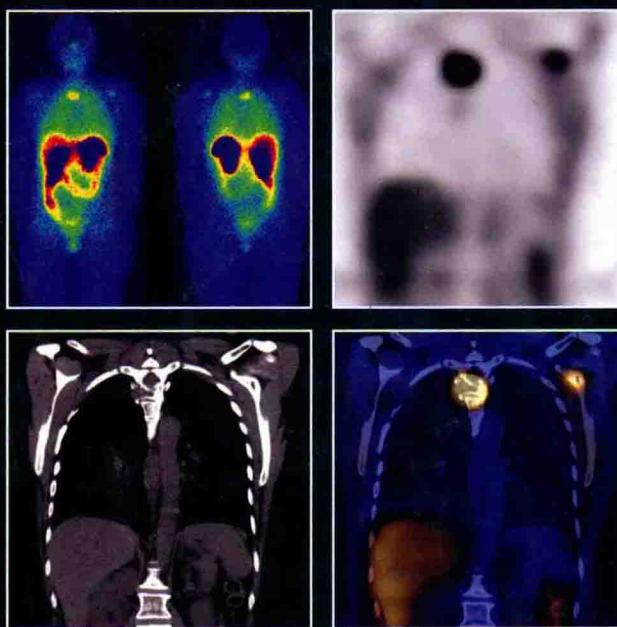


An Atlas of Clinical Nuclear Medicine

Third Edition



Ignac Fogelman
Susan E. M. Clarke
Gary Cook

Gopinath Gnanasegaran

AN ATLAS OF

CLINICAL NUCLEAR MEDICINE

THIRD EDITION

IGNAC FOGELMAN

BSc, MD, FRCP

Professor of Nuclear Medicine, King's College, London, UK
and

Honorary Consultant, Guy's and St Thomas', NHS Foundation Trust, London, UK

SUSAN E. M. CLARKE

MB, BS, MSc, FRCP, FRCR, FBIR

Senior Lecturer, Division of Imaging Sciences and Biomedical Engineering,
King's College, London, UK

and

Honorary Consultant, Guy's and St Thomas', NHS Foundation Trust, London, UK

GARY COOK

MB, BS, MSc, MD, FRCP, FRCR,

Professor of Clinical PET Imaging, Division of Imaging Sciences and
Biomedical Engineering, King's College, London, UK
and

Honorary Consultant, Guy's and St Thomas', NHS Foundation Trust, London, UK

GOPINATH GNANASEGARAN

Consultant Physician, Department of Nuclear Medicine,
NHS Foundation Trust, London, UK

Guy's and St Thomas',



CRC Press

Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an informa business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2014 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed and bound in India by Replika Press Pvt. Ltd.

Printed on acid-free paper
Version Date: 20130930

International Standard Book Number-13: 978-1-84184-653-8 (Hardback)

This book contains information obtained from authentic and highly regarded sources. While all reasonable efforts have been made to publish reliable data and information, neither the author[s] nor the publisher can accept any legal responsibility or liability for any errors or omissions that may be made. The publishers wish to make clear that any views or opinions expressed in this book by individual editors, authors or contributors are personal to them and do not necessarily reflect the views/opinions of the publishers. The information or guidance contained in this book is intended for use by medical, scientific or health-care professionals and is provided strictly as a supplement to the medical or other professional's own judgement, their knowledge of the patient's medical history, relevant manufacturer's instructions and the appropriate best practice guidelines. Because of the rapid advances in medical science, any information or advice on dosages, procedures or diagnoses should be independently verified. The reader is strongly urged to consult the drug companies' printed instructions, and their websites, before administering any of the drugs recommended in this book. This book does not indicate whether a particular treatment is appropriate or suitable for a particular individual. Ultimately it is the sole responsibility of the medical professional to make his or her own professional judgements, so as to advise and treat patients appropriately. The authors and publishers have also attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

AN ATLAS OF

**CLINICAL
NUCLEAR
MEDICINE**

THIRD EDITION

IGNAC FOGELMAN

MD, MRCP

Professor of Nuclear Medicine, King's College, London, UK

and

Honorary Consultant, Guy's and St Thomas' NHS Foundation Trust, London, UK

SUSAN E. MCCLURE

MD, MRCP, FRCR, FRCR

Professor, Division of Imaging Sciences and Biomedical Engineering

King's College, London, UK

Honorary Consultant, Guy's and St Thomas' NHS Foundation Trust, London, UK

GARY COOK

MD, MRCP, FRCR, FRCR

Professor of Clinical PET Imaging, Division of Imaging Sciences and
Biomedical Engineering, King's College, London, UK

and

Honorary Consultant, Guy's and St Thomas' NHS Foundation Trust, London, UK

GOPINATH GNANASEKARAN

Consultant Physician, Division of Imaging Sciences and Biomedical Engineering, Guy's and St Thomas' NHS Foundation Trust, London, UK

MD, FRCR

© 2013

CRC Press

Taylor & Francis Group

ISBN 9781444185444

FOREWORD

The experienced interpreter of diagnostic medical images is well versed in the concept of pattern recognition. This is of particular importance in Nuclear Medicine because of the non-specificity of many of the findings we may encounter on a radionuclide image. Over the past several decades, many Nuclear Medicine atlases have appeared either devoted to a specific area of organ imaging, or more generally, attempting to encompass a broader overview of radionuclide imaging methodology. The first two editions of this current work fall into this latter category. All of these publications have served their timely purpose in the overall history of our specialty.

In the 1600 pages that follow, Drs. Fogelman, Clarke, Cook and Gnanasegaran have created a classic work that should stand for many years as the standard of what a comprehensive atlas should be. In their preface, the authors indicate that they "have made a valiant attempt to include most of what one would expect to observe routinely and to contend with issues that we personally have found interesting and challenging." They have succeeded. The net result of their "valiant attempt" is a wonderful, comprehensive, compendium of everything you want to know about interpreting radionuclide images and more.

Each of the 13 chapters has introductory sections structured as a mini-test dealing with basic anatomy, physiology and pathophysiology stressing the normal and its variants. Superb line drawings, photographs and numerous tables add to the

ease of the readers' comprehension of the subject matter. I, in particular, enjoyed the beautiful, colourful anatomic casts of the bronchopulmonary segments in the lung chapter and coronary arterial tree in the cardiology chapter. The explanatory "bullets" following a great number of the figure legends provide valuable additional commentary on the particular finding being discussed. The inclusion of SPECT and PET/CT in this similar teaching format significantly adds to the uniqueness of the Atlas.

I have long known and admired Dr. Ignac Fogelman's great talents as a clinical investigator, teacher and author of innumerable articles and texts; primarily dealing with osseous disease. With the invaluable assistance of his colleagues in Great Britain, he has created this third masterful edition of an Atlas of Clinical Nuclear Medicine, which will stand as a greatly appreciated invaluable contribution to both Nuclear Medicine physicians and clinicians interested in learning how radionuclide methodology can enhance their patient care.

Our great thanks to Dr. Fogelman and his associates for their tireless efforts over several years to provide us with this ultimate reference on how to interpret radionuclide images.

Leonard M. Freeman, M.D.
Bronx, New York
June, 2013

PREFACE

It is some 18 years since the last edition of this Atlas was published. That is a long time to keep you waiting, and we are truly sorry. However, it seemed a daunting task to produce a new Atlas of Clinical Nuclear Medicine; to include all the new radiopharmaceuticals, advances with SPECT/CT; and to cover the revolution in imaging, that is PET/CT. Fortunately, help was to hand with our younger colleagues (Dr. Gnanasegaran and Dr. Cook) who injected knowledge, dynamism, and stamina into the project. Nevertheless, this remains a hugely ambitious task with an aim to provide a truly comprehensive Atlas. We have made a valiant attempt to include most of what one would expect to observe routinely and to contend with

issues that we personally have found interesting and challenging. Many simple, easy-to-remember teaching points have been included throughout this text, and our hope is that the end product will be clinically useful and of practical value. Thus, our success depends on you, dear reader, as it is upon your opinion as to how close we have come to achieving our goal that we will ultimately be judged.

Ignac Fogelman

Susan E. M. Clarke

Gary Cook

Gopinath Gnanasegaran

ACKNOWLEDGEMENTS

We would like to thank all of the contributors to the Atlas, who are identified by their contributions. We would also like to thank the staff of the Department of Nuclear Medicine at Guy's and St Thomas' Hospital who have assisted in obtaining the new material for this third edition. In particular, we acknowledge the valuable contribution made by Dr. Petra Lewis

Prof. Adil Al-Nahhas, UK
Dr. Parthiban Arumugam, UK (Nuclear Cardiology chapter)
Prof. Dale Bailey, Australia
Stacey Baker, UK
Dr. K. K. Balan, UK
Dr. James Ballinger, UK
Dr. Sally Barrington, UK
Dr. Tara Barwick, UK
Nynke S. van den Berg, the Netherlands
Dr. Lorenzo Biassoni (Paediatrics chapter), UK
Dr. Shankar Kumar Biswas, Bangladesh
Dr. Jamshed Bomanji, UK
Prof. S. E. Bouyoucef, Algeria
Dr. John R. Buscombe, UK
Dr. Sugama Chicklore, UK
Dr. Dhruba Dasgupta, UK
Dr. Indirani Elangovan, India
Dr. Rashika Fernando, UK
Dr. Mohamed Halim, UK
GE Healthcare, UK
Robin Karugaba, UK
Dr. Gilbert Keng, Singapore
Dr. Sujeeth Konan, UK
Dr. B. A. Krishna, India
Dr. Rakesh Kumar, India
Dr. Werner Langsteger, Austria
Prof. Richard Lawson, UK
Prof. Valerie Lewington, UK
Dr. Petra Lewis, UK
Dr. Chen Low, UK
Dr. Shahid Mahmood, Singapore
Julie Martin, Hermes Medical Solutions Ltd, UK

(Brain chapter), Dr. Lorenzo Biassoni (Paediatrics chapter), and Dr. Parthiban Arumugam (Nuclear Cardiology chapter). They have collated all the new material and assisted in the reconstruction of these chapters. Finally, our thanks go to the staff of CRC Press for their constructive help throughout the preparation of this new edition.

Prof. Gynter Moedder, Germany
Dr. Hosahalli Mohan, UK
Dr. Nicola Mulholland, UK
Dr. Malavika Nathan, UK
Dr. Shaunak Navalkisoor, UK
Dr. Alp Notghi, UK
Dr. Ewa Nowosinska, UK
Dr. Tom Nunan, UK
Prof. Michael O'Doherty, UK
Dr. Saabry Osmany, Singapore
Howmedica Osteonics Corp (Stryker), USA
Dr. Ann-Marie Quigley, UK
Dr. Venkat Ratnam, India
Dr. Paul J. Roach, Australia, UK
Dr. Stephen M. Schlicht, Australia
Dr. Gregory Shabo, UK
Dr. Shelly Simon, India
Dr. Natasha Singh, India
Dr. Ajay Sreedasyam, UK
Dr. Shanmuga Sundaram, India
Dr. Teresa Szyszko, UK
Dr. Muriel-Buxton Thomas, UK
Deborah Tout, UK
Dr. Fahim Ul-Hassan, UK
Dr. Renato A. Valdés Olmos, the Netherlands
Dr. Sanjay Vijayanathan, UK
Dr. Zaid Viney, London, UK
Dr. Sobhan Vinjamuri, UK
Dr. Hans Van der Wall, Australia
Dr. Vikki Warbey, UK
Rob Williams, Australia

CONTENTS

	Foreword	vii
	Preface	ix
	Acknowledgements	xi
1	Bone	1
2	Endocrinology	307
3	Renal	443
4	Oncology	593
5	Brain	879
6	Nuclear cardiology	941
7	Lung	1075
8	Liver and spleen	1175
9	Gastrointestinal tract	1245
10	Paediatrics	1297
11	Infection	1389
12	Radionuclide therapy	1507
13	Miscellaneous	1547
	Index	1585

An appendix listing of Common SPECT and PET Radionuclides and Radiopharmaceuticals used in Nuclear Medicine can be found on <http://www.crcpress.com/product/isbn/9781841846538>.

BONE

CHAPTER CONTENTS

INTRODUCTION

ANATOMY/PHYSIOLOGY

Mechanism of diphosphonate uptake on bone

RADIOPHARMACEUTICALS

Chemical structures of diphosphonates

NORMAL SCANS

Normal whole-body scan

Three-phase bone scan

Blood pool scans

Bone scan quantitation

Miscellaneous

Artefacts

Contamination

CLINICAL APPLICATIONS

Investigation of malignancy

Staging

Assessment of extent of disease

Localisation problems

Superscan of malignancy

Significance of SPECT

Assessment of disease progression and response

Resolution

Flare phenomenon

Osteogenic sarcoma

Chondrosarcoma

Histiocytosis X

Investigation of benign bone disease

Benign bone lesions

Benign bone tumour

Trauma

Bilateral stress fractures

Knee trauma: meniscal tears

Trauma: non-accidental injury (NAI)

Surgical trauma

Arthritis

Sacroiliitis

Metabolic bone disease

Osteomalacia

Fibrous dysplasia

Paget's disease

Miscellaneous

Bone SPECT/CT

Malignant bone disease

Spine

Benign bone disease

Thorax

Osteitis pubis

Femoroacetabular impingement syndrome

Ankle: impingement syndromes

Stress fractures

Miscellaneous

INTRODUCTION

Bone imaging encompasses a wide spectrum of pathologies from benign conditions such as trauma and infection to primary and secondary malignant lesions. Despite advances in anatomical imaging, including magnetic resonance imaging (MRI) and multidetector computed tomography (MDCT), bone scintigraphy continues to play a major role in the diagnosis of bone pathology.

Bone scintigraphy is commonly used as a screening test for suspected bone metastases because of its high sensitivity, availability, low cost, and ability to scan the entire skeleton. Historical data and clinical experience have established bone scintigraphy as the reference standard in the search for skeletal metastatic disease, and, in the same way, many indications have been established for benign skeletal disorders. For many years ^{99m}Tc -labelled diphosphonates, particularly ^{99m}Tc -methylene diphosphonate (MDP), have been the most widely used radiopharmaceuticals.

A ^{99m}Tc -MDP bone scan shows exquisite sensitivity for skeletal pathology, but this technique has the limitation that scan appearances may be non-specific. However, in many clinical situations recognisable patterns of scan abnormality are seen,

which often suggest a specific diagnosis. The mechanism of tracer uptake in bone is not fully understood, but it is believed that diphosphonate is adsorbed onto the surface of the bone, with particular affinity for sites of new bone formation. 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 structural change in most pathologies, 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 visualised on the bone scan; indeed, there are many examples of renal pathology which have been detected for the first time on a bone scan. Improvements in gamma camera design, including the increased availability of tomographic scintigraphy [single photon emission computed tomography (SPECT)], have also helped in bone imaging by increasing sensitivity and specificity. In recent years, there has been increasing interest in the use of positron emission tomography (PET) tracers, such as ^{18}F -FDG and ^{18}F -fluoride, in the investigation of various aspects of skeletal disease especially bone metastases (Table 1.1).

Mechanism of diphosphonate uptake on bone

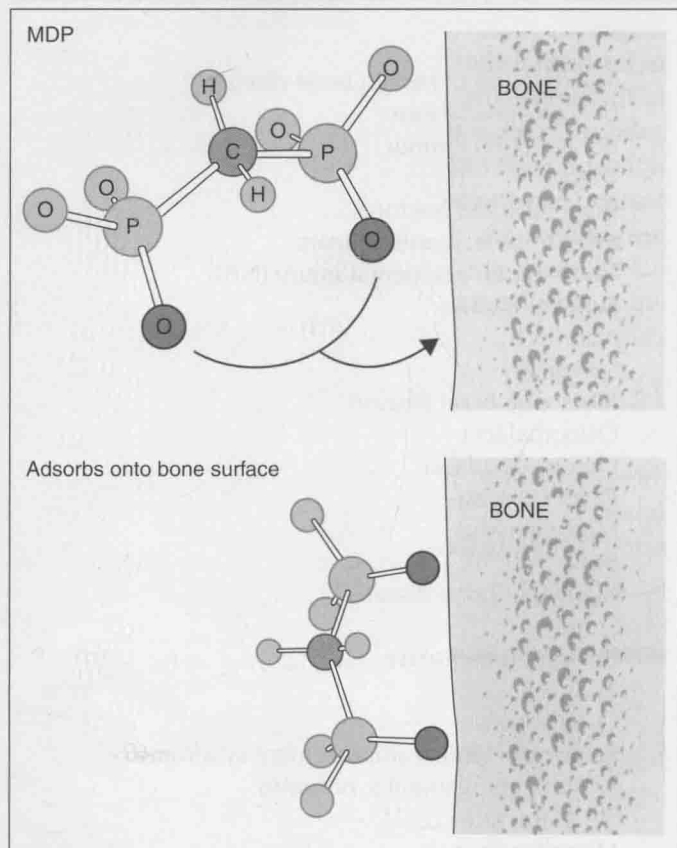


Figure 1.1 Mechanism of diphosphonate uptake on bone.

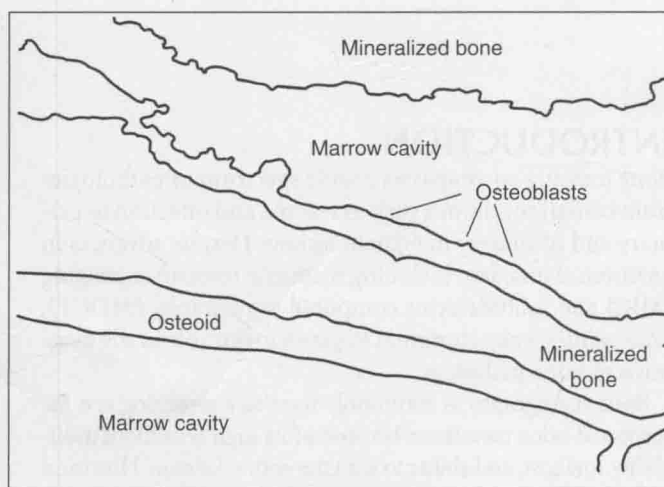
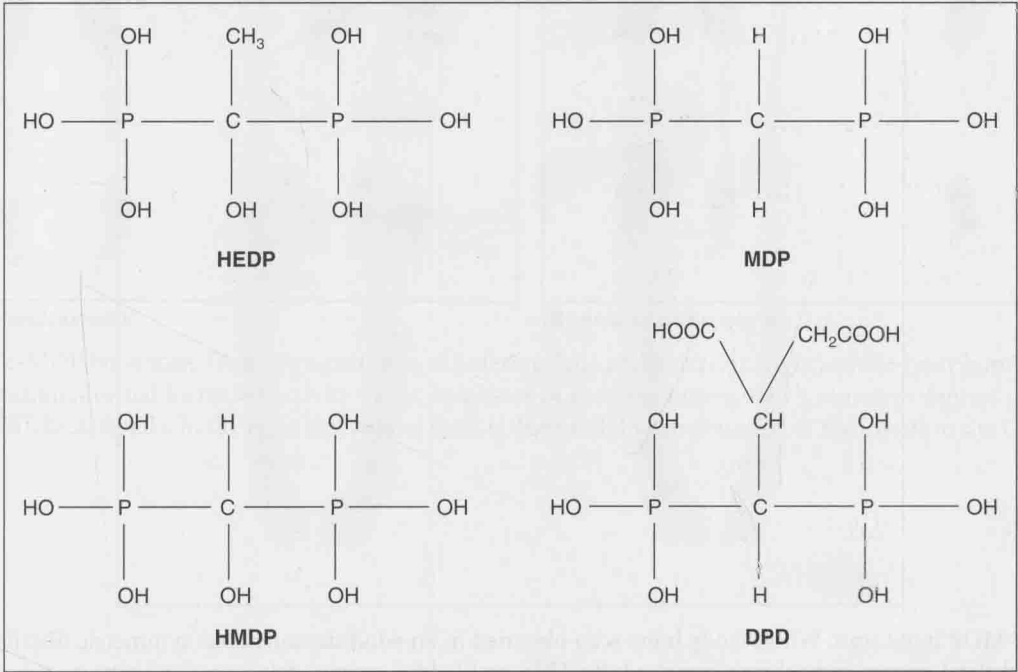


Figure 1.2 Microautoradiography of rabbit bone showing adsorption of ^3H -hydroxyethylidene diphosphonate on bone surfaces. The heavy concentration of silver grains is at the interface between osteoid and bone, that is, at the site where mineralisation occurs. Source: Courtesy of Dr. M.D. Francis, Cincinnati, USA.

Table 1.1 Specific and Non-specific SPECT and PET Radiopharmaceuticals for Bone Imaging

SPECT tracers	PET tracers
Specific ^{99m} Tc-methylene diphosphonate (MDP)	Specific ¹⁸ F-Fluoride
Non-specific ⁶⁷ Gallium ²⁰¹ Thallium ^{99m} Tc-Sestamibi (MIBI) ^{99m} Tc-Tetrofosmin ^{123/131} I-meta iodobenzylguanidine (MIBG) ^{123/131} I-Iodine ¹¹¹ In-Octreotide	Non-specific ¹⁸ F-fluorodeoxyglucose (FDG) ¹¹ C-Choline ¹¹ C-Acetate ⁶⁸ Ga-DOTATOC/DOTANOC

Chemical structures of diphosphonates



OH

H

OH

HO—P—

C—

P—OH

OH

OH

OH

HMDP

HOOC

CH₂COOH

OH

CH

OH

HO—P—

C—

P—OH

OH

H

OH

DPD

Figure 1.3 Chemical structures of bone tracers. At the present time MDP is the most widely used agent. Abbreviations: HEDP, hydroxyethylidene diphosphonate; MDP, methylene diphosphonate; HMDP, hydroxymethylene diphosphonate; DPD, dicarboxypropane diphosphonate.

NORMAL SCANS

Normal whole-body scan



Figure 1.4 ^{99m}Tc -MDP bone scan. Whole-body bone scan obtained in an adult demonstrates symmetric distribution of activity throughout the skeletal system in healthy normal adults. Urinary bladder activity, faint renal activity, and minimal soft-tissue activity are commonly seen.

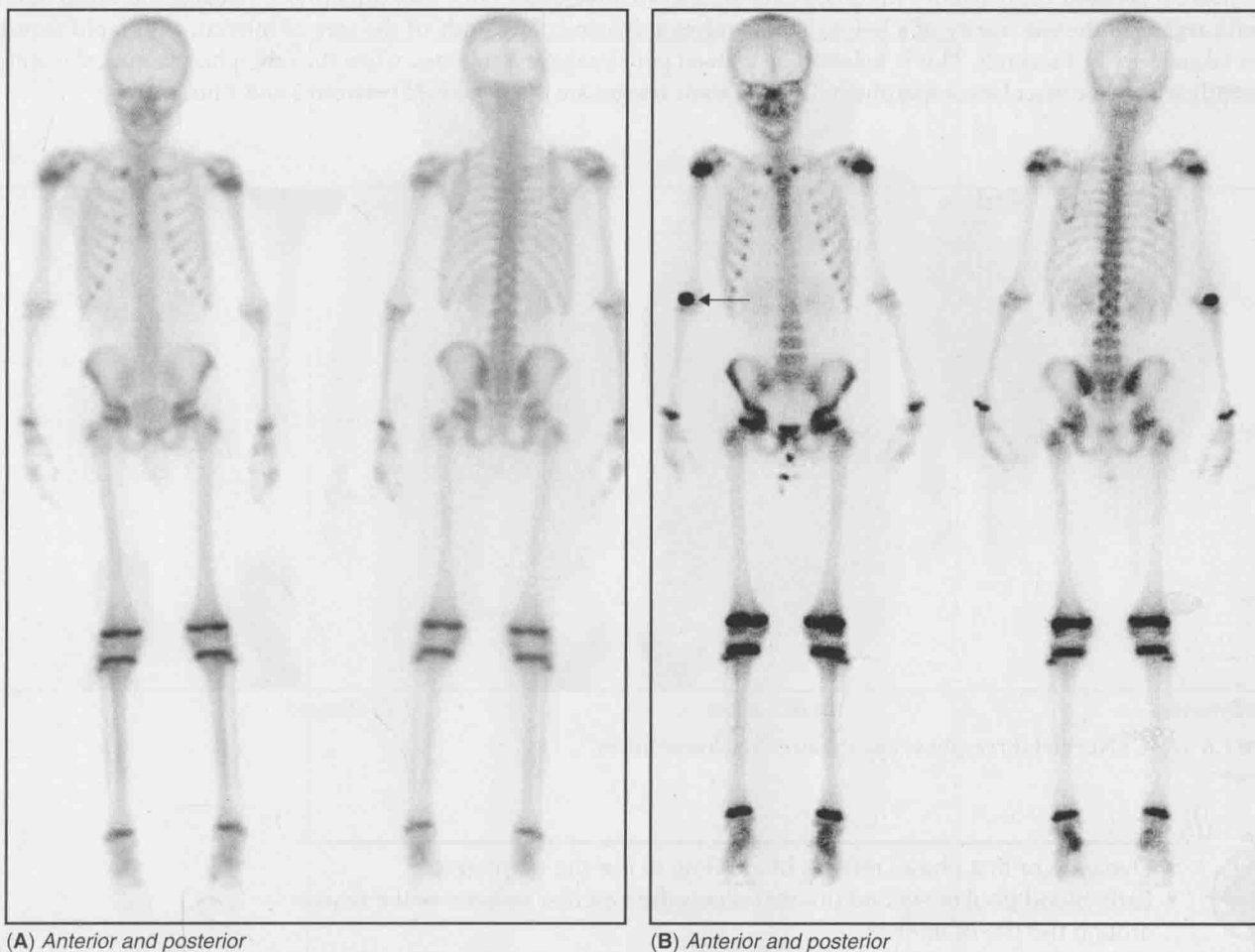
Normal paediatric whole-body scans

Figure 1.5 ^{99m}Tc -MDP bone scan. (A,B) Two examples of anterior (left) and posterior (right) whole-body bone scans obtained in children demonstrate normal increased activity in the epiphyses of the long bones, which represent centres of normal growth. Note in image (B), focal uptake in the right antecubital fossa is due to slight extravasation at the injection site (arrow).

Three-phase bone scan

The timing of bone scan images will depend upon the clinical problem under investigation. In general, it is customary to obtain static images at between 2 and 4 hours. In certain circumstances a three-phase bone scan will provide valuable additional information with regard to the vascularity of a lesion. This involves a dynamic flow study of the area of interest, with rapid sequential images taken every 2–3 seconds. This is followed by a blood pool image at 5 minutes, when the radiopharmaceutical is still predominantly within the vascular compartment. Delayed static images are then obtained between 2 and 4 hours.

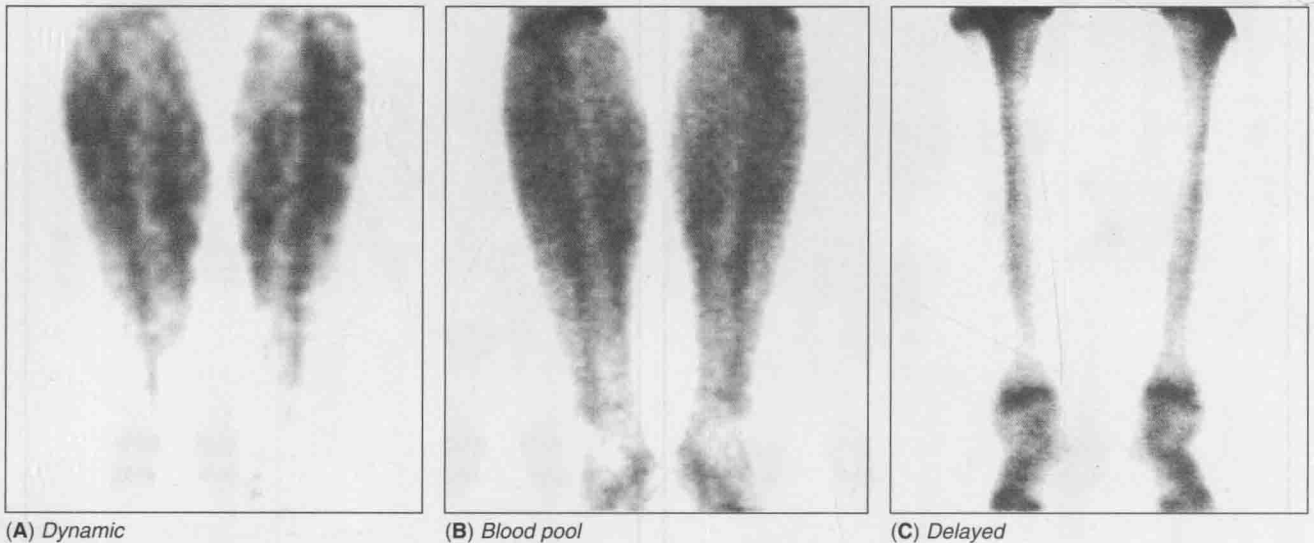


Figure 1.6 (A–C) Normal three-phase bone scan of the lower limbs.



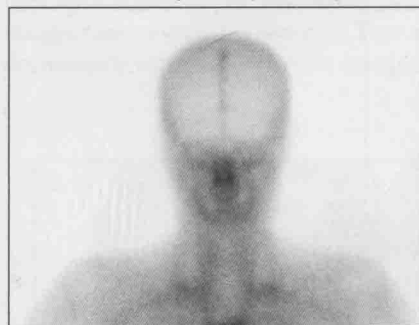
- Dynamic or first phase: reflects blood flow to the site of interest.
- Early blood pool or second phase: reflects the vascular volume of the tissues around the site of interest.
- Delayed, static, or third phase: reflects the skeletal metabolic activity.
- Many departments carry out two-phase bone scan as a compromise, that is, blood pool and delayed images only, arguing that adequate information regarding vascularity is contained in the blood pool images.

Blood pool scans***Normal whole-body blood pool image***

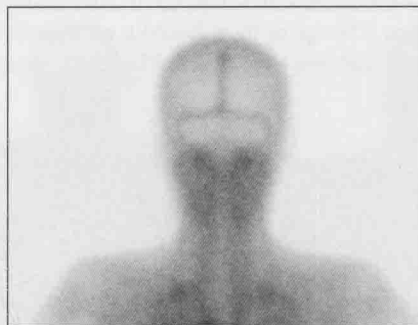
Figure 1.7 ^{99m}Tc -MDP bone scan, anterior and posterior views. Normal whole-body blood pool image. Increased activity in the distal right arm is the site of injection. Incidental asymmetric renal size is noted (*arrow*).

Skull: Normal early blood pool and delayed images

Skull: Normal early blood pool images



(A) Anterior



(B) Posterior

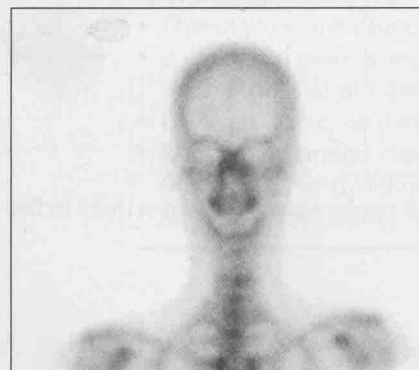


(C) Right lateral

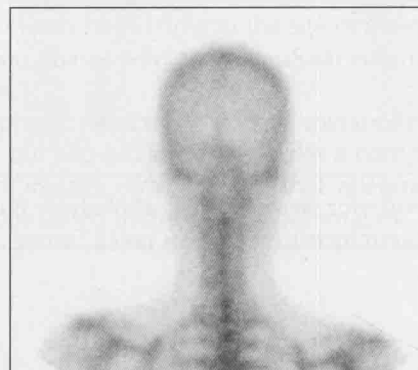


(D) Left lateral

Skull: Normal delayed images



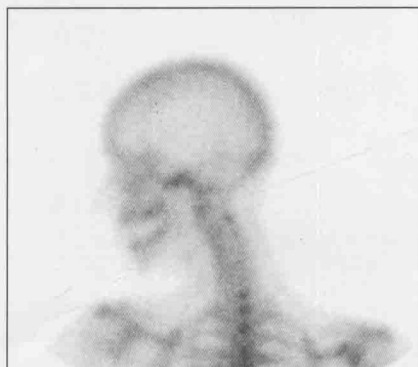
(E) Anterior



(F) Posterior



(G) Right lateral



(H) Left lateral

Figure 1.8 ^{99m}Tc -MDP bone scan of a normal skull. (A–D) early blood pool and (E–H) delayed images. The venous sinuses are prominent in the early blood pool images.

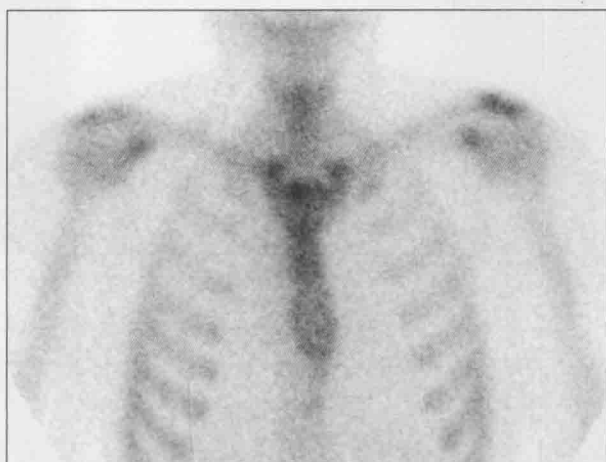
Normal blood pool and delayed images of the thorax**(A)** Anterior blood pool**(B)** Posterior blood pool**(C)** Anterior delayed**(D)** Posterior delayed

Figure 1.9 ^{99m}Tc -MDP bone scan. (A–D) Normal two-phase bone scan of chest/thorax.



Blood pool images (phase 2) should be acquired immediately after the dynamic phase (phase 1) of the scan. Blood pool images should be completed within 10 minutes post tracer injection.