Yong-Whee Bahk

Combined Scintigraphic and Radiographic Diagnosis of Bone and Joint Diseases

Yong-Whee Bahk

Combined Scintigraphic and Radiographic Diagnosis of Bone and Joint Diseases

Foreword by Henry N. Wagner, JR

3rd, revised and enlarged edition

With 692 Figures in 1329 Separate Illustrations

Springer

Yong-Whee Bahk, MD, PhD, Professor Emeritus
Department of Nuclear Medicine & Radiology
Sung Ae General Hospital
Seoul, 150-051 Korea

Library of Congress Control Number: 2006923239

ISBN 10	3-540-22880-2	Springer Berlin Heidelberg New York
ISBN 13	978-3-540-22880-6	Springer Berlin Heidelberg New York
ISBN 10	3-540-66424-6 2nd edition	Springer Berlin Heidelberg New York

Springer is a part of Springer Science+Business Media
springer.com

Editor: Dr. Ute Heilmann, Heidelberg
Desk editor: Dörthe Mennecke-Bühler, Heidelberg
Production editor: Nadja Kroke, Leipzig
Cover design: Frido Steinen-Broo, e-Studio Calamar, Spain
Production: LE-TeX Jelonek, Schmidt & Vöckler GbR, Leipzig
Typesetting: Arnold & Domnick, Leipzig
Printed on acid-free paper SPIN 11314073 21/3100/YL – 5 4 3 2 1 0

To those who suffer from skeletal disease
and those who heal and help the sufferers

Foreword to the third edition

In this refreshing 3rd edition of his classic book, Prof. Bahk has made further very important contribution to advancing bone and joint as well as soft-tissue imaging, among the most important and most widely used procedures in nuclear medicine. In his 25-year endeavor focusing on the scintigraphic imaging of the skeletal system, he has rightly emphasized the usefulness of the improved spatial resolution of bone scans obtained with the pinhole collimator. At the same time he has not forgotten to duly emphasize and illustrate the efficacy of 99mTc-HMPAO and 67Ga citrate scans and to discuss a recently introduced metabolic imaging technique, the 18F-FDG PET scan, in the diagnosis of bone and joint diseases.

The two previous editions have been thoroughly revised, rearranged, and expanded to include five new chapters on Normal Variants and Artifacts, Drug-induced Osteoporosis, Soft-tissue Tumors and Tumor-like Conditions, PET/CT in Bone and Joint Diseases, and A Genetic Consideration of the Skeletal Disorders with many new patient studies to realistically illustrate the immense value of all these new approaches. The diagnostic scope of some existing topical chapters on, for example, rheumatic skeletal disorders, benign and malignant bone tumors, and versatile traumatic injuries have also been broadened in depth and enriched by the addition of fresh cases.

Bone and joint and soft-tissue imaging reinforced with pinhole magnification have undeniably stood the test of time and have prosperously continued to improve in the solution of patients' problems on skeletal diseases, which are uncertain or nebulous in existence and character, often manifesting little or no sign on planar bone scintigraphs or images of other diagnostic modalities.

Professor Bahk's philosophy is that the combination of anatomical studies with high resolution biochemical imaging remains one of the best approaches to solving the problems in not only the bones and joints but also the entheses and soft tissues. His greatest contribution in this new edition is his fair emphasis on the irreplaceable advantages of pinhole imaging. The book is a must read for all practitioners and researchers of nuclear medicine as well as radiology, orthopedic surgery and pathology.

Baltimore, October 2006

Henry N. Wagner, Jr. M.D.
Johns Hopkins Medical Institutions
Baltimore, Maryland, USA

Preface to the third edition

As was remarked in the first preface the primary purpose of this humble book is aimed at introducing and establishing a more accurate, objective means of scintigraphic diagnosis of bone and joint diseases through a piecemeal analysis of scan findings: The tool is pinhole magnification (Fig. 1). Thus, endeavors have actually been made at further refining and enhancing the diagnostic yield of ^{99m}Tc-MDP pinhole bone scan using the anatomic and metabolic data thereof obtained along with that of collaterally performed radiography, ultrasonography, MRI or CT (Fig. 2). On the other hand, since this book was first brought out in 1995 a sizable volume of new knowledge has accumulated in the field of bone scan diagnosis through ever-increasing interest in and application of an array of scan methods that include SPECT, pinhole scintigraphy, 99mTc-HMPAO scan, immunoscintigraphy and most recently ^{18}F-FDG PET/CT in addition to already widely utilized three-phase bone scintigraphy, ^{67}Ga citrate scan and others.

It is due to the advent and wide spread use of those scan modalities and the compilation of harvested crops that this third edition is more or less thoroughly rewritten and enlarged. The revision is intended first to update the extended applicability and widened scope of the pinhole scintigraphic diagnosis of not only bone and joint diseases but also many soft tissue disorders in as much as they evolved during the last decade. Thus, in addition to former 18 chapters, current edition presents 5 new chapters to describe Normal Variants and Artifacts, Drug-Induced Osteoporosis, Soft-Tissue Tumors and Tumor-like Conditions, PET-CT in Bone and Joint Diseases and Bone Scintigraphic Consideration of Genetic Skeletal Disorders. In addition, the chapters on Rheumatic Skeletal Disorders, Malignant Tumors of Bone, Benign Tumors of Bone and Traumatic Diseases are completely rewritten and complemented by the addition of some 90 fresh cases. The second aim is to underscore the undisputed usefulness of pinhole scintigraphy (Fig. 3).

It is my conviction that even in this era of surging molecular imaging and burgeoning nanoscience techniques best possible grasping of macro-anatomy and fine visible chemical change continues to be the most essential orientation for well founded bone scintigraphic diagnosis and, on its extension, a more holistic understanding of bone and joint diseases. As we know high resolution and sensitivity are two important parameters that effectively enhance the diagnostic acumen of imaging study, and, fortunately, both can be attained to a significantly raised level when one properly uses the pinhole magnification technique.

Fig. 1. Pinhole scanner showing pinhole collimator inserted at the top of the cone shield assembly. The optimum aperture size is 4 mm

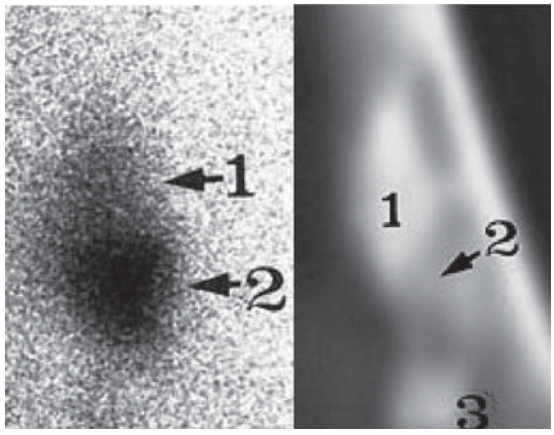


Fig.2. Anterior pinhole scan (left) and reconstructed coronal CT (right) of enchondromas in the left distal femur showing different 99mTc-MDP uptake according to the grade of mineralization. Tumors with advanced mineralization (1, 3) reveal low uptake and tumor with weak mineralization (2) reveals high uptake, reflecting different evolutional stages and metabolic activities of tumors

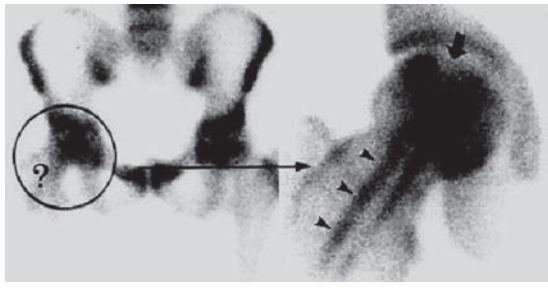


Fig. 3. Anterior planar (left) and pinhole (right) scan of the right hip with vascularized fibular graft implanted for avascular necrosis treatment. Note incredible improvement of both resolution and sensitivity. The graft is completely assimilated (arrowheads) with a small residual defect at the femoral capital top (arrow)

Acknowledgement

First of all, I am most grateful for many encouraging remarks and constructive opinions expressed by the reviewers in the United States, Germany, United Kingdom, Australia, Japan, Italy, Spain and Korea, my homeland, not to say the very generous acceptance of the earlier two editions of this book by anonymous readers and friends.

My very special thanks are due to Prof. Dr. Henry N. Wagner, Jr. who has graciously written the forewords on all three occasions. I am also deeply indebted to Dr. Yoon Kwang Kim, Chairman of the Sung-Ae Medical Foundation, Seoul, for his generous support. I wish to salute Mr. Tae Sung Choi, Mr. Kee Sup Chung and Mr. Dae Hee Moon, nuclear medicine technologists, for beautifully performing pinhole scintigraphy and Mr. Seun Mok Jeung, Mr. Pil Bok Wi and Miss Hyung Sook Hong for excellent photographic work.

Dr. Ute Heilmann and Ms. Dörthe Mennecke-Bühler and staff at the Springer-Verlag in Neuenheim, Heidelberg fully deserve my high admiration for their superb cooperation and fine editorial performance in creating this third edition.

Finally, I would like to pay a special and loving tribute to my wife, Rosa Yeun-Soo Cho, sons and daughter and grandchildren for everything that we have shared together during all these years.

Yong-Whee Bahk

Contents

1 Introduction and Fundamentals of Pinhole Scintigraphy

To those who acquired their anatomical knowledge of the skeleton with the aid of clean, dried bone specimens or a plastic mannequin it may appear as a mere inert weight-bearing scaffold of the human body. However, like all other organs, bone constantly undergoes remodeling and tubulation through the physiological and metabolic activities of osteoblasts and osteoclasts. The principal role played by these bone cells is the maintenance of bone integrity and calcium homeostasis by balancing between the ratio of bone collagen production and resorption and by governing mineralization processes. Collagen production is a histological property common to various connective tissues, but mineralization is unique to bone cells.

One of the first images of living human bone was a radiograph of the hand of the anatomist Kölliker taken by Wilhelm Conrad Röntgen at Würzburg University on 23 January 1896 (Fig. 1.1). Radiography then became the sole modality for visualizing the skeletal system in vivo, and it remained so until 1961 when Fleming and his coworkers produced the first

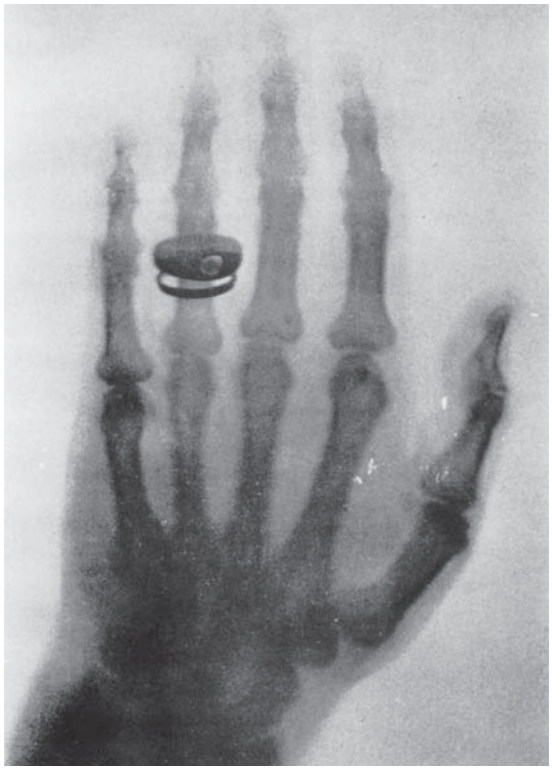


Fig. 1.1 One of the first radiographs of living human skeleton: anatomist Kolliker's hand, by Professor Röntgen in January 1896 at Würzburg University

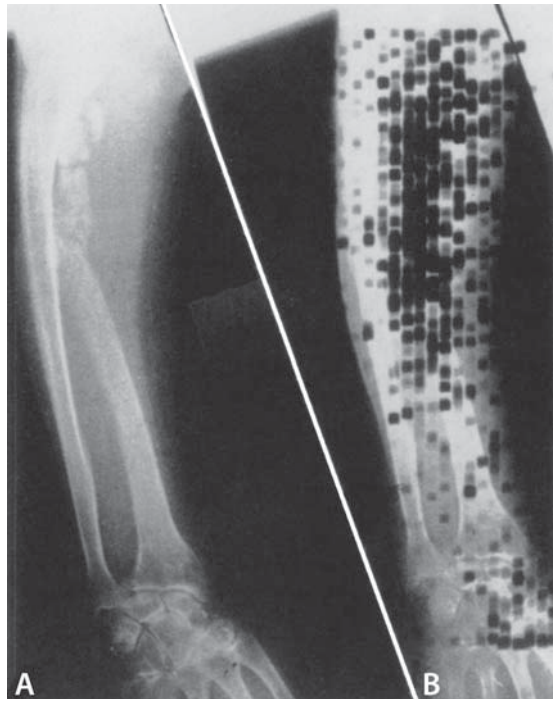
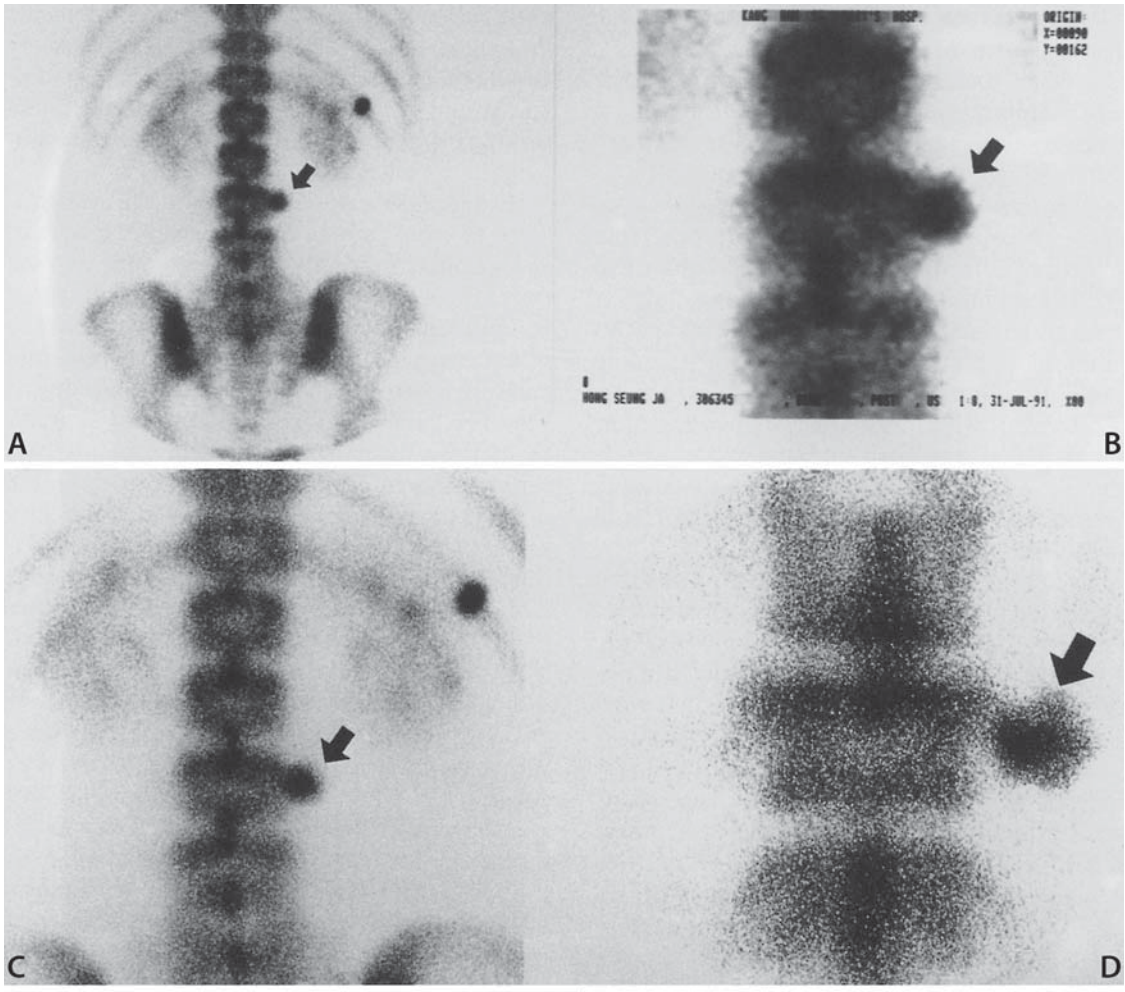


Fig. 1.2A, B One of the first bone scans made with ^{85}Sr. **A** Radiograph of forearm shows bone destruction due to metastasis in the proximal radius. **B** Dot photoscan reveals intense tracer uptake in the lesional area (from Fleming et al. 1961)

bone scintigraphic image using ^{85}Sr, a gamma ray-emitting radionuclide (Fig. 1.2). Using bone scintigraphy they successfully diagnosed bone metastasis and fracture. Historically, the event marked the beginning of the clinical use of bone scintigraphy for diagnosing skeletal disorders. During the development stage, bone scintigraphy suffered from many problems, particularly the limited image quality and consequent low diagnostic specificity. But with the wide availability of high-technology gamma camera systems furnished with efficient detector-amplifier assemblies, high-resolution collimators including fine pinhole, refined software, and ideal radiopharmaceuticals such as ^{99m}Tc-labeled methylene diphosphonate (MDP) and ^{99m}Tc-labeled hydroxydiphosphonate (HDP), bone scanning has long become established as an indispensable nuclear imaging procedure. Bone scanning is highly valued for two major reasons: exquisite sensitivity and unique ability to assess metabolic, chemical, or molecular profile of diseased bones, joints, and even soft-tissue structures. The usefulness of nuclear bone imaging modalities have most recently been enriched by the advent of bone marrow scintigraphy and positron emission tomography (PET) or PET-CT, further expanding the already wide scope of nuclear bone imaging science.

Indeed, bone scintigraphy is recognized for its sensitivity in detecting bone metastasis weeks before radiographic change is apparent and even ahead of clinical signs and symptoms. Its usefulness has also been thoroughly tested in the diagnosis of covert fracture, occult trauma with enthesitis, contusion, transient or rheumatoid synovitis, early osteomyelitis and pyogenic arthritis, avascular osteonecrosis, and a number of other bone and joint diseases. The introduction of single photon computed tomography (SPECT) has significantly enhanced lesion detectability by enhancing the image contrast through slicing complex structure of the pelvis, hip, spine and skull. In addition, ^{67}Ga citrate and ^{111}In- or ^{99m}Tc -labeled granulocyte scans have made important contributions to the diagnosis of infective bone diseases. As an adjunct the quantification of bone scan changes has been proposed (Pitt and Sharp 1985), and data are now automatically processed. This analytical approach is based on the calculation of the activity ratios of bone to soft tissue, bone to bone, and bone to lesion. Measurement of bone clearance of ^{99m}Tc-MDP, photon absorptiometry, and quantitative bone scan are used increasingly in the study of osteoporosis and osteomalacia. Most recently, ^{18}F FDG-PET has been shown to be a potent imaging method for the detection of not only the early primary cancers but also metastases to the bones, lymph nodes, and soft tissues (Abe et al. 2005; Buck et al. 2004).

In spite of unprecedented progress in computer technology, electronic engineering, and radiopharmaceuticals, the specificity of bone scintigraphic diagnosis has remained suboptimal and accordingly for more specific diagnosis of many bone and joint diseases additional information is still sought from radiography, CT, MRI and sonography, and finally such want has led to the hybridization of PET with CT. Silberstein and McAfee (1984) laboriously worked out a scintigraphic appraisal system to raise the specificity, but their success was partial. The factors counted on for scintigraphic diagnosis in the past were not specific morphological features that more or less directly reflected the pathological process in question, but included the following: increased or decreased tracer uptake, the number of lesions, unilaterality or bilaterality, homogeneity or not, and most problematically approximate anatomy. More essential determinants such as the size, shape, contour, accurate location, and internal texture of lesions cannot be portrayed by tracer uptake and distribution. Clearly, the reason for not analyzing more essential determinants was the relatively low resolution of the scan images made with multiple-hole collimators (O'Conner et al. 1991). This limitation remained unremedied even after the introduction of SPECT. While SPECT is very effective for the elimination of the overlap of neighboring bones and significantly enhances contrast, the resolution remains unimproved. PET, a tomographic modality like SPECT, can sensitively indicate



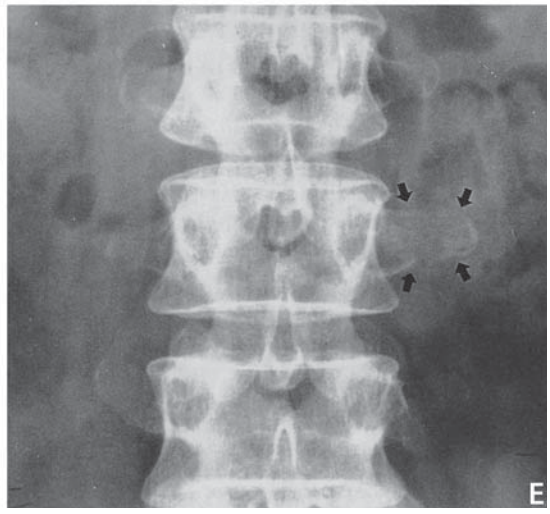


Fig. 1.3 Spot scintigraphs (**A–D**) showing the difference in the grade of resolution among four scanning methods used for displaying a metastasis (*arrows*) in the transverse process of L3 vertebra. **A** LEAP collimator. **B** Blowup or computer zooming. **C** Geometric enlargement. **D** Pinhole magnification. The lesion can be localized specifically in the transverse process only by pinhole scintigraphy (**D**). **E** Anteroposterior radiograph shows osteolysis in the transverse process of the L3 vertebra (*arrows*)

where increased amounts of FDG are deposited in the cytoplasm of, for example, cancer cells. A PET scan alone, however, cannot identify exact anatomy, needing the help of CT in the form of PET-CT hybridization. It is evident that on the whole the interpretation of scintigraphy has traditionally relied on nonspecific or indirect findings.

Fortunately, pinhole bone scintigraphy can in greater detail display pathological changes in the individual disease of bones and joints as well as the soft tissues through an optical magnification with highly improved resolution. It must be remembered that mere blow-up, computer zooming or multihole collimator magnification does not truly enhance spatial resolution (Fig. 1.3). Pinhole scintigraphy appears ideal for establishing an improved piecemeal interpretation system at least for skeletal disorders. The level of spatial resolution and image contrast attained by pinhole scintigraphy has been shown to be of an order that is practically comparable to that of radiography both in normal and many pathological conditions (Bahk 1982, 1985, 1988, 1992; Bahk et al. 1987). For example, the small anatomical parts of a vertebra in adults and a hip joint in children can be distinctly discerned using this method. In an adult vertebra the pedicles, apophyseal joints, neural arches, and spinous process are clearly portrayed and in a pediatric (growing) hip the acetabulum, triradiate cartilage, capital femoral epiphysis and physis, and trochanters are regularly discerned (Chap. 4).

Clinically, pinhole scanning permits differential diagnosis, for example, among metastases, compression fractures, and infections of the spine (Bahk et al. 1987). The "pansy flower" sign of costosternoclavicular hyperostosis, a pathognomonic "bumpy" appearance of the long bones in infantile cortical hyperostosis, and the "hotter spot within hot area" sign of the nidus of osteoid osteoma are just a few examples of diagnoses that can be made by observing characteristic or pathognomonic signs of the individual diseases (Bahk et al. 1992; Kim et al. 1992).

To summarize, it appears that, used along with the holistic physicochemical data derived from whole-body, triple-phase, and spot ^{99m}Tc-MDP bone scans, the detailed anatomicometabolic profiles of skeletal disorders portrayed by pinhole scintigraphy enormously enhance diagnostic feasibility. In addition, it is indeed worth reemphasizing that the diagnostic accuracy of pinhole scintigraphy can be greatly sharpened if the scintigraphs are read side-by-side with radiographs—the common royal road to all image interpretations (Fig. 1.3D, E).

1.1 A History of Nuclear Bone Imaging

Conceptually, the nuclear imaging of bone can be dated from the mid-1920s when the notion of bone-seeking elements evolved from the clinical observation of radium-related osteomyelitis and bone necrosis (Blum 1924; Hoffman 1925). Shortly following successful isolation by the Curies, radium was processed to produce self-luminous materials to be painted on watch dials and instrument panels. During the painting of such radioactive materials with small brushes, workers habitually pointed the brush tip between their lips, and this resulted in chronic ingestion and subsequent bone deposition of hazardous radioactive elements, eventually causing deleterious effects (Hoffman 1925). The initial theory was that bone deposition of radium was caused by phagocytosis of the reticuloendothelial cells in bone marrow, but soon it was found that bone itself actively accumulates radioelements (Martland 1926). This was later confirmed by Treadwell et al. (1942) who showed by radioautography that ^{89}Sr, a beta-emitting bone-seeking element, was laid down in both normal and sarcoma tissues.

Two decades elapsed until, with the advent of the γ-counter, γ-scanner, and γ-emitting bone-seekers such as ^{47}Ca and ^{85}Sr, a new era of nuclear bone imaging was opened. In 1961 Gynning et al. detected the spinal metastases of breast cancer by external counting of the in-vivo distribution of ^{85}Sr. The data were displayed in a profile graph so that increased radioactivities in diseased vertebrae were indicated by an acute spike. In the same year, the first photographic scintigraph of bone showing selective accumulation of ^{85}Sr at the site of metastasis with fracture in the radius was published (Fig.