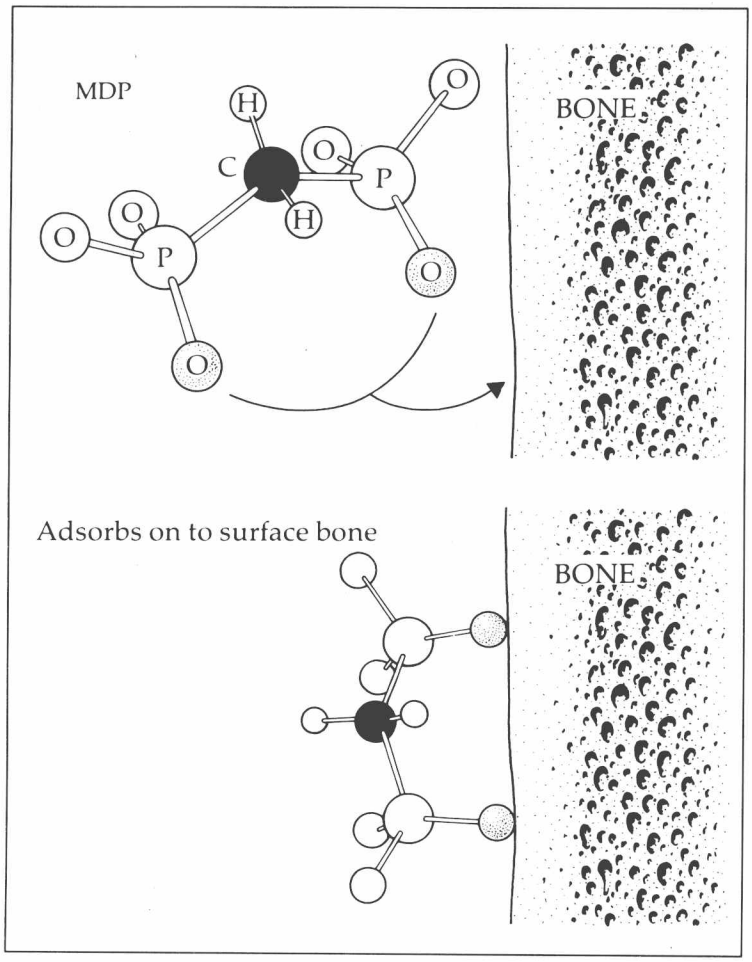
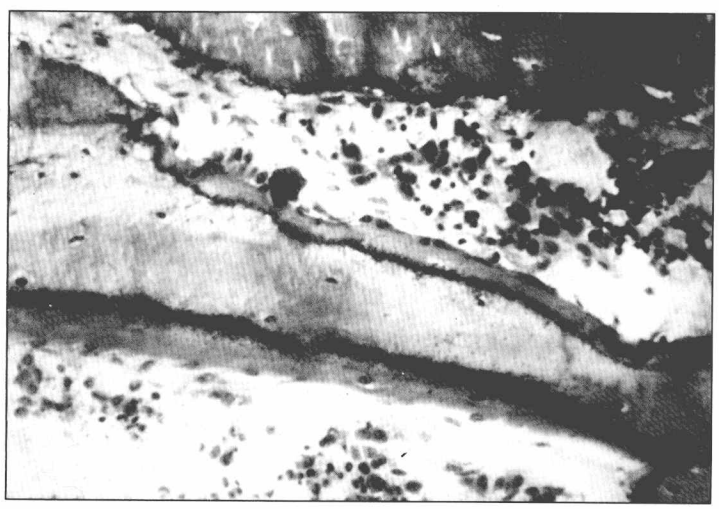


Figure 1.2



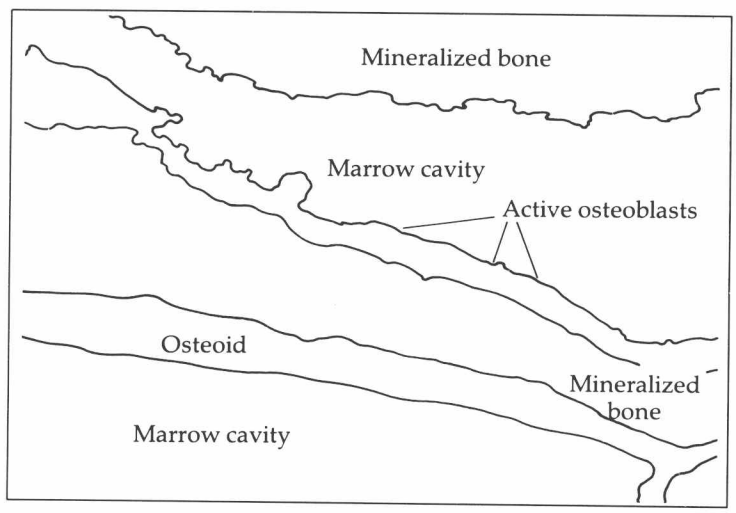


Figure 1.3

Microautoradiograph of rabbit bone showing adsorption of ^{3}H-HEDP on bone surfaces. The heavy concentration of silver grains is at the interface between osteoid and bone, ie, at the site where mineralization occurs.

Bone scan techniques

A brief outline of the author's protocols for both planar and SPECT bone scanning is given in Tables 1.1–1.5. When compared with planar imaging, SPECT offers both cross-sectional anatomical detail and improved image contrast. SPECT removes from each diagnostic image the activity originating outside the tomographic plane of medical interest. For example, in the hip the acetabulum extends around and behind the femoral head. Therefore, a planar bone scan abnormality within the femoral head may be obscured by activity originating in the underlying acetabulum. Using SPECT it is possible to separate underlying and overlying distributions of activity into sequential tomographic planes. For this reason, SPECT often improves detection of an abnormality within the femoral head itself.

The improvement in image contrast and anatomical detail available with SPECT must be weighed against the superior spatial resolution of planar bone scanning. For the high resolution bone SPECT technique used at the authors' institutions, spatial resolution for the spine is no better than 14 mm full width half maximum. This is compared with 8 mm or better resolution (at a depth of 5 cm or less using a high resolution collimator) for a state-of-the-art planar bone scan. When evaluating the hands, feet or other relatively small and superficial bony structures, high resolution planar bone scanning usually provides superior images. However, SPECT can make a valuable contribution to the examination of large, anatomically complex structures such as the spine, hips and knees. SPECT may also be essential for examining small bony structures which one may want to image individually. For example, SPECT can isolate the temporomandibular joint (TMJ) from activity originating in other bony structures of the face and base of the skull.

SPECT supplements but does not replace planar bone scanning. Therefore, the time and expense of SPECT is an addition to the bone scan examination. Since many patients complaining of bone pain may benefit from a dynamic study and blood pool image, SPECT often becomes the fourth component of a patient's bone scan. At our institutions, the imaging sequence for patients without a history or suspicion of malignancy who complain of back, hip, knee or TMJ pain is as follows:

1 Dynamic study (2–5 seconds per frame)
2 Blood pool image (500000 counts)
3 Planar bone scan
4 SPECT bone scan

Patients referred to nuclear medicine for the evaluation of osteomyelitis, orthopaedic disorders or sports injuries require bone scans that are carefully tailored to their individual needs. For example, osteomyelitis should be evaluated with a dynamic study, blood pool image and subsequent delayed planar bone scan images. The evaluation of orthopaedic disorders and sports injuries usually calls for planar bone scans which show the best possible anatomical detail. This requires high resolution collimation and may call for special positioning, such as oblique views of the shoulder or plantar views of the feet. Even when optimal high resolution planar bone scans have been obtained, the addition of SPECT to these orthopaedic examinations will frequently yield further valuable diagnostic information.

When evaluating oncology patients, the authors prefer to obtain multiple overlapping bone scan images rather than use whole body imaging techniques. Multiple overlapping 'spot' images always have higher resolution than the total body images obtained with a scanning mechanism. The superior resolution of 'spot' images aids detection of bone metastases and facilitates accurate anatomical localization of skeletal lesions.

Table 1.1 Protocols for planar bone scanning

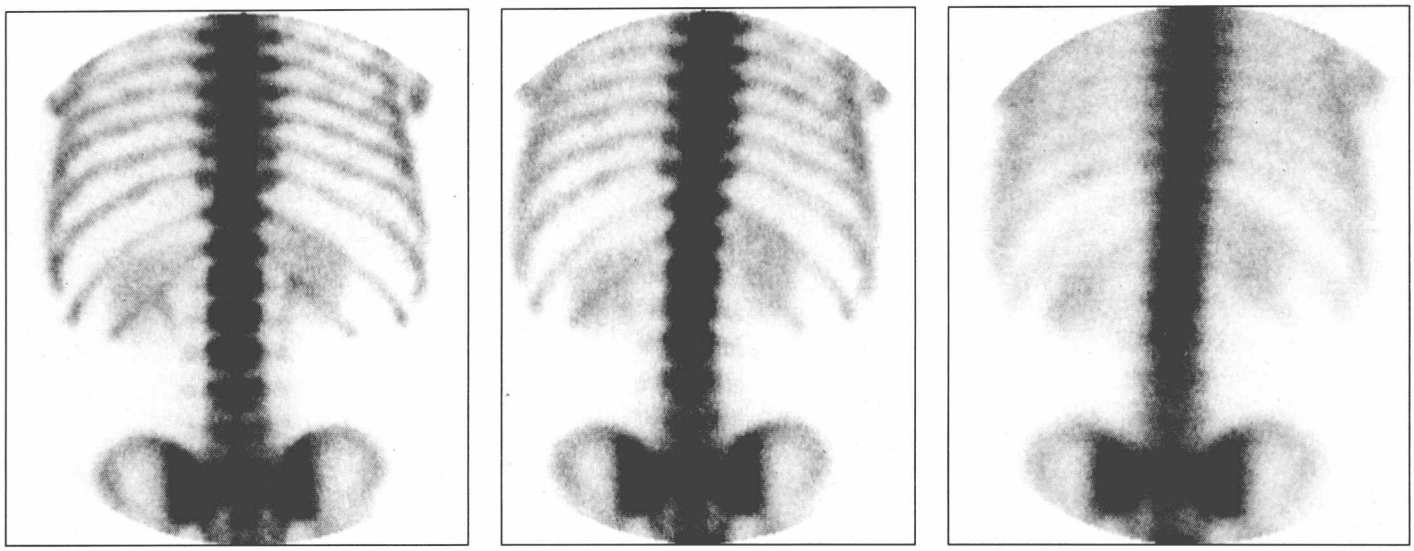
Patient preparation
Encourage fluids and frequent voiding
Remove metal objects and ask patient to void before scan

Adult dose
550 MBq ^{99m}Tc-MDP

Scanning 3–4 hours after injection
1 Whole body technique; or
2 Multiple overlapping bone scan views
- Low energy all-purpose, or low energy high resolution collimator
- 500000 to 1000000 count thoracic spine scan
- Obtain all other scans for same length of time

Table 1.2 Planar bone scanning pitfalls

Pitfall	*Result*
Over 5 cm collimator-to-patient separation	Loss resolution
Wrong energy windows	Loss resolution
Low count study	'Grainy' scan
^{99m}Tc-MDP impurities	Increased background activity and soft tissue uptake
Renal failure	Increased background activity
Slight patient motion	Loss resolution
Obesity	Increased background and scattered activity



a b c

Figure 1.4

Posterior view bone scans of the thoracolumbar spine obtained with the collimator **(a)** in close apposition to the patient's back, **(b)** 13 cm from the back and **(c)** 25 cm from the back. It is apparent that as the collimator is moved away from the patient, spatial resolution decreases and image clarity deteriorates.

Table 1.3 Protocols for SPECT bone scanning

Adult dose
925 MBq ^{99m}Tc-MDP
Acquisition 3–4 hours later
64 × 64 matrix (400 mm field-of-view gamma camera)
General method
Low energy all-purpose collimator
20 seconds per projection, 64 projections over 360 degrees
High resolution method (option for lumbar spine)
High resolution collimator
25 seconds per projection, 64 projections over 360 degrees
Processing
Uniformity correction
Hanning filter (frequency cut-off = 0.8 cycle/cm pre-processing)
Reconstruction by filtered back-projection with Ramp filter
No attenuation correction
6 mm (one pixel) thick transaxial, sagittal and coronal images
Display
Use linear grey scale map for TMJ, lumbar spine and knee SPECT
Use log grey scale when searching for femoral head avascular necrosis

Table 1.4 Special patient positioning for SPECT bone scanning

Bony structure	*Special positioning*	*Comments*
Knees	5–7.5 cm pad between knees; secure knees with straps to prevent motion Secure feet in neutral position to prevent rotation	For obese patients both knees may not fit in field of view
Hips and pelvis	Empty bladder before examination Position hips symmetrically and secure knees and/or feet to prevent motion	Bladder filling during examination creates artefacts
Lumbar spine	Keep arms out of field of view A pillow under the knees may relieve back pain	Patients with back pain often move during the examination
TMJ	Secure neck in comfortable hyperextension Instruct patient not to talk	Check lateral view to be sure the chin is in the field of view

Table 1.5 Gamma camera quality control for planar and SPECT bone scanning

Daily

Extrinsic flood for uniformity check:

- 3.0 million counts, 400 mm field-of-view camera
- 4.5 million counts, 500 mm field-of-view camera

Weekly

Update energy correction per manufacturer recommendation

Intrinsic flood for uniformity check:

- 3.0 million counts, 400 mm field-of-view camera
- 4.5 million counts, 500 mm field-of-view camera

Update tomographic centre of rotation

Update high count extrinsic flood for uniformity correction:

- 30 million counts for 64 × 64 matrix
- 120 million counts for 128 × 128 matrix

Monthly

Image bar phantom for check of planar resolution

Image tomographic phantom (optional)

Pattern recognition 2

In order to be able to recognize an abnormal bone scan, the physician must be familiar with normal bone scan appearances and the commonly seen variants. While the scan appearances may be non-specific, recognizable patterns of abnormality are often seen which may suggest a specific diagnosis. An experienced observer will regularly be correct in suggesting that a specific diagnosis has a high probability of being present. However, even an expert will be mistaken from time to time. A bone scan should not be considered to be a definitive investigation, but rather one that provides high sensitivity for lesion detection which often will require further investigation.

The following patterns of scan findings will be considered:

- Normal bone scan
- Variants
- Artefacts and pitfalls
- Metastases
- Marrow hyperplasia
- Trauma
- Arthritis
- Metabolic bone disease
- Vertebral collapse
- Paget's disease.