The Decline and Fall of the Rectilinear Scanner: Nuclear Medicine Instrumentation 1970–1995

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Key Words: nuclear medicine instrumentation; history

J Nucl Med Technol 1995; 23:16S–20S

The chicken and egg question can readily be applied to the development of nuclear medicine instruments. Do new instruments appear on the scene because procedures require them? Or do new instruments appear first and then procedures are developed, stimulated by a new instrument's potential? 1970 to 1995 was a very exciting era for the development of electronic instruments. Vacuum tubes were replaced by transistors, whose short life in turn led to hybrid chips, integrated circuits and finally to microprocessors.

Progress in nuclear medicine during this period was much slower. Many exciting developments occurred earlier in the 1950s. The clinical scintillation counter (*1*), the gamma ray spectrometer (*2*), the rectilinear scanner (*3*) and the scintillation camera (*4*) had all been invented by the start of the 1970s.

NUCLEAR MEDICINE IN THE 1970s

In 1973 the American College of Radiology, through their Commission on Nuclear Medicine chaired by James L. Quinn, initiated a survey of all active nuclear medicine sections in 2,534 institutions in the United States. These were identified from a listing of all hospitals holding Atomic Energy Commission (AEC) licenses (forerunner of the Nuclear Regulatory Commission, or NRC) and all hospitals registered with the American Hospital Association having radioisotope facilities. They succeeded in getting 1,415 responses—a very high return of 56% (*5*). Using a correction factor to account for the remaining 44%, they determined that 6,323,839 diagnostic nuclear medicine procedures were performed in 1972.

The breakdown of the total procedures into categories is shown in Table 1, including therapy procedures. As illustrated, nuclear medicine was not a dominant imaging discipline. Of scanning procedures, 62% involved the brain. Rectilinear scanners dominated the scintillation camera by a factor of almost 2:1. The only procedure at that time that required a camera was the fast blood-flow study that often preceded static brain images.

Nuclear medicine was in a precarious position, as many institutions found out in the next few years. The advent of Hounsfield's computed axial tomography (CAT) (*6*) soon replaced the most popular study, the brain scan. The result of the introduction of the CT scanner on the reduction of radionuclide brain scans in one institution is shown in Figure 1.

RISE OF THE SCINTILLATION CAMERA

It was realized, in retrospect, that what appeared to be a devastating loss was actually a boon to nuclear medicine. With the most important procedure, brain scanning, disappearing fast, the field of nuclear medicine was wide open to welcome new radiopharmaceuticals, new instruments and new procedures emphasizing the functional aspect of nuclear medicine techniques.

The decline of brain scanning carried with it the slow decline of the rectilinear scanner. Most of the scanning procedures that remained–liver and spleen, lung, bone or whole-body, kidney–involved regions that were a little bit larger than the conventional 25-cm diameter scintillation camera. Rectilinear scanners were manufactured with larger and larger detectors, chiefly to allow faster scanning of large areas and to maintain good detection efficiency at higher photon energies. Bone

TABLE 1
Total Number of Nuclear Medicine Procedures Performed in 1973 in the US*

In vitro diagnosis	2,984,071
Diagnostic imaging procedures	2,598,065
Diagnostic functional studies	741,703
Therapy	31,763
Total	6,355,602

*Data from Quinn (*5*).

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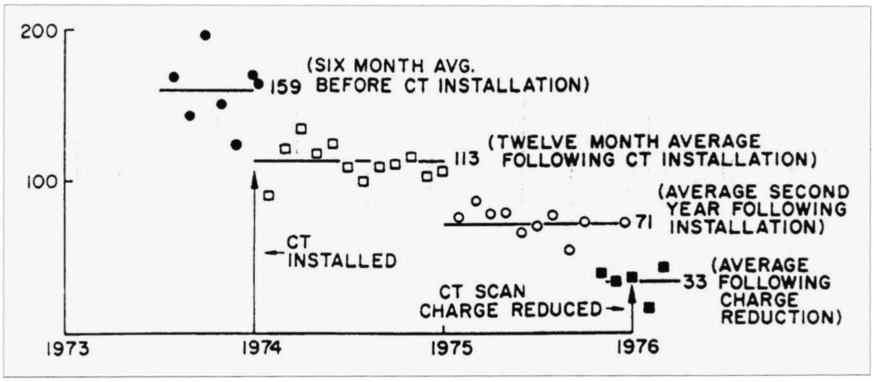

FIGURE 1. Decrease in number of patients referred for radionuclide brain scans following the introduction and continued use of CAT.

scanning, performed with ^{85}Sr and ^{89m}Sr, required large, thick detectors for these high-energy emitters that were administered only in small amounts of activity. The development of scanners reached its peak by 1972, but cameras were just beginning a series of vital performance improvements, driven not only by competition, but by the need for better energy and spatial resolution and for a more uniform field of view.

Perhaps the most profound impact on camera development came from the changes that were taking place in radiopharmaceuticals. The radionuclide ^{99m}Tc came into use in the early 1960s because of its radiation properties: a 6-hr half life and a single-gamma photon energy of 140 keV. First used as sodium pertechnetate, or $Na^{99m}TcO_4$, ^{99m}Tc turned out to be somewhat useful in brain scanning and in measuring early thyroid trapping function. As time went on, technetium chemistry became better understood and more useful ^{99m}Tc compounds emerged.

In 1971 ^{99m}Tc-pyrophosphate was introduced for bone scanning. The radiopharmaceutical scene and the future of scanning instrumentation were irreversibly altered. Even the thin detectors of current scintillation cameras could capture the 140-keV photons of ^{99m}Tc with good efficiency, making camera detectors even more efficient than those of rectilinear scanners. Bone, lung and renal scanning with ^{99m}Tc compounds came into greater use. As a result of increased usage, improved camera performance was accelerated.

This situation set the scene for the introduction of the 40-cm camera in 1975 (*7,8*). Prior to that, the larger fields were obtained by placing a divergent collimator on the standard field-of-view cameras. The divergent collimator had holes that were increasingly angled outward from the center of the crystal to the periphery. It did increase the field of view, but at a loss of resolution that was unacceptable (Fig. 2).

Now the large field-of-view (LFOV) cameras had essentially taken over as the dominant imaging unit in nuclear medicine (*9*). The detector heads ranged from 39-cm circular diameter to a rectangular dimension of 44.5 cm by 66 cm (Fig. 3). These units increased the throughput of lung, liver and kidney imaging and were well-adapted, especially as a dual anterior and posterior scanning system, to whole-body bone scanning.

The increase in liver, lung and bone scanning helped offset the loss of brain scanning, but it was not until the late '70s that a major new market emerged. Early attempts to perform myocardial scanning with potassium analogs, such as ^{42}K, ^{43}K, ^{84}Rb, ^{86}Rb and ^{129}Cs, were not entirely satisfactory. It was left to the appearance of ^{201}Tl (*10*) to inaugurate a new era of myocardial imaging. It was quickly recognized that if planar ^{201}Tl myocardial imaging was good, single-photon emission computed tomography (SPECT) myocardial imaging was even better.

It was also recognized that the resolution performance of scintillation cameras with the low-energy emissions of ^{201}Tl needed improvement, particularly for SPECT. As a result, a new round of performance enhancements ensued.

THE SPECTRE OF SPECT

The abbreviation SPECT is used instead of SPET to distinguish the transaxial technique, which requires a computer, from the earlier single-photon emission tomographic techniques which involved longitudinal scanning but no computer. These systems

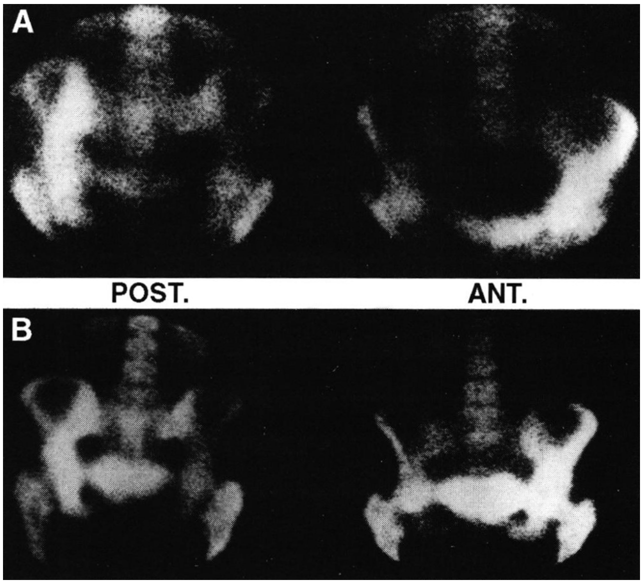

FIGURE 2. Comparison of pelvic images with (A) standard field-of-view camera with diverging collimator and (B) large field-of-view camera with high-efficiency parallel-hole collimator. Imaging time was threefold longer with the standard camera. (Figure courtesy MacIntyre et al. (*9*)).

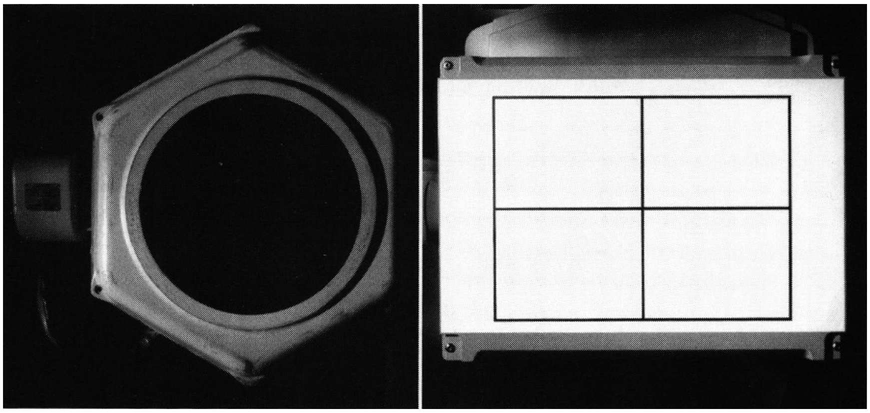

FIGURE 3. (A) An early large field-of-view camera (Searle, Siemens, Hoffman Estates, IL) with a diameter of 39 cm. (B) A recent rectangular LFOV design with dimensions of 44.5 cm by 66 cm (Trionix, Twinsburg, OH). (Figure courtesy MacIntyre et al. (*9*)).

used multiple pinholes or angled rotating collimators by which a plane at a certain focal distance from the collimators would give the sharpest image, with planes above or below being blurred. Developments with these systems were intense but the transaxial technique with a computer was soon welcomed.

Although early cardiac SPECT was accomplished by using a stationary detector with the patient rotating in front of the detector, it was realized that a rotating detector would be much more practical. This demand put new requirements on camera design. Transaxial operation required a greater precision of movement to avoid appreciable deviation of the center of rotation. Uniformity was also a primary requisite so that the cameras of this period were continually being improved with stronger gantries and greater attention to uniformity correction techniques.

Dual-headed cameras made their appearance at this time and were useful in cardiac SPECT to obtain a 360° data acquisition (*11*) in half the time of a single-headed camera with 360° data acquisition. The dual-head did not become popular because most users accepted the distortion of the 180° acquisition rotation (*12*). These users obtained scans in half the time of the single-headed, 360° camera rotation without the need to keep the characteristics of the second head balanced with the first head.

It was not until the triple-headed camera was commercially available in 1988 that the multi-headed detector approach became well accepted. This system had the advantages of close placement to the tomographic target as well as the threefold increase in sensitivity. In spite of the dire warnings of the single-detector manufacturers, the center of rotation was stable for the three heads, as well as the similarity of characteristics of the detectors.

By this time, dual-headed cameras were well accepted for taking simultaneous independent views, such as anterior and posterior whole-body bone images or anterior and posterior lung images. But when used in SPECT, it was necessary that both heads have the same center of rotation, the same field of view and the same sensitivity. The three-headed cameras of late 1988 to 1990 accomplished these controls with computer-monitored corrections. The dual-headed camera of 1980 for the most part depended on operators using analog controls to balance the center of rotation and extent of field on the x and y axes. While attention to these details enabled some institutions to use the dual-headed SPECT units for 15 yr, many of the operators were not willing to spend the time and effort. The success of the three-headed camera encouraged the dual-headed cameras to return in 1989, with computer control much more common.

CONTROL OF INSTRUMENTATION BY THE TECHNOLOGIST

The demands on and responsibilities of the nuclear medicine technologist have been continually changing since the time of the rectilinear scanner.

The rectilinear scanner brought many features of imaging to the attention of the participants. It demonstrated the value of the gamma ray spectrometer in reducing the effect of scatter, it showed the advantages and pitfalls of various collimator configurations, it explained the need and execution of contrast enhancement and it explained the theory and practice of count-rate density.

User-friendly the rectilinear scanner was not. Or perhaps it was too friendly. The rectilinear scanner offered an infinite variety of ways to obtain a specific count density. One could change the collimator, change the scan speed, change the line spacing or change the time of acquisition. The result is that in many institutions, the use of the rectilinear scanner became an art. In some cases, the operation was arbitrarily decided by the physician in charge or by an engineer or physicist. The production of rectilinear scanners ceased sometime around 1976.

When the scintillation camera finally took over, technologist training in imaging could finally become standardized. For example, a general purpose collimator from one manufacturer was almost the same as a general purpose collimator from any other company. Procedures also became reasonably standardized, physicians were weaned away from operating their own imaging devices and technologists took over. Technologists also assumed their rightful responsibility for quality control of the imaging systems.

In 1973 the College of American Pathologists began distributing organ-simulated emission phantoms for proficiency testing. The results of these early tests showed that participants using scintillation cameras had better success than the rectilinear scanner operators.

In 1975, the Society of Nuclear Medicine initiated its comparative survey of several types of transmission resolution phantoms expressly for cameras to measure uniformity, linearity and resolution. The recommendations suggested that uniformity measurements should be done every day and resolution and/or linearity measurements be done every week. This responsibility was assumed by the technologist but it was not until several years later, when the Joint Commission on Accreditation of Hospitals (now called the Joint Commission on Accreditation of Healthcare Organizations) required these measurements to be performed, that the quality control practice really was implemented.

ADDING A COMPUTER TO THE CAMERA

It was just as well that the quality control procedures were accepted because imaging procedures were getting more and more complex. With the advent of the multiple-gated ejection fraction (*13*) in 1975 and cardiac SPECT in 1980, the computer was brought from the remote off-line position, where magnetic tapes were fed to it regularly, into the imaging room for on-line acquisition and analysis.

Both of these studies are cardiac procedures and, together with a small number of first-pass cardiac flow studies, made nuclear cardiology account for almost 40% of all imaging procedures performed in nuclear medicine in 1986 (*14,15*). The loss of brain scanning in the '70s was finally compensated.

The prominence of these studies meant that computers had to be part of every nuclear medicine laboratory. The change in instrumentation in the decade of the '80s progressed from buying a camera *and* buying a computer to buying a camera *with* computer. In the early part of this decade, there were several computer systems that would interface with cameras and perform nuclear medicine procedures along with other analyses. By the end of the decade, however, it was customary that each manufacturer would have a specific computer interfaced to the camera, along with its own software.

This development ensured compatibility between camera and computer, but software and displays differed greatly among various manufacturers. It became increasingly difficult for users to change or install their own software. Thus, the procedures which became more similar in the early days of the camera now became more disparate.

INSTRUMENTATION 1990–1995: THE APPEARANCE OF CLINICAL PET

Position emission tomography (PET) was not a 1990 development, but actually had been reported in 1975 (*16*). What evolved during this recent period was the appearance of PET systems that were used exclusively for patient care. In addition, there were many more sites that were combining some clinical studies with their regular research projects.

Today clinical studies are being performed even though, as of January 1995, only two radiopharmaceuticals, ^{82}Rb and ^{18}F-fluorodeoxyglucose have been recognized by the FDA. Rubidium-82 was approved in December 1989 and ^{18}F-FDG in August 1994 (*17*). Myocardial perfusion images are obtained with ^{82}Rb. Fluorine-18-FDG is used for many studies, most commonly brain imaging, myocardial viability and various oncologic studies.

In some instances, the clinical application of PET has resulted in the incorporation of these studies into the regular operation of nuclear medicine. In the Cleveland Clinic, for example, there is no PET chemist, PET physicist or PET technologist. All of these duties have been assumed by the existing nuclear medicine personnel. No technologists are assigned solely to the PET operation, instead many technologists rotate through the service as well as performing other regularly scheduled duties of nuclear medicine.

AFTER 1995, WHAT?

Instrumentation in nuclear medicine will probably not change radically in the near future. After all, the three-headed camera is over seven years old and cameras that are 20 yrs old are still in operation. What came in with the three-headed camera was a new word and a new concern—throughput. Throughput means how many patients can be handled in a nuclear medicine department given a certain number of cameras, computers and, last but not least, technologists. The time spent on the patient by all three of these components is the dominant factor in the cost of the procedure.

What is expected in the future will be a number of devices that will make the technologists' role in imaging procedures much easier. These innovations are not stimulated by humanitarian reasons, but by the desire to decrease the technologist's time spent on the technical aspects of imaging.

Thus, we are now seeing devices that will automatically contour the movement of the camera to the patient's body configuration. It is hoped that, with the camera closer to the patient, a better image will be recorded. What is more important is that the technologist's time required for setting up the patient will be greatly reduced. With the economics of imaging in its present state, it is expected that advances in instrumentation will continue to improve in these directions in order to increase throughput.

Improvements in resolution are still welcome and will be expected with the truly digital camera. The collimator is still the biggest factor in system resolution but no advances are expected in that area since Oak Ridge discontinued their gold collimator line.

What is sadly lacking in present nuclear medicine instrumentation is a greater similarity in the final product. Everyone expects a chest x-ray to show the same results regardless of which manufacturer has made the x-ray machine. This is not true of nuclear medicine's imaging devices.

The various ejection fractions reported from measuring a simple mechanical phantom at a steady 60-cycle beat is shown in Figure 4. This figure illustrates the spread of results from 200 participants using cameras and computers from nine different manufacturers. The standard deviation was ±6.3% for a 57% average value, but values as low as 38% and as high as 72% have been reported.

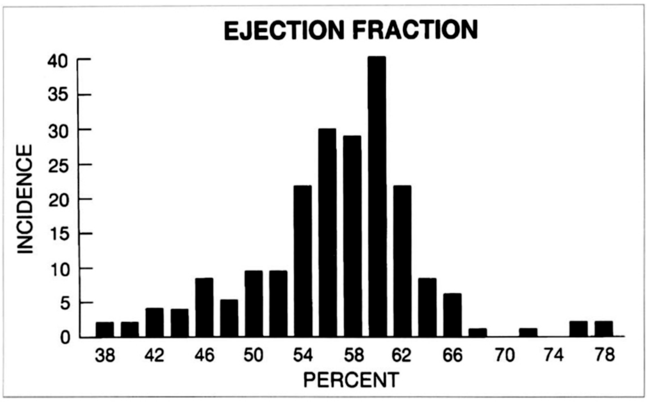

FIGURE 4. Response curve from the results of 200 measurements of left ventricular ejection fraction. The FWHM of the Gaussian curve was 10% with ejection fractions varying from 52% to 62%. The standard deviation was ±6.3%. Note the widespread response to the calibrated value of 57%.

What is hoped for in the future is a reconciliation of the various characteristics displayed by individual systems. Results from one manufacturer's system should be reasonably comparable with results from another.

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