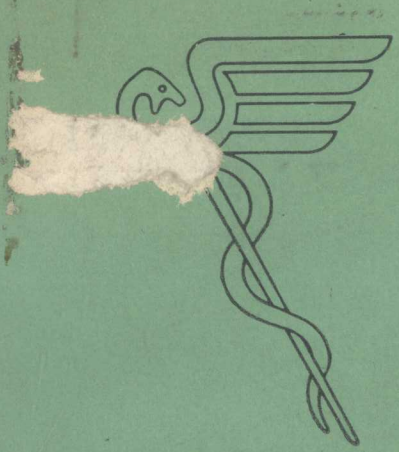

1976
YEAR BOOK OF
NUCLEAR MEDICINE

1976
YEAR BOOK OF
NUCLEAR MEDICINE

The YEAI

Nuclear Medicine

1976

Edited by

JAMES L. QUINN, III, M.D.
Professor of Radiology and Pathology, Northwestern University Medical School; Director of Nuclear Medicine, Northwestern Memorial Hospital, Chicago

YEAR BOOK MEDICAL PUBLISHERS, INC.
35 EAST WACKER DRIVE • CHICAGO

Printed in U.S.A.

Library of Congress Catalog Card Number: CD38-24

International Standard Book Number: 0-8151-6985-x

Table of Contents

The material covered in this volume represents literature reviewed up to July, 1975.

Introduction

The nuclear medicine "organ of the year" has to be the heart. Twenty-five papers on myocardial imaging were presented at the 1975 American Heart Association meeting. The arrogance and emotionalism displayed by the differing "hot spot" and "cold spot" camps are sure to retard the growth of this field and delay the much needed sorting out process.

Thought by many to be a threat to their livelihood, computerized axial tomographic scanning is but part of the exciting new renaissance in medical imaging that should see this method blend in with already established technics and help us realize our common goal of earlier, safer and more specific diagnosis. Our rallying cry should not be the passive "accept it because it's here" but rather, "accept it because it's good."

Dr. Michel Ter-Pogossian of Washington University has written an excellent and thought-provoking editorial for this volume, "The Challenge of Computerized Axial Tomography to Nuclear Medicine Imaging." You'll like it.

J. L. Q.

THE CHALLENGE OF COMPUTERIZED AXIAL TOMOGRAPHY TO NUCLEAR MEDICINE IMAGING

MICHEL M. TER-POGOSSIAN, PH.D.,

Professor of Radiation Sciences,
The Edward Mallinckrodt Institute of Radiology,
Washington University School of Medicine

In the past 3 years computerized axial tomography (CAT) has emerged as a new radiologic imaging modality for the study of the central nervous system. In this relatively short time, tens of thousands of patients have been studied by this procedure, and today there are over 200 CATs in use in the United States. Several significant comparative studies have already been completed for the assessment of the relative role of nuclear medicine brain scanning and CAT imaging. The conclusions of these studies are similar. Both modalities give a precision of about 90% in the localization of cerebral lesions, the effectiveness of the two procedures differs somewhat with the nature of the lesion imaged and the combined application of the two methods is superior to their separate use. However, the experience of most institutions where both nuclear and CAT scanning are used is that the latter provides more diagnostic information, such as visualization of the ventricles and sulci, zones of edema, identification of calcification, etc. As a result, the referring physician tends to select CAT imaging first. Because of the very high degree of success of this method, only a few of the patients thus prescreened require another radionuclidic scan, with a resulting decrease of referrals to this heretofore all important nuclear medicine procedure.

Shortly after the development of CAT devices dedicated to the head, whole body systems became available. At this time our experience with the body devices is limited, and no definite conclusions have been reached as to their

clinical usefulness. Yet the several hundred body examinations that have been performed by CAT devices already have clearly revealed, with astonishing resolution, disease in organs such as the pancreas, previously inaccessible to noninvasive procedures. In a number of cases, they have provided images of liver malignancies smaller than those previously identifiable by nuclear scanning. Furthermore, in the chest these devices reveal blood vessels (without the help of contrast materials), tumors and differences in density in the lungs with startling detail. It is relatively safe at this time to extrapolate the capabilities of body CAT devices to the visualization of the heart chambers using gating of the data acquisition system. Thus, although no thorough comparison between body CAT and nuclear medicine imaging has as yet been carried out, there seems to be little doubt that a number of nuclear medicine examinations might be challenged by this new technology.

Two other areas where nuclear medicine faces a formidable challenge from CAT is in competition for funds and, perhaps, more importantly, for brain power. The industrial development of CAT is characterized by an astonishingly fast rate of growth, which is unprecedented in the history of the development of medical instrumentation. Indeed, at this time, the financial magnitude of this field for a single company (EMI) is probably close to $100,000,000 a year, which represents a very substantial fraction of the total x-ray equipment market in the United States. It is also likely that this figure is very near to (if not in excess of) the total value of all nuclear medicine equipment sold yearly throughout the world. This situation is not surprising in light of the fact that in all probability the future market for CAT equipment is vastly greater than that for nuclear medicine equipment. The potential of the CAT market is implicitly acknowledged by the fact that between 10 and 20 industrial companies are now actively pursuing the development of such equipment. At least three of these companies are major suppliers of nuclear medicine equipment. Since research and development of new equipment are expensive, it is not unreasonable to assume that such research and development are being carried out with funds that otherwise might have been used in the field of nuclear medicine. A similar competition

for funds has also occurred in a number of hospitals where the purchase of additional or new nuclear medicine equipment has been postponed in favor of the purchase of a CAT device.

Perhaps a more serious challenge by CAT is taking place in the medical schools: The media have been lavishly generous (for excellent reasons) in the publicity that they have granted to computerized tomography and this instant recognition by the lay population of this exciting new modality did not remain unnoticed at the medical school level, where the imagination of a number of promising future physicians is naturally stimulated by CAT, perhaps at the expense of nuclear medicine.

The above observations clearly point out that in certain areas there is potential competition between established nuclear medicine imaging and computerized axial tomography. How significant this challenge is to the future of nuclear medicine imaging is certainly not clear at this time. What is clear, however, is that it is not negligible. Therefore it appears important to take stock of the strengths and weaknesses of nuclear medicine imaging with the purpose of identifying areas of judicious utilization of the former and correcting of the latter.

In the past few years nuclear medicine imaging has been strongly dominated by the synergistic use of the scintillation camera and ^{99m}Tc-labeled radiopharmaceuticals. This marriage has provided a superb tool for the imaging of most organs. Perhaps a measure of its success is the fact that this combination has endured with relatively minor changes over a period of almost a decade. In that time, both the scintillation camera and the radiopharmaceuticals used have undergone many improvements, but with no fundamental changes in the basic tool. The constancy of the camera-^{99m}Tc system reflects a high degree of maturity in the perfection of this instrument. But such maturity is often the first sign of old age. And whereas the combined use of the scintillation camera and of ^{99m}Tc has been extremely fruitful, it is also seriously stifling in the following respects:

1. The scintillation camera compresses the distribution of activity within a three-dimensional object into a two-dimensional image, and activity contained in tissues over-

lying and underlying the region of interest are superimposed on the image. This seriously interferes with the identification of the structures of interest.

2. The gamma radiation detected by the camera is attenuated, in general unaccountably, in the tissues interposed between the structure of interest and the crystal of the scintillation camera. In most cases, this renders quantitative studies difficult, if not impossible.

3. Technetium-99m is a nuclide of an element foreign to physiologic processes, and consequently its utilization does not permit the direct study of in vivo physiologic processes.

Although it is outside the scope of this discussion to elaborate on the consequences of the above limitations, it is well established that the physical weaknesses of nuclear medicine imaging limits it to gross differences in contrast, and that the very nature of ^{99m}Tc all but precludes direct in vivo metabolic studies.

Another serious weakness of nuclear medicine imaging is the resolution which is typically of the order of approximately 1.5 cm, and which is limited by collimator design (imposed by counting statistics), rather than by the inherent resolution of the image-forming device. Under such circumstances, one should not expect any appreciable gains in resolution unless higher doses of radiation to the patient become acceptable or unless the photons emitted isotopically by radionuclides can be utilized more efficiently than they are at present.

In assessing the relative strengths of nuclear medicine imaging and transmission CAT, it is important to consider the image-forming variables utilized in each procedure. In CAT the image is a representation of the spatial distribution of x-ray attenuation coefficients. Such an image is formed because x-rays are attenuated to a variable degree, and pathology is visualized only because it attenuates x-rays differently than normal structures: cerebral edema is imaged as a zone of lower density than normal brain because it contains more water and therefore attenuates x-rays less than surrounding normal structures.

Because of the extremely large photon fluxes available in this method of imaging, a high spatial resolution (of

the order of 1 mm) and an exquisite contrast resolution (of the order of 0.5%) are achieved.

In nuclear medicine the image is that of the distribution of a radionuclide, and structures that do not contain the radionuclide do not appear on the image at all. As a result, nuclear medicine imaging is potentially capable of providing considerably greater contrast than CAT. Furthermore, in nuclear medicine the same organ or structure can be imaged very differently depending on the radiopharmaceutical used. For example, a myocardial infarct may appear as a positive image after the administration of ^{99m}Tc-labeled pyrophosphate or as a negative shadow if myocardial perfusion is imaged by the injection of ionic thallium-201. Bone formation is superbly imaged by the use of bone-seeking radiopharmaceuticals, and a number of soft-tissue malignancies are revealed by their concentration of radioactive gallium. To summarize, transmission CAT technics provide us with images of morphologic differences between organs and pathologic structures as evidenced by differences in their attenuation of x-rays. The great strength of nuclear medicine imaging is that it images the distribution of a selected radiopharmaceutical, which in some cases does provide us with information about the function of the organ, and in many instances functional changes do precede morphologic alterations.

Whereas the above described strengths of nuclear medicine imaging are severely handicapped by the physical limitations of the scintillation camera-^{99m}Tc system, these limitations can be overcome. Indeed, the same method of image reconstruction that provides the third dimension in transmission CAT, can be applied in nuclear medicine and provide images unencumbered by the superimposition of activity from surrounding regions. The success of this approach has already been demonstrated in the laboratory and in a small number of clinical studies, although the unavailability of equipment has so far prevented its wide distribution. Also, the number of radionuclides potentially more useful for functional studies than ^{99m}Tc is steadily growing. Particularly, radionuclides akin to physiologic processes (such as carbon-11, nitrogen-13, oxygen-15 and fluorine-18 [incorporated in metabolic substrate analogues]

and others) offer the hope of following biochemical processes in vivo and regionally. In this area, certainly, nuclear medicine imaging is not challenged by transmission CAT.

In conclusion, it appears at this time, and by extrapolating from admittedly scanty information, that transmission CAT presents a formidable challenge to a major portion of nuclear medicine imaging procedures. Transmission CAT procedures, which include the visualization of lesions of the brain, liver, pancreas and lung, measure morphologic changes with an exquisite spatial and contrast resolution. On the other hand, the strength (potential and already realized) of nuclear medicine imaging lies in functional studies, such as assessment of myocardial damage, localization of bone and soft-tissue tumors, thyroid function, etc, where biochemical alterations precede morphologic changes in x-ray attenuation coefficients. This strength of nuclear medicine, however, can be best realized by the use of emission CAT and radiopharmaceuticals designed to identify function rather than the more conventional armamentarium.

Radiation Physics and Instrumentation

Positron-Emission Transaxial Tomograph for Nuclear Imaging (PETT). With current methods of imaging organs containing gamma-emitting nuclides, image contrast is severely reduced by activity in surrounding tissues and the effective resolution of some imaging devices is limited by that of the collimator. Michel M. Ter-Pogossian, Michael E. Phelps, Edward J. Hoffman and Nizar A. Mullani[1] (Washington Univ.) have developed an apparatus that provides high-contrast transaxial tomographic images of organs and structures containing positron-emitting nuclides. It improves contrast by minimizing interference from surrounding tissue through the use of annihilation coincidence detection and mathematical reconstruction of cross section images from a series of views obtained at a number of discrete angles. The resolution achieved is uniform and independent of the depth of the region examined.

The prototype PETT consists of 24 NaI (Tl) scintillation detectors in a hexagonal array, each opposing pair being connected in coincidence. A Fourier-based approach has been taken for transaxial tomographic section imaging. The reconstruction algorithm used was evaluated by performing reconstructions of computer-simulated phantom data. Rotation of the platform is computer controlled. Coincidence data from the detectors are recorded every 7.5 degrees.

In phantom studies the line-spread functions for the reconstructed image were in good agreement with the coincident detector response. The PETT image provided better recognition of the phantom structure than did a scintillation camera used in the conventional mode. Studies in dogs showed the distribution of equilibrated water in soft tissues, with the use of $H_2{}^{15}O$, liver activity with the use of $^{13}NH_3$,

(1) Radiology 114:89–98, January, 1975.

and the blood distribution in large vessels, the liver and spleen with the use of ^{11}CO-hemoglobin.

Positron-emission transaxial tomographic reconstruction permits the visualization of structures not ordinarily perceptible with conventional imaging devices. There are a number of positron-emitting nuclides with characteristics favorable for use in nuclear medicine. Use of this approach opens new areas of exploration in nuclear medicine by removing some of the restrictive barriers imposed by present-day technics, instrumentation and limited choice of radionuclides.

► [Excellent instrument advance is presented. We are eagerly awaiting the initial clinical results with this equipment. A second, more complete morsel follows.—J.L.Q.] ◄

Application of Annihilation Coincidence Detection to Transaxial Reconstruction Tomography is discussed by Michael E. Phelps, Edward J. Hoffman, Nizar A. Mullani and Michel M. Ter-Pogossian[2] (Washington Univ.). The EMI scanner uses a high-contrast, narrow x-ray beam-scanning technic and removes the superimposition of information with a mathematical algorithm to reconstruct the cross-sectional distribution of attenuation coefficients. The technic has yielded tomographic images of the brain that contain information unattainable by conventional radiographic methods. Annihilation coincidence detection (ACD) of positron-emitting nuclides has now been applied to transaxial reconstruction tomography. A prototype positron emission transaxial tomograph (PETT) with ACD was used. The simultaneous detection of two 511-kev photons from positron annihilation establishes an "electronic" collimation. Coincidence detection of annihilation radiation provides a means of detecting nuclides with a depth-independent sensitivity. The prototype PETT consists of 24 NaI(Tl) scintillation detectors in a hexagonal array. Computer-simulated phantom data were reconstructed with attenuation correction.

In phantom studies comparing the PETT and scintillation camera, with use of ^{64}Cu and ^{99m}Tc, the reconstructed image from the PETT gave an excellent reproduction of the cross-sectional distribution of activity in the phantom, whereas the camera images were ambiguous. In dog studies with

(2) J. Nucl. Med. 16:210–224, March, 1975.