CONF-8602146--Exc.

American College of Nuclear Physicians
Annual Meeting

West Palm Beach, Florida

February 26 - March 2, 1986

I. Title of Symposium:

PEDIATRIC NUCLEAR MEDICINE - Sunday, March 2, 1986

II. Sponsoring Organization:

American College of Nuclear Physicians
Suite 700
1101 Connecticut Avenue, N.W.
Washington, D.C. 20036

CONF-8602146--Exc.

DE87 014167

III. Goals:

This symposium will present the latest techniques and approaches to the proper medical application of radionuclides in pediatrics. An expert faculty, comprised of specialists in the field of pediatric nuclear medicine, will discuss the major indications as well as the advantages and potential hazards of nuclear medicine procedures compared to other diagnostic modalities. Tape recordings of the presentations will be available for wide distribution among both attendees and those unable to attend.

IV. Objectives of Symposium:

Nuclear Medicine studies have primarily been carried out in adult patients in the past, and the administration of radionuclides to children has often been discouraged, thus most nuclear medicine research has been done in adult patients. In recent years, newer radiopharmaceuticals labeled with technetium-99m and other short-lived radionuclides with relatively favorable radiation characteristics have permitted a variety of diagnostic studies that are very useful clinically and carry a substantially lower radiation burden than many comparable X-ray studies. This new battery of nuclear medicine procedures is now widely available for diagnosis and management of pediatric patients. Many recent research studies in children have yielded data concerning the effacacy of these procedures, and current recommendations will be presented by those involved in conducting such studies.

A number of special considerations must be heeded in carrying out pediatric nuclear medicine studies, including radiopharmaceutical dose, scintigraphic equipment, positioning and patient comfort. The session has been designed to emphasize those aspects of nuclear medicine that maximize the information yield from the use of [illegible] nuclides in children while minimizing risk to young patients. Methods to reduce anxiety and emotional stress in pediatric patients will also be discussed.

There are many medical conditions that are peculiar to children, such as congenital anomalies and a variety of tumors, in which nuclear medicine offers clinically useful studies that give more accurate information with a lower radiation dose compared to X-ray studies. A number of clinical conditions have received much attention lately, such as biliary atresia, in which hepatobiliary scanning is of great value, and the battered-child syndrome, in which skeletal scintigraphy gives much information. Many current nuclear medicine studies are more frequently indicated in children than adults, such as radionuclide cystography and scintigraphic detection of Meckel's diverticuli. Those studies specifically indicated in children will be emphasized.

In the current climate of cost-containment, safe, cost-effective diagnostic studies are desireable in all patient groups, thus pediatric nuclear medicine studies should be encouraged where appropriate. The purpose of the session will be to acquaint both practicing nuclear physicians and pediatricians with the wide range, advantages and indications for diagnostic nuclear medicine studies in pediatric patients. The session will emphasize the major organ systems and common disorders that are reliably assessed with nuclear medicine studies.

V. Summary:

Many advances in nuclear medicine as well as recent changes in the diagnostic approach to patients have created the need to assess the current role of nuclear medicine in the care and management of pediatric patients. This symposium, comprised of several experts in the field of pediatric nuclear medicine, will present the latest technology and approaches to the radionuclide assessment of childhood disorders. This session is expected to reach a large, national audience of both nuclear medicine physicians and pediatricians, in part because it has been scheduled to take place on the day immediately preceding the start of the mid-winter Conjoint Meeting of the Society of Nuclear Medicine in the same city. In addition, tape recordings will be available for wide distribution to reach those unable to attend.

Following are papers presented by Drs. James J. Conway, Joe C. Leonard, Philip Matin, John H. Miller and Aslam R. Siddiqui.

Andrew M. Keenan, M.D.
Moderator
Pediatric Nuclear Medicine Program

PEDIATRIC NUCLEAR MEDICINE:
PRACTICAL CONSIDERATIONS AND SPECIALIZED STUDIES

JAMES J. CONWAY, M.D.

HISTORICAL VIGNETTE:

The initial application of radioisotopes in children was to study thyroid diseases. The development of rectilinear imaging had minimum impact upon the growth of pediatric nuclear medicine because of the time constraints which limited its usefulness in the restless child. The major stimulus for the growth and development of pediatric nuclear medicine was the development of the gamma camera and suitable radiopharmaceuticals of short half-life. Among these were ^{99m}Tc pertechnetate introduced by Paul Harper at the University of Chicago and ^{123}I sodium iodide introduced by William Myers at the University of Ohio. Further stimulus occurred with the development of ^{99m}Tc sulfur colloid kits and the introduction of ^{99m}Tc phosphate compounds by Subramanian in New York. The early gamma cameras were small in size but were suitable for the study of entire organs in small pediatric patients. The early pioneers in the introduction of radionuclide imaging with hospitals were Mel Tefft at the Boston Children's Hospital, Larry Samuels at the Columbus Children's Hospital and James Conway at the Children's Memorial Hospital in Chicago. The development of pediatric nuclear medicine was further stimulated by Ted Treves at the Boston Children's Medical Center and David Gilday at the Hospital for Sick Children in Toronto, Ontario, Canada.

A number of impediments inhibited the growth and development of pediatric nuclear medicine. Included among these impediments were; the limitations of early instrumentation designed for primary use in adults; the adoption of strict Regulatory requirements for the use of radioisotopes in children by the Nuclear Regulatory Commission and the Food and Drug Administration; the lack of clinical trials in pediatric patients for new drug applications; the public attitude (Radiation Hysteria); and the physicians conservative approach to the use of any

radiation in children. Finally, there was and continues to be a lack of training programs for physicians and technologists in the application of radioisotopes in children.

The nuclear medicine community has attempted to overcome these impediments through education via scientific presentations, seminars and books on pediatric nuclear medicine. Important in this effort was the Nuclear Chicago Corp. of Chicago through their early nuclear medicine seminars, the Johns Hopkins Institutions seminar by Henry Wagner and A. Everett James and their subsequent publication of the first book on pediatric nuclear medicine and the 1973 seminar from the Children's Hospital of San Francisco with the publication of its proceedings by Hirsch Handmaker. Subsequent founding of the Pediatric Nuclear Medicine Club in 1974 insured a continuing growth and development of interest in the field of Pediatric Nuclear Medicine.

PRACTICE PHILOSOPHY:

Pediatric nuclear medicine must be approached as a consultative service. All available information should be utilized, including examining the child, talking with the parents, reviewing the patient records, other imaging studies and discussing the problem with the referring physician. Studies should be tailored to answer specific questions of the referring physician. Equipment must be adapted to the patient's needs. The "limited examination" has a very limited role in pediatric nuclear medicine.

The increased sensitivity but low specificity rendered nuclear medicine techniques ideal for screening patients with suspected disorders. As clinical acumen increased, specificity improved and nuclear medicine studies became more directed toward specific problem solving.

RADIATION PHILOSOPHY:

The correct utilization of nuclear medicine techniques in children requires a philosophy regarding the use of radiation in children. These include no unnecessary radiation, risk vs. benefit considerations, and complete understanding of the comparative value of nuclear medicine techniques in relationship to other imaging techniques. Pediatric studies are more costly due to the need for extra personnel, time, equipment and radiopharmaceuticals. A good study, however, is more cost effective. Important considerations for the referring physician are availability which provides night or weekend coverage, and the economic efficiencies of nuclear medicine as related to other studies.

TECHNIQUE CONSIDERATIONS

Pediatric nuclear medicine is not simply the study of smaller people with radioisotopes. The pathologic disorders, pathophysiology and clinical presentation of "comparable diseases" in adults are different in children. There is the tendency to study congenital anomalies, trauma, infection and neoplasia peculiar to the pediatric population. There is less concern with acquired disorders such as arteriosclerotic vascular disease.

ADMINISTERED DOSE:

One of the most frequent questions asked is what administered dose should one use for a specific study and age group. This information is available from multiple sources including the package insert which accompanies the radiopharmaceutical. Such information is also available from multiple publications and text books. Surveys conducted by the FDA in the mid 1970's suggested that overdosing of children was a problem for consideration. However, these studies were based on limited numbers of institutions and pediatric patients. My own experience indicates that there is an appropriate concern on the

part of most practitioners and if anything, many pediatric studies were being conducted with insufficient radioactivity for adequate imaging. A recent survey conducted by the FDA has not been fully analyzed but a cursory review of the data suggests that there is not a major problem of significant overdosing of pediatric patients in the community hospital.

The traditional method of determining administered dose is based upon scaled down versions of dose per weight, dose per surface area, fixed doses, combinations of dose per weight and surface area and finally, the empiric method. All of these methods produce dose ranges which are similar but there are minimum and maximum levels at the ends of the weight ranges and peculiarities such as fixed dosages for specific studies such as radionuclide cystography. One must always consider risk vs. benefit in the determination of administered dose and in some instances the maximum limits can be exceeded due to the malignant nature of the patient's disease, the patient's condition, cooperativeness or other factors which determine the necessity of the study. These instances are exceptions and must be addressed on an individual basis by the nuclear physician. Administered dose limits are guidelines which are provided by the Food and Drug Administration, however, one must adhere to their license requirements as specified by the Nuclear Regulatory Commission. The final decision as to what constitutes an appropriate administered dose is most dependent upon the technical factors involved in image production. Specifically, one must consider the information desired, the type of equipment available, the image generation time at the specific interval following the radiopharmaceutical injection and the cooperativeness of the patient. In general, delayed imaging, total body imaging with moving tables, pinhole or magnification imaging require greater administered doses than multiple spot images. These determinations can only be developed within ones own institution. Therefore, the various formulae serve as guidelines for the initial utilization of a radiopharmaceutical and one must expect modifications of that administered dose depending upon the individual situation.

THE LIMITED STUDY:

Once a radiopharmaceutical is injected into a child, every effort should be made to derive an appropriate answer to the referring physician's questions. Because of economic considerations, the "put through" of many departments limits the number of images. Additional information, however, is available particularly in bone scintigraphy when one considers angiographic, blood pool and delayed static imaging which encompasses the entire skeletal system. Examples considered to be errors caused by limited studies leading to malpractice are presented for discussion. Of specific concern are the limited skeletal studies in patients who already have neoplastic disease.

PATIENT POSITIONING:

Perhaps the most common source for error in pediatric studies is poor positioning. Rotation of the cylinder shaped infant and child occurs much more readily than in the ovate shaped adult. Misinterpretations of "shine through" of rib endings, and rotation of the hips or extremity views have resulted in misinterpretation as well as failed interpretation. Almost invariably such failures stimulate litigation against the nuclear physician supervising and interpreting the study.

MOTION:

The management of uncooperative children is perceived as a significant problem in the community hospital. Motionograms are common and yet the means of immobilization and sedation in pediatric nuclear medicine have been well-documented for almost 20 years. A brief discussion of appropriate sedatives and immobilization techniques with the technique of immobilization by wrapping should be part and parcel of the armamentarium of the nuclear physician practicing on pediatric patients.

SPECIALIZED STUDIES

With time permitting, topics not included in the remainder of the program and which have recently stimulated our interest at the Children's Memorial Hospital are presented. Among the topics to be discussed:

1. Specific scintigraphic signs of brain death in the pediatric patient.

2. A scintigraphic classification of Legg-Calve-Perthes disease.

3. Scintigraphic imaging in the hypothyroid neonate.

4. The scintigraphic diagnosis of chondrolysis.

5. A miscellanea of interesting pediatric conditions.

PEDIATRIC UROLOGIC EVALUATION

Joe C. Leonard, M.D.
Chief, Nuclear Medicine Service
Oklahoma Children's Memorial Hospital

A. Radiopharmaceuticals

DTPA is utilized when functional parameters, such as GFR and lasix response are to be monitored.

Gluceptate is utilized when morphologic detail is desired, as in pyelonephritis and renal masses. Functional data can be obtained, since the majority is cleared by GFR. On report of its use to measure GFR, using the Gates' method, has been published. (1)

DMSA is excellent for cortical imaging. I prefer gluceptate because of combined functional data.

B. Renal imaging and the IVP

The IVP is clinically "more comfortable"

What is accepted as valid for the IVP, because of clinical experience" must be proven for renal imaging.

No allergic reactions to renal imaging agents.

Renal imaging is more costly, but there is considerably more objective available.

Additional views don't increase the radiation exposure with renal imaging.

C. Technique

1-3 mCi 99mTc-DTPA or gluceptate is given intravenously. Imaging is carried out for a minimum of 22 minutes. Lasix can be given whenever pelvocalyceal filling is noted. I routinely give it at 18-22 minutes and continue imaging until 40 minutes.

Differential renal function

$$\text{Lt.kidney cts} - \left(\frac{\text{(Lt.bkg.cts} * \frac{\text{Lt.kidney pixels}}{\text{Lt. bkg pixels}})}{\text{(Bkg.corr.Lt.kidney)} + \text{Bkg.corr.Rt.kidney)}} \right) * 100$$

GFR is calculated using Gates' method (2).

Background is placed inferior to the kidney, versus laterally.

The calculated value may be corrected for body surface area because of differences in volume of distribution.

D. Applications

1. Newborn

Flank mass

Ultrasound should be the initial exam. A normal US, however, doesn't mean a normal functioning kidney.

Hydronephrosis and multicystic dysplastic kidney are the most common flank masses in this age group. Hydronephrosis will generally show a rim of functional cortex on images during the first 20 minutes. Multicystic kidneys usually produce a photopenic area without cortical visualization. Delayed imaging may reveal "islands" of cortical tissue and some activity within the cyst. Infants need to be evaluated to exclude involvement of the contralateral kidney.

Mesoblastic nephroma is generally diagnosed under the age of two years. On gluceptate imaging, the mass may show very intense localization initially with mass effect noted later. Wilms' tumor rare below the age of two years.

Neuroblastoma and adrenal hemorrhage may produce photopenic defects superior to the kidney.

Screening of neonates with GI tract anomalies detects GU tract pathology in up to 30%.

Anuria and/or decreased function

Renal vein thrombosis is associated with decreased to absent function. US frequently shows enlargement, but may be normal.

ATN is generally associated with prematurity and dehydration or other insult. Function is decreased bilaterally and activity is not seen in the pelvocalyceal system..

Dysplastic kidney are small with poor uptake. The stomach bubble may be confused with a renal or suprarenal mass.

Obstruction - UVJ, UPJ and posterior uretheral valves may all occur in this age group. Lasix is frequently helpful and only valves will present with an enlarged bladder.

2. Lasix renography (3)

Use 0.5 -1.0 mg/kg

Patient preparation requires that they be well-hydrated, have satisfactory renal function in the kidney(s) in question to respond to lasix. Some people recommend that all patients be catheterized to avoid overdistention of the bladder (4). I routinely catherize any patient with a neurogenic bladder and leave the catheter in place in any patient with a prior cystogram. All other patients who are able to void, are asked to empty their bladder before starting any renal examination.

Analog images may not reflect emptying due to loss of gray scale associated with film intensity settings.

Post-operative evaluation is necessary because these systems generally remain dilated, even after relief of the obstruction. Lasix may be given each time or reserved until there is evidence of reduced function.

3. Inflammatory processes

Abscesses cannot be differentiated from other mass lesions with gluceptate. Ultrasound and gallium can be very helpful in these patients.

Pyelonephritis results in decreased tubular localization and produces striking images, as compared to the IVP which is usually normal.

E. Cystography (5)

Technique

The fluid level is placed 1 meter above the table in line with a manometer whose top is at 50 cm. 100-200 uCi of 99m-TcO4 is introduced into the catheter followed by saline to capacity.

The pressure and volume instilled are noted if reflux is seen on the persistence scope.

Bladder filling is stopped when there is; a) bilateral reflux, b) patient discomfort, c) the volume (cc) is greater than the age(in years) plus two ounces(6) or greater than 10cc/kg for patients less than one year of age or d) there is leakage around the catheter.

The end volume and pressure are recorded.

The catheter is left in place if renal imaging is to be done. It is clamped for the first 15 minutes to evaluate upper tract emptying as the bladder fills.

Findings

Reflux when present is into the pelvocalyceal system. If lower, consider bladder augmentation or diverticulum.

The volume refluxed can be calculated

Small bladder capacity and associated increased pressure may indicate neurogenic dysfunction and be an indication for urodynamics and vesicostomy.

References

1. Long SE, et al. Tc-99m glucoheptonate estimation of glomerular filtration. Clin Nucl Med 9:271, 1984.

2. Gates GF. Split renal function using Tc-99m DTPA. A rapid technique for determining differential renal glomerular function. Clin Nucl Med 8: 400, 1983.

3. Koff SA, et al Diuretic radionuclide urograph: A non-invasive method for evaluating nephroureteral dilatation. J Urol 122:451, 1979.

4. Kass EJ, et al Comparison of the diuretic renogram and the pressure perfusion study in children. J Urol 134:92, 1985.

5. Conway JJ, et al. Detection of vesicoureteral reflux with radionuclide cystography. AJR 115: 720, 1972.

6. Koff SA. Estimating bladder capacity in children. Urology 21:248, 1983.

BONE SCANNING OF TRAUMA AND BENIGN CONDITIONS

Philip Matin, M.D.

Characteristics of Benign and Malignant Lesions

One of the more common requests in a clinical nuclear medicine practice is to determine whether an ambiguous skeletal lesion detected on X-ray is benign or malignant. Although there is no way to establish an exact differentiation without a biopsy, there are certain scintigraphic characteristics that allow us to make a reasonable decision about the nature of a bone abnormality.

Three primary features of bone scan abnormalities can be used to guide us toward this decision. They include (a) the avidity of the lesion for the radiopharmaceutical (intensity of uptake), (b) the number of lesions detected, and (c) the location of the lesions. Among the most intensely abnormal lesions found on bone scintigraphs are metastases, fractures, Paget's disease, and developed osteomyelitis. Some benign bone lesions may also be quite intensely abnormal. Examples include the region of the nidus of an osteoid osteoma, some fibrous dysplasias, and richly vascularized neoplasms. In our experience, most benign lesions, however, will concentrate the technetium-99m phosphate or phosphonate compounds to a lesser degree than malignant lesions.

It is safe to say that, if a known radiographic lesion is normal or only slightly abnormal on a scintigraph, it is probably benign. However, an intensely abnormal scintigraphic lesion could be either benign or malignant.

The number of lesions detected on a whole body scintigraph can also provide information about the relative probability of a lesion being benign or malignant. In a recently published survey of over 400 patients, the incidence of solitary metastases was only 14%. This correlates with a previous study where the same percentage of solitary metastatic lesions was found. Although this information may not be especially helpful when a new or primary bone lesion is being investigated, it is useful in making a statement about the probability of a lesion being a metastasis. A solitary lesion has a significantly lower probability of being a metastasis than do multiple lesions. As a corollary, if multiple or widespread lesions are detected, we are probably not dealing with a benign disorder.

The location or distribution of the scintigraphic abnormalities adds the third parameter in helping us determine the nature of a skeletal lesion. Some patterns, such as a linear array of rib lesions, are almost certainly due to trauma.

A suspicion that a pattern is caused by trauma can usually be confirmed by asking the patient about recent injuries. Symmetrically arrayed lesions, especially near joints or muscle attachments, can almost always be ascribed to benign causes, and isolated joint abnormalities are only infrequently due to malignancy.

The pattern of skeletal spread of various carcinomas has been studied by several authors. The most recent survey found that in patients with skeletal metastases of breast and lung cancer, in whom the hematogenous mode of spread is similar, 83% of the lesions were found in the thoracic region. While only 15% of the total number of lesions were in the limbs, 52% of the patients with skeletal metastases had limb lesions. This information helps to classify limb lesions in which there are also thoracic or other abnormalities as probably due to malignancy.

Other factors, such as the shape of a lesion, can occasionally be useful in helping to differentiate between benign and malignant disease. A focal rib lesion has a greater probability of being a fracture, whereas an elongated lesion is probably due to tumor. By using these features of a scintigraphic abnormality, plus the three parameters discussed above, a reasonable decision about the nature of a lesion can usually be made.

Characteristics of Normal Studies

The diagnosis of benign diseases often requires the detection of a relative change in the uptake of tracer in the joints, epiphyseal areas, and long bones. Therefore, it is very useful to have a good idea of the normal distribution of skeletal radioactivity in patients of various ages. This can be accomplished by maintaining a reference file of normal, or almost normal, patients at various age intervals from infancy to old age. A reasonable approach would be to keep an updated file of studies of about a dozen patients, including an infant, a case for every 5 years up to age 25, and a case representing every decade thereafter. Since the detection of craniosynostosis by bone imaging has been proposed, it would also be useful to maintain a reference file of the suture line patterns in infants and young children.

When comparing bone scans of patients of various ages, it is obvious that children have greater concentration of tracer in the joint and epiphyseal areas that becomes less prominent as they approach maturity. One reason for this phenomenon is that the greatest amount of tracer localization occurs in areas where bone has maximum blood flow and maximum stress and, therefore, the greatest amount of remodeling. Stress on bone is basically a matter of either weight bearing or of tension on bone from muscle attachment. Sites of muscle attachment, even on smaller bones, can show a considerable increase in the relative concentration of radiopharmaceutical. Many of the areas of stress change with age, and probably also with the types of activities of the individual patients. This can make the interpretation of injury, arthritis, metabolic diseases, and other benign bone abnormalities difficult to detect. Fortunately, computer quantification techniques are being developed to help resolve some of the ambiguity in the diagnosis of some arthritic and traumatic skeletal processes.

OCCULT SKELETAL INJURY

Although radiography is the primary diagnostic modality for the detection of skeletal trauma, there are occasions where X-rays may initially fail to diagnose an injury. The category of injuries that are initially undetectable by X-ray but can be diagnosed with nuclear medicine studies has become known as occult fractures. Because not all of the injuries detected are true fractures, I prefer the term "occult injury". The types of injuries that have been described can be placed into three groups: (a) stress fractures, (b) periosteal reaction, and (c) occult traumatic fractures.

Stress Fractures and Periosteal Reaction

The improvements in the spatial resolution of bone scintigraphs in recent years now allow us to differentiate between two rather distinct patterns of abnormality that I call periosteal reaction and stress fracture. In the former, there is increased tracer concentration localized to the periosteal region, usually in a linear distribution along the surface of the bone. In many instances, these lesions never become abnormal on X-ray. The type of lesion that exhibits significant extension into the cortex, or transversely across the cortex, is called a stress fracture. In our experience, most of these lesions will be detected by radiography. Of course, there will be many lesions that are in the intermediate stage. The reason for making the differentiation is that the patients with only periosteal reaction appear to heal more rapidly clinically, and their scintigraphs return to normal more quickly than those of the patients whose scans reveal stress fractures. Because of this fact, the referring

physician can judge how long an immobilization period is required for his patient. The periosteal injury patients may require only a change of regimen or a period of three or so weeks of rest, whereas the stress fracture patients may require several weeks of abstinence from potentially harmful exercise.

In a discussion of the continuum of bone response to increasing levels of stress, Roub et al devised a diagram showing the manner in which the factors of pain, radionuclide images, and radiographs are related at any given level of stress. This diagram helps to explain the difference between periosteal reaction and true fractures as a function of the amount of stress applied to the bone and the response of the bone to this stress. Subperiosteal hemorrhage has also been postulated as a cause of the increased tracer concentration in patients without evidence of fracture.

The use of nuclear medicine bone imaging to detect stress fractures was first described in detail during the mid-1970s. In most cases, the patient develops pain, and often swelling, in a local area but the radiographic signs of "fracture line", supraperiosteal or subperiosteal bone deposition, and/or sclerosis are not present initially. Although these signs usually develop within two to three weeks, the scintigraph is usually abnormal when the patient complains of pain severe enough to cause him to seek medical advice. A normal scintigraph is usually sufficient evidence to rule out a significant skeletal injury or stress fracture.

Although most stress fractures are diagnosed in the tibiae and fibulae of athletes, especially runners, the technique is useful for essentially any skeletal structures, including the small bones of the feet and wrist.

Traumatic Fractures

Traumatic fractures can best be defined as those skeletal injuries that are caused by sufficient force to be immediately apparent clinically. Occasionally, these injuries are not detected on initial radiographs, especially in certain bones such as the carpal navicular bone or in the proximal femurs of osteoporotic patients. Scintigraphs are very helpful in these instances, and have become part of the fracture workup of many orthopedic surgeons and family practitioners. It had been widely accepted that traumatic fractures might not appear on a bone scintigraph for several days following the injury. However, as a result of improvements in imaging techniques, we now know that almost all fractures are detected by bone scintigraphy within hours of the injury. In our original study, published in 1979, and with additional confirmatory data, we found that in patients under 65 years of age who were not osteoporotic, approximately 95% of the closed fractures could be detected within 24 hours after injury. Patients in the older age group had a somewhat lower percentage of abnormal studies at 24 hours. Within 72 hours after injury, 95% of the patients over 65 had abnormal scans, whereas all of the younger patients were abnormal prior to this time. This indicates that the diagnosis of fracture by bone scan can usually be made within a day of the injury, and certainly within three days after the trauma.

It should be emphasized that images of good quality are required, but they are available on any "well-tuned" newer scintillation camera, even with a plaster or fiberglass cast immobilizing the limb. We have found that the detection of hip fractures in older patients can be difficult, but that the images of the hips can be improved by bladder catheterization of patients in whom complete urinary bladder emptying cannot be obtained.

At times, it can be difficult to distinguish soft tissue trauma from a fracture on the early scintigraphs. Typically, the fracture is confined to skeletal structures, is more discrete in appearance, and usually more intensely abnormal than soft tissue abnormalities. Experience in the interpretation of these studies is a valuable asset.

The scintigraphic pattern of fractures changes over a period of time, with three rather distinct stages being evident. The first phase (acute stage) persists for about three to four weeks after injury and is characterized by a slightly diffuse area of increased tracer concentration about the fracture site. A distinct fracture line is often seen in this stage. The second phase (subacute stage) is characterized by a well-defined linear abnormality at the site of the fracture. This stage lasts about eight to twelve weeks and shows the most intense uptake at the fracture site. The third phase (healing stage) is characterized by a gradual diminution in the intensity of the abnormality until the scan returns to normal.

The time required for fractures to return to normal on bone scintigraphs extends well beyond the period for clinical, or even radiographic, healing. Factors that prolong it include surgery, the use of orthopedic fixation devices, and old age. By two years after injury, 90% or more of the fractures had returned to normal. Rib fractures showed the most rapid healing, with almost 80% of the scans being normal by one year after injury.

The bone scans on the 42 patients who required open reduction of their fractures, or in whom orthopedic fixation devices were inserted, remained abnormal for a considerably longer time than the scans of those with simple reductions. The studies on this group also appeared to have three distinct phases, but the time course of each was more prolonged. By three years after fracture, less than 50% had returned completely to normal.

Surprisingly, three patients who had simple fractures with closed reductions more than 40 years before their bone scans showed an abnormality at the fracture site. In all three cases, the abnormality was asymptomatic and located in a long bone. Here the abnormality was an incidental finding, detected during total-body bone scans for possible metastatic disease, and in all three, radiographs of the areas showed no evidence of fracture.

In general, the time for an uncomplicated fracture to return to normal on a bone scan appeared to depend on the age of the patient, with the older patients showing a greater delay. However, about 90% of all fractures of the vertebrae, distal extremities, and ribs were normal by two years after injury, and over 95% were normal by three years.

A knowledge of the characteristic appearance of fractures, as well as the length of time they are expected to remain abnormal, is not only important when studying orthopedic diseases, but it is also useful when attempting to differentiate between fracture and neoplasm on an abnormal bone scintigraph.

DELAYED HEALING AND NONUNION

Although the distinction between delayed healing and nonunion may be difficult both clinically and semantically, recent scintigraphic studies have attempted to help in making the differentiation. Nonunion can be defined as the failure of a fracture site to heal completely by six to eight months after injury. This entity, which occurs in approximately 5% of all fractures, is more likely when the fracture is open (compound), comminuted, immobilized for an insufficient time, insecurely fixed, or kept from healing by improperly placed orthopedic fixation devices. Physiologic factors that may increase the probability of nonunion include infection, inadequate blood supply, poor nutritional status, osteoporosis, and metabolic abnormalities, especially those

involving bone metabolism such as hyperparathyroidism. The incidence of nonunion is greatest in the tibia and femur, with a lesser incidence in the humerus, radius, ulna, and clavicle.

Two types of nonunion have been described, according to the amount of metabolic activity at the fracture site. They are atrophic nonunion, in which there is a diminution in radioactivity at the fracture site (when compared with the expected intensity of tracer concentration), and reactive nonunion, when the tracer concentration is normal or increased.

Atrophic nonunion may be evidenced by a generalized decrease in radionuclide concentration in the region of the bone fragments, or by a region of essentially absent radioactivity at the fracture site. The generalized decrease probably reflects the inability of the bone ends to respond properly in the healing process, whereas the focal photopenic (decreased tracer concentration) area may often be due to a pseudoarthrosis, the interposition of soft tissues, the location of an infectious process or region of interrupted blood supply. True pseudoarthroses may form at the fracture site with the presence of an actual synovial-lined cavity and synovial fluid. This group of nonunited fractures was found not to respond to the percutaneous electrical stimulation procedures used by orthopedic specialists to help stimulate bone healing. The reactive nonunion group of patients, in whom the increased radionuclide concentration probably indicates an attempt at callus formation, have shown significant improvement after percutaneous electrical stimulation.

The attempt to separate delayed union from nonunion by scintigraphic means has not been as successful as the capacity to differentiate between the types of nonunion. Part of the problem is that the definition of delayed union is nebulous. It refers to those fractures that seem to be taking too long to heal normally, but that cannot yet be called nonunion. Typically, these fractures will still show considerably increased radionuclide concentration at the fracture site when delayed union is suspected, both clinically and radiographically. We have not been successful in our attempt to detect consistently a diminution in tracer concentration in these patients when compared with cases of normally healing fractures.

One would expect some physiologic parameter, such as decreased osteogenesis, might allow a visual or quantitative differentiation in the amount of tracer concentrated at the fracture site. In some cases, this distinction can be made but, as others have found, it may not be possible to differentiate normal fractures from delayed union fractures with a high enough degree of certainty to make the procedure clinically useful.

The use of gallium-67 citrate has been advocated to help detect infectious processes as a cause of delayed healing or nonunion. This may be useful in many cases; however, it should be remembered that gallium-67 citrate will concentrate in areas of traumatic injury for a considerable period of time after the injury. Differentiation between infectious and traumatic localization may be difficult if there has been recent surgery, placement of an orthopedic fixation device, manipulation, or injury.

Osteonecrosis, or bone death, may also occur as a complication of traumatic injury and cause a delay in the normal healing process. It can occur spontaneously, in association with collagen diseases, prolonged corticosteroid therapy, sickle cell disease, Gaucher's disease, and caisson disease; however, vascular insufficiency is probably the reason for most cases of osteonecrosis. In some injuries, such as fracture of the proximal femur or carpal navicular bone, the presence of avascular necrosis is a fairly common and feared complication. While spontaneous osteonecrosis may lead to osteoarthritis, it often resolves without long-term complications and does not require surgery. Unfortunately, patients who experience traumatic osteonecrosis usually require surgical intervention.

The scintigraphic appearance of early spontaneous or traumatic osteonecrosis would be expected to be that of a region of decreased tracer concentration due to diminished blood supply. This pattern can be elicited soon after injury in patients with some fractures, especially of the proximal femur. In some cases, the patients are not studied scintigraphically until after the reparative process has begun. In these patients, such as those with Legg-Calve-Perthes' disease, the scintiphotos show a rather intense area of increased tracer concentration at the involved site. Of course, this pattern would be more difficult to detect in fracture patients because of the preexisting injury. The referring physicians should be reminded to perform studies for aseptic necrosis as soon as possible after injury or the onset of symptoms suggesting the diagnosis.

This procedure allows the orthopedist to determine whether to attempt to stabilize the fracture with fixation devices or replace the injured bone with a prosthetic hip joint. In some cases, fixation devices probably would not be successful because of avascularity.

The technical quality of the scintigraphs must be adequate to identify regions of relatively increased and decreased tracer concentration in the pelvic region. We have found that urinary bladder catheterization is very helpful, since many of these patients are elderly and in pain, and cannot empty their bladders completely. Also, it is important to image both hips with equal intensity, preferably in the anterior and posterior projections, so that the femoral head on the injured side can be compared directly with the contralateral extremity.

JOINT AND SOFT TISSUE INJURY AND ABNORMALITIES

At one time, areas of increased tracer concentration in the soft tissues and the vicinity of joints were called "false positive" findings. Today, many bone scans are performed to look for these very same regions of increased tracer uptake as a diagnostic clue to possible joint and soft tissue abnormalities.

The advent of total body bone imaging, with the rectilinear scanner and then the scintillation camera, provided a greater capacity to image for trauma, arthritis, and other joint diseases. Although individual joints could be imaged without whole body scintigraphs, total body scans allowed the many joints of the body to be compared with each other in one picture. Quantitation by simple computer techniques helped to remove some of the subjectivity from the interpretation of joint images. The quantitative methods of studying the sacroiliac joints were the first to be investigated with a computer. Examples include the heel region, when calcaneal periostitis (plantar fasciitis) is suspected, and the hips for Legg-Calve-Perthes' disease.

Sacroiliac joint uptake quantification can be obtained between the sacroiliac joints and the sacrum by delineating an "area of interest" cursor along a line that encompasses the joints and the sacrum. It is important to obtain normal values for individual departments. For example, the earlier literature stated that ratios of sacroiliac-to-sacral radioactivity above approximately 1.3:1 were indicative of sacroiliitis; however, in our department we found that this ratio was present in many asymptomatic patients who had normal X-ray films. We now use a ratio of 1.5:1 as an indication of a pathologic process, such as sacroiliitis. It should be noted that the ratio depends on the concentration of the bone imaging agent in the sacrum as well as in the sacroiliac joints. Some patients have increased tracer concentration in the sacrum due to normal anatomic variation, arthritis, or other causes. In these patients, the sacroiliac-to-sacral ratio will not give an accurate prediction of sacroiliac disease.

An example is the group of patients with the anatomic variation of a prominent S-1 posterior spinous process, or sacral tubercle. This area can appear as intense a region of uptake on a bone scintigraph as the sacroiliac joints and cause the ratio of sacroiliac-to-sacral radioactivity to be lower than expected. It is reported that 4% of adult males have sacral tubercle uptake that is equal in intensity to that of the SI joints. The percentage is lower in women and children.

Because of possible variations in sacral tracer concentration, the posterior-view bone scintigraph should always be inspected before reporting the results of sacroiliac-to-sacral ratio determinations. In some cases, a lateral view may be necessary to determine the exact extent of a sacral variation, and the "area-of-interest" cursor may need to be moved up or down slightly to obtain a valid ratio.

It is known that patients with marked radiographic sclerotic changes in the sacroiliac region may not have correspondingly abnormal SI ratios. This has been attributed to the cessation of increased osteoblastic activity after bony ankylosis has taken place.

Nonquantitative imaging of the hips and spine for ankylosing spondylitis and similar disorders has also been discussed in recent publications. Ankylosing spondylitis is a chronic inflammatory process that usually involves the sacroiliac and intervertebral joints, but may also involve several peripheral joints. Sternal and costal involvement has been reported to mimic angina. The disease can lead to bony ankylosis of the apophyseal articulations and osseous fusion of the vertebral bodies. Clinically, this results in a rigid spine that is more vulnerable to fracture and the formation of pseudoarthroses. The typical scintigraphic image of active ankylosing spondylitis is of slight to moderately increased radionuclide concentration in the articular surfaces of the vertebrae with an often overlying diffuse increase in tracer concentration throughout the spine. Focal areas of significantly increased uptake, especially if localized to a vertebral body, should create a suspicion that another abnormality such as a fracture is present.

A recently published discussion on the quantitative evaluation of calcaneal periostitis uses a "heel inflammation index", which is a ratio of the tracer uptake over the back of the calcaneus to an equal-sized area over the junction of the middle and lower thirds of the tibia. Control patient ratios ranged from 0.9 to 1.8, whereas patients with inflammatory disease of the attachment of the long plantar tendon into the calcaneus had pretreatment ratios in the range of 1.6 to 5.4. The study also provided a method of objectively evaluating the response to treatment in this group of patients with "painful heel syndrome".

The quantitative study of the hips for the identification of patients with Legg-Calve-Perthes' disease used a ratio comprised of average counts in the femoral capital epiphysis, divided by the average counts in the adjacent iliac bone and femoral neck. The capital femoral epiphysis was divided into quadrants so that regional analysis of the epiphysis could be performed and classes related to the severity of the avascularity developed. Patients with ratios of under 0.60 in at least one quadrant were considered to be abnormal and the degree of involvement was found to be related to the location and extent of the areas of avascularity.

The quantitative methods noted above could also be used to help diagnose many of the various other "enthesopathies", the term used to describe pain and inflammation at sites of tendon insertion into bone. Normal and abnormal values for joints other than the sacroiliac joint would also be useful in imaging for the arthritides.

Other reviews and texts have discussed joint abnormalities in detail and do not require additional discussion here, with perhaps the exception of the procedures that allow nuclear medicine to interface with dental practice. Bone scans of the face and jaw have been suggested to help with the diagnosis of inflammation, injury, and other abnormalities involving the joints and structures associated with dental disease. An example is the evaluation of the temporomandibular joint in patients with chronic headache or facial pain due to problems such as dental malocclusion.

Some patients with malocclusion develop temporomandibular joint abnormalities, such as arthritic changes, due to the abnormal stress persistently applied to the joint. Many of these patients have pain for years and may undergo many dental and medical procedures before the diagnosis is made. In fact, in some patients the diagnosis of temporomandibular disease is never established because distinct X-ray changes either do not develop or are not looked for. Facial bone scintigraphy in these patients usually shows a distinct and localized increase in tracer uptake in the temporomandibular joint. It is often unilateral, but may involve both joints.

CHILDHOOD INJURY AND DEVELOPMENTAL ABNORMALITIES

The bone scan has been reported to be of little use in diagnosing osteomyelitis in the newborn; however, it has been shown to have significant utility in diagnosing juvenile trauma and has been reported to be useful in detecting congenital abnormalities. In almost all cases, the studies can be performed with as little as 2 or 3 mCi of a 99m-technetium radiopharmaceutical, which imparts a quite minimal radiation dose to the child.

We have found that by utilizing certain "tricks", we can image infants and young children without the necessity of administering sedatives or tranquilizers. These include not feeding the child and keeping him awake until immediately prior to imaging. The lights in the camera room are then turned out, the doors closed, and all unnecessary personnel are asked to leave the room. Wherever possible, the child is held by the mother during imaging. In almost all cases, the child falls asleep long enough for images of good quality to be obtained.

Imaging of the infant skull has become popular in some institutions for the detection of skull deformities due to trauma in utero and during delivery, as well as for evaluating developmental abnormalities. The scintigraphic findings in infantile trauma are similar to those in adults, with the exception of the presence of suture line uptake in the neonates. A reference file of normal infant skull scintigraphs, either obtained in the individual department, from an atlas, or from reprints is extremely useful in deciding which linear band of tracer uptake might be due to an abnormality. The reference file is even more critical in helping to detect early suture closure, or craniosynostosis, in infants. This procedure has been said to be of some use, especially in conjunction with skull radiographs, but we have found the variability of infant suture patterns to be sufficiently diverse to make interpretation quite difficult unless there is a distinct asymmetry in tracer concentration.

Analogous to cranial trauma, the scintigraphic joint abnormalities of children are similar to those of adults, with the exception of the increased epiphyseal tracer concentration found near children's joints. Fortunately, this nearby area of increased uptake does not obviate early and accurate diagnosis of pediatric joint abnormalities, as evidenced by the significant increase in the number of children being imaged for processes such as juvenile rheumatoid arthritis.

There are three types of presentation of juvenile rheumatoid arthritis, all of which can be diagnosed with the help of nuclear medicine bone imaging. The most common presenting pattern is the spontaneous complaint of pain or evidence of inflammation in a few or several joints. Monoarticular arthritis is the next most common presentation, followed by the group of patients who have a systemic type of illness with high spiking fever and arthralgias. In the last group, the definitive signs of arthritis may not appear for several weeks or months after the prodromal illness.

In addition to early identification of the synovial abnormality associated with the arthritis, bone scintigraphy can be used to evaluate therapeutic success, or to detect possible toxic effects of therapy such as premature closure of the epiphyses secondary to prolonged steroid administration.

Congenital dislocation of the hips is an abnormality occasionally found in female infants. It is usually easily diagnosed during the routine newborn physical examination or by radiographs. However, a recent report describes the interesting scintigraphic findings in congenital dislocation of the hips. The scintigraphs show empty acetabular fossae with the femoral heads located above and lateral to the acetabulae.

Similar to the use of bone imaging for multiple injuries ("battered child syndrome"), total body scintigraphy could be utilized to detect multiple joint and skeletal congenital disorders with a minimal radiation dose. However, any such use would probably be of benefit only where radiographs were equivocal or where repeated follow-up studies were contemplated.

In a scintigraphic study of childhood hip pain, Heyman and associates listed the most common entities as synovitis, trauma, infection, Legg-Calve-Perthes' disease, slipped femoral epiphysis, and juvenile rheumatoid arthritis. Nuclear Medicine studies can help to differentiate among them in some cases. For example, toxic synovitis usually shows an early increase in tracer concentration in the joint, whereas Legg-Calve-Perthes' patients have a widened joint space due to absent or decreased uptake in the region of the proximal femoral epiphysis when studied early in the course of the disease.

The metabolic diseases that affect children frequently involve the skeletal system and are often identifiable on bone scintigraphs. An example is rickets, which is the osteomalacia of childhood, resulting from vitamin D deficiency. The scintigraphic imaging pattern, although not diagnostic of this disease, does show some characteristic signs, including intensely increased tracer concentration at the costochondral junctions ("rosary beading"), a generalized increase in uptake throughout the entire skeleton, and focal areas of increased uptake in the metaphyses of long bones and the ribs ("pseudo fractures"). There may also be a noticeable decrease in renal tracer concentration, due to the increase in uptake of the radiopharmaceutical by the skeletal structures.

Decreased bone uptake may be seen in the conditions that produce decreased bone activity, such as hypoparathyroidism or elevated corticosteroid levels due to Cushing's disease or exogenously administered corticosteroids. In children with chronic renal failure who require prolonged corticosteroid therapy, we have seen aseptic necrosis of the femoral heads, as well as generalized osteoporosis. These patients may also sustain multiple fractures, due to the relative fragility of their bones. Probably the most characteristic feature of patients with chronic renal disease is the pattern of renal osteodystrophy, in which there is a symmetric and generalized increase in tracer uptake, especially in the long bones, the extremities, the calvarium, sternum, and mandible.

NONOSSEOUS ACCUMULATION OF BONE-SEEKING RADIOPHARMACEUTICALS

The primary purpose of using bone-seeking radiopharmaceuticals is to obtain information about osseous structures. However, there are innumerable instances

when the tracer is seen to distribute or localize in soft tissues or specific organs other than bone. The nonosseous concentration of these agents may be due to an abnormality of the organ involved or an etiology that is only indirectly related to the region or areas of increased concentration. Examples of organ abnormality are the localization of 99m-Tc-pyrophosphate in injured myocardial tissue and the skeletal muscle uptake seen after muscle injury. The appearance of increased tracer in the colon, stomach, and thyroid gland is usually due to faulty labeling of the radiopharmaceutical and is an example of the nonpathologic accumulation of tracer in specific nonosseous tissues. A generalized increase in soft tissue accumulation may be seen when the radionuclide cannot be excreted normally from the body, as in advanced renal disease, or from the local area when venous obstruction is present.

A knowledge of the various forms and mechanisms of nonosseous tissue concentration can be very helpful in making clinical decisions about bone scintigraphs and, in many instances, can lead to a correct etiologic diagnosis.

REFERENCES

Silberstein, E.B. Nuclear orthopedics. J. Nucl. Med., 21:997-999, 1980.

Rosenthall, L., and Lisbona, R. Role of radionuclide imaging in benign bone and joint diseases of orthopedic interest. In: Nuclear Medicine Annual Vol. 1, edited by L.M. Freeman and H.S. Weissmann. Raven Press, New York, 1980.

Roub, L.W., Gumerman, L.W., Hanley, E.N., Jr., Clark, M.W., Goodman, M., and Herbert, D.L. Bone stress: A radionuclide imaging perspective. Radiology, 132:431-438. 1979.

Matin, P. Appearance of bone scans following fractures, including immediate and long-term studies. J. Nucl. Med., 20:1227-1231. 1979.

Matin, P., Lang, G., Carretta, R., Simon, G. Scintigraphic evaluation of muscle damage following extreme exercise. J Nucl Med 24:308-311. 1983.

Matin, P. Bone scintigraphy in the diagnosis and management of traumatic injury. Sem in Nucl Med XIII:104-122. 1983. (contains 100 references).

Matin, P. Bone scanning of trauma and benign conditions. Nucl Med Annual 1982, edited by L.M. Freeman and Heidi S. Weissmann. Raven Press, New York 1982.

GASTROESOPHAGEAL SCINTIGRAPHY

John H. Miller, M.D.

Associate Professor of Radiology

University of Southern California School of Medicine

Head, Division of Nuclear Radiology

Childrens Hospital of Los Angeles

Gastroesophageal scintigraphy has become one of our more requested procedures. The majority of these are gastric emptying studies made for an assessment of gastric motility. During the conduct of the examination, an assessment for the presence of gastroesophageal reflux is made as well. The examination is conducted in the following manner: A normal meal for the infant is given to the patient which contains approximately 250 uCi of Technetium (Tc)-99m sulfur colloid. In specific instances this may be administered via nasogastric tube or gastrostomy tube. Older children and teenagers are fed a standard meal which also contains approximately 250 uCi of Tc-99m sulfur colloid. The patient is placed in the supine position and imaged anteriorly for 90 minutes. Five minute scintiphotos are obtained and data is acquired by computer interface at one minute intervals for this period. Following completion of the examination, the computer acquired study is dynamically reviewed, in a manner analogous to x-ray fluoroscopy, and ROIs are placed on the esophagus, body of the stomach, and the lung fields to assess for reflux, aspiration, and to determine gastric emptying. The total counts in the stomach at the first minute of the examination is used for a standard for subsequent emptying value determinations. A decay correction but no attenuation is utilized and the percent of gastric emptying is calculated (see worksheet). Any episodes of gastroesophageal reflux are evaluated as to time of occurrence, level of reflux (complete - to the level of the hypopharynx or incomplete retained within the esophagus). Also the time of residence of the refluxed activity in the esophagus is reported and all episodes of discernable reflux are mentioned. Emesis occurring during the conduct of the examination requires a recalculation based on the next sequential one minute acquisition as the baseline which is then decay corrected for the determination of emptying values. When faced with delayed gastric

emptying, one must bear in mind that there is anatomic information available on these studies and evidence of malrotation should be sought. Often these examinations are conducted prior to and following the administration of a gastric stimulant such as metacopromide to determine the efficacy of that agent.

The advantages of gastrointestinal scintigraphy include the sensitivity of the procedure which is much more sensitive than gastrointestinal barium studies and almost as sensitive as the 24 hour pH probe, a more physiologic procedure than radiographic barium studies, longer periods of continuous observation, and the ability to detect small amounts of reflux and pulmonary aspiration. Furthermore, the procedure can be tailored to specific problems. There is no risk to the patient and the radiation delivered dose is dramatically less than radiographic barium studies. The disadvantages of gastrointestinal scintigraphy include low anatomic resolution. The inability of many surgeons to relate to the scintigraphic pictures. A certain population of patients which should have barium examinations prior to GI scintigraphy. These include tracheoesophageal fistulae, vascular rings, patients with pyloric stenosis, antral or duodenal webs, and those patients suspected of malrotation.

The next aspect of scintigraphic evaluation of the pediatric gastrointestinal tract includes the radionuclide esophagram and motility study. The examination is conducted in the following manner: Approximately 250 uCi of Tc-99m sulfur colloid are suspended in 10-15 cc of tap water or sterile saline (for those patients who have not eaten or who are suspected of tracheoesophageal fistulae). Older children, teenagers, or young adults receive approximately 30 cc of solution containing approxi-

mately 250 uCi of Tc-99m sulfur colloid. A small tube is placed in the pharynx with the patient supine. Posterior imaging is utilized and the 10-20 cc administered in a continuous bolus. Cooperative children are asked to swallow the bolus. Sequential scintiphotos are acquired at three second intervals and computer data is acquired at one second frame rate for 120 seconds. The study is reviewed dynamically, again in a manner analogous to x-ray fluoroscopy. Areas of interest are placed over the esophagus and the lung fields and motility patterns determined. Abnormalities seen in tracheoesophageal fistula and achalasia can be well demonstrated by this method. In patients with motor incoordination of the esophagus, this may be a manifestation of a generalized motor defect. Assessment for palatine incontinence should be made. The radionuclide esophagram may be used in the evaluation of patients with gastroesophageal stricture or colonic interposition.

Gastrointestinal bleeding in children is a difficult diagnostic problem. In infants and young children, our initial evaluation is the Meckel scan. This procedure should be performed in the following manner: The patient should be NPO for four hours prior to the examination. The patient is imaged in a steep LPO position with the detector parallel to the abdomen. The diagnosis of functioning ectopic gastric mucosa may be made only be demonstration of coincident appearance of activity in the body of the stomach and at the ectopic site. Evaluation of chronic gastrointestinal blood loss may necessitate the use of Tc-99m red blood cells (RBC) scintigraphy or Tc-99m sulfur colloid scintigraphy. I prefer the utilization of Tc-99m RBCs as there is much more anatomic information and sites of slow blood loss may be identified.

Inflammatory conditions in the abdomen may be addressed utilizing Indium-111 white blood cells (WBC). In several patients at our institution, information derived from this study has been pivotal in their management. There is still a vital role for Gallium-67 scintigraphy, particularly for the evaluation of lesions of the upper gastrointestinal tract.

GASTRIC EMPTYING STUDIES

Date_____

Minute 1 - Gastric count: (A)_____

(A) X 0.89 = 60 minute Standard (B) _____

(A) X 0.85 = 90 minute Standard (C) _____

(A) X 0.81 = 10 minute Delay (D) _____

(This can be linked - A x 0.89 = B x 0.95 = C x 0.97 = D)

Calculations (retained gastric activity):

60 minute gastric observed/B = (E) _____%

90 minute gastric observed/C = (F) _____%

10 minute delayed observed/D = (G) _____%

GASTRIC EMPTYING at:

60 minute = 100 - E = _____%

90 minute = 100 - F = _____%

10 minute delayed = 100 - G = _____%

Reflux observed at: _____minute

Aspiration: yes no (circle one)

Esophageal motility study: yes no (circle one)

Motility: normal abnormal (circle one)

GASTROINTESTINAL EMPTYING STUDY

1. STANDARD MEAL FOR INFANTS (FORMULA, FOOD, THICKENED FEEDINGS, CARDIAC FORMULA OR EVEN MOTHER'S MILK) IS GIVEN TO THE PATIENT. THIS IS ADMINISTERED BY MOUTH, BY NASOGASTRIC TUBE, VIA GASTROSTOMY TUBE. OLDER CHILDREN AND TEENAGERS ARE FED A STANDARD MEAL CONSISTING OF ONE EGG SALAD SANDWICH, 100 GRAMS OF SLICED PEACHES, AND 240 cc OF APPLE JUICE.

2. PATIENT IS PLACED IN THE SUPINE POSITION, USUALLY FLAT ON THE TABLETOP UNLESS THIS IS CONTRAINDICATED. THE PATIENT IS IMAGED ANTERIORLY FOR 90 MINUTES. FIVE MINUTE 300,000 COUNT SCINTIPHOTOS ARE OBTAINED. DATA IS ACQUIRED BY COMPUTER INTERFACE AT ONE MINUTE INTERVALS IN WORD MODE.

3. PRIOR TO INITIATION OF THE 90 MINUTE STUDY, THE TECHNOLOGIST MAKES AN ASSESSMENT OF THE ACTIVITY WITHIN THE STOMACH AND SMALL BOWEL. THIS IS ONLY GERMANE FOR THOSE PATIENTS WHO HAVE BEEN FED VIA NASOGASTRIC TUBE OR GASTROSTOMY TUBE. FOLLOWING COMPLETION OF THE EXAMINATION, IF THERE APPEARS TO BE DELAYED GASTRIC EMPTYING, THE PATIENT IS PLACED IN THE UPRIGHT POSITION FOR TEN MINUTES OR IS ALLOWED TO AMBULATE FOR TEN MINUTES. FOLLOWING THIS, THE PATIENT IS PLACED AGAIN UNDER THE CAMERA AND A DELAYED SCINTIPHOTO IS OBTAINED. THIS IS USEFUL FOR THE ASSESSMENT OF THE EFFECTS OF POSTURE ON GASTRIC EMPTYING.

GASTROINTESTINAL EMPTYING STUDY

4. FOLLOWING COMPLETION OF THE EXAMINATION, THE COMPUTER ACQUIRED STUDY IS REVIEWED DYNAMICALLY, IN A MANNER ANALOGOUS TO X-RAY FLUOROSCOPY.

5. AREAS OF INTEREST ARE PLACED ON THE ESOPHAGUS, THE BODY OF THE STOMACH, AND THE RIGHT AND LEFT LUNG FIELDS TO ASSESS FOR GASTROESOPHAGEAL REFLUX, GASTRIC EMPTYING, AND PULMONARY ASPIRATION.

6. BECAUSE OF THE SMALL SIZE OF THE MAJORITY OF OUR PATIENTS, NO ATTENUATION CORRECTION IS UTILIZED. THE ONE MINUTE DOSE IS DECAY CORRECTED FOR 60 AND 90 MINUTES AND USED AS A STANDARD FOR DETERMINATION OF EMPTYING VALUES. IN OUR LABORATORY, WE CONSIDER THE MINIMAL VALUES TO BE 45% AT 60 MINUTES AND 60% AT 90 MINUTES.

7. REFLUX IS REPORTED AS BEING COMPLETE (TO THE LEVEL OF THE INTROITUS OF THE ESOPHAGUS AND/OR HYPOPHARYNX) OR INCOMPLETE. ALL EPISODES OF REFLUX, EVEN THOSE INTO THE DISTAL ESOPHAGEAL SEGMENT ARE REPORTED AS POSITIVE STUDIES FOR REFLUX. THIS IS OF PARTICULAR IMPORTANCE IN THOSE INDIVIDUALS WITH ASTHMA.

8. IF THE PATIENT EXPERIENCES AN EPISODE OF EMESIS, THIS IS REPORTED AND A NEW ONE MINUTE VALUE IS OBTAINED AND A CORRECTION INSTITUTED.

GASTROESOPHAGEAL MOTILITY STUDY

1. IN THOSE INDIVIDUALS SUSPECTED OF TRACHEOESOPHAGEAL FISTULA OR WHO HAVE NOT TAKEN FOOD BY MOUTH, STERILE SALINE IS UTILIZED. IN THOSE INDIVIDUALS IN WHOM FOOD IS NORMALLY TAKEN BY MOUTH, THE TRACER IS SUSPENDED IN TAP WATER. APPROXIMATELY 250 uCi ARE UTILIZED.

2. A 19 GAUGE SCALP VEIN NEEDLE TUBE IS UTILIZED. THIS IS CUT IN A MANNER TO ALLOW IT TO REACH THE HYPOPHARYNX.

3. WITH THE PATIENT SUPINE AND THE GAMMA CAMERA CRYSTAL POSTERIOR TO THE PATIENT, THE 10-20 CC IS ADMINISTERED IN A CONTINUOUS BOLUS. IN OLDER CHILDREN AND TEENAGERS, 30 CC IS PLACED IN THE MOUTH AND THE PATIENT IS INSTRUCTED TO SWALLOW THIS IN ONE BOLUS FOLLOWED BY TWO DRY SWALLOWS.

4. SEQUENTIAL SCINTIPHOTOS ARE ACQUIRED AT THREE SECOND INTERVALS. COMPUTER ACQUISITION IS PERFORMED AT A ONE SECOND FRAME RATE IN BYTE MODE FOR A MAXIMUM OF 180 SECONDS. AREAS OF INTEREST ARE PLACED ON THE UPPER, MID, AND LOWER ESOPHAGUS, BODY OF THE STOMACH, AND BOTH LUNG FIELDS.

MECKEL SCINTIGRAPHY

NPO FOUR HOURS (MINIMUM PRIOR TO STUDY)
PATIENT IN STEEP (75° - 80°) LPO POSITION
DIAGNOSIS MAY BE MADE ONLY BY DEMONSTRATION
OF COINCIDENT APPEARANCE OF ACTIVITY IN
THE BODY OF THE STOMACH AND THE ECTOPIC SITE

PEDIATRIC TUMORS

ASLAM R. SIDDIQUI, M.D.

Annual Incidence - 12.1/100,000 white children
9.3/100,000 black children
6,000 - 7,000 new cases every year

Male to female ratio - 1.1:1 (1:1 in neonates)
Common tumors under 5 years of age - acute lymphocytic leukemia
neuroblastoma, Wilms' tumor
retinoblastoma, liver malignancies

Common tumors over 10 years of age - Hodgkin's and non-Hodgkin's lymphomas, bone malignancies, testicular malignancies

Overall most common pediatric tumors - leukemia, central nervous system, lymphomas, neuroblastoma, kidney, soft tissue, bones

Neuroblastoma - As many as half of the patients have skeletal metastases at presentation. Bone scans are very helpful. Sequential imaging during the first 20 minutes after the injection provide information about the effects of the primary tumor on renal anatomy and physiology. These early images are also helpful in distinguishing intrarenal from extrarenal masses. Patency and displacement of inferior vena cava can be assessed if the injection is made in the foot.

Metaphysis is a common site of metastatic spread from neuroblastoma. Growth plates should be examined carefully, as the only evidence of abnormality may be a change in shape or blurring of the margins. Orbit is another frequent site of metastasis. Metastatic spread can be symmetrical and the radiotracer uptake in the lesions may be only slightly more than that in normal bones. "Cold" defects may be present. In approximately 69% of the patients, the primary tumor accumulates the bone imaging agent. This uptake most likely is a reflection of calcium turnover, rather than the amount present. About 90% of the neuroblastomas have calcifications as documented by plain radiographs, CT, or histology. Soft tissue or liver metastases generally do not accumulate bone tracers.

Tc-99m sulfur colloid bone marrow scanning is very useful in the detection of sites of tumor involvement. The scan acts as a guide for marrow biopsy and often makes interpretation of the bone scan easier. Liver metastases are generally multiple, small and vascular. The more common liver scan abnormality is the mass effect from the primary tumor. The retroperitoneal neuroblastoma on the right displaces the liver anteriorly and medially. Neuroblastoma on the left, if large, displaces the spleen anteriorly.

It has been suggested that gallium scanning be used as a prognostic indicator; it appears that primary neuroblastomas that concentrate gallium have poorer prognosis compared to nongallium avid ones. The activity of gallium in the tumor is not related to the stage of the disease.

MIBG localizes in the chromaffin cells. I-123 and I-131 labeled MIBG can be used both in the diagnosis and therapy of patients with widespread neuroblastomas.

Lymphomas and Leukemias - The sensitivity of gallium scanning in childhood Hodgkin's and non-Hodgkin's lymphomas is reported to be 87%, with a specificity of 100%. Burkitt's lymphoma heads the list. Sensitivity decreases during and after therapy; the gallium scan generally parallels the course of the disease. It confirms remissions and detects recurrences reliably. The problematic areas are liver and spleen. They usually are involved diffusely and since they accumulate considerable amounts of gallium normally, it is difficult to detect somewhat more than normal uptake in these organs. In our experience, histiocytic lymphomas often involve the liver focally.

In acute leukemia, the most common finding is that of gallium bone scan, where there is increased uptake in bone marrow at the expense of normal sites. Other scan findings include uptake in the lymph nodes and kidneys, focal bone uptake and prominent uptake in live and spleen.

Liver-spleen scans may show increased activity in spleen compared to liver, focal defects in liver and spleen, and apparent defect in the porta hepatis due to enlarged lymph nodes in that region.

Skeletal metastases are uncommon. When they occur, they are more often diffuse than focal and the involvement is mainly in the extremities near the joints. Bone and bone marrow scans are the diagnositc modalities of choice.

Bone Tumors - Osteosarcoma and Ewing's sarcoma are the two most common childhood primary bone tumors and the diagnosis is usually made by plain radiographs. On bone scans, both tumors are hypervascular and have marked uptake of the radiotracer. The uptake in primary osteosarcoma is more likely to be patchy than in Ewing's sarcoma. Bone metastases are present in about 5% of the patients with osteosarcoma at presentation but the prevalence approaches 40% during followup. Bone scan is extremely sensitive with the detection rate approaching 100%. Since osteosarcomas are osteoid - producing tumors, lungs and other soft tissue metastases often accumulate bone - imaging agent. Uptake of the radiotracer in lung metastases is seen in 43%, rarely bone scan is the first evidence of pulmonary metastases. Hypertrophic pulmonary osteoarthropathy in association with pulmonary metastases is rare in children. When present, it has typical appearance on bone scan, showing increased linear accumulation of radiotracer in the long bones. In Ewing's sarcoma skeletal (11%) and pulmonary (11%) metastases may exist at initial examination; during followup they occur in 45% to 60% of patients. Bone scanning is very sensitive and detects virtually all sites of bone metastases. Soft tissue or lung metastases, as well as primary extraosseous Ewing's sarcomas generally do not accumulate bone radiotracer.

Wilms' Tumor - On renal scans, these tumors appear as areas of decreased radiotracer accumulation reflecting the replacement of normal renal parenchyma. The main use of renal scanning is in differentiating intrarenal from extrarenal mass. Wilms' tumor is bilateral in 5-10% of patients. Serial Tc-DMSA scans document compensatory hypertrophy, as well as detect asynchronous presentation of bilateral disease.

After lungs, liver is the second most common site of metastases. Liver scans can be used to detect metastases, as well as local effects of the tumor (invasion or displacement).

Skeletal metastases are rare; they occur in patients who have tumors with clear cell histology. If the bone scan is performed, the injection should be in the foot to evaluate inferior vena cava and early renal images should be obtained. Approximately 5% of the Wilms' tumors accumulate bone tracer.

Complications of therapy - Radiation produces liver defects (radiation hepatitis) corresponding to the therapy port. The part of skeleton in the radiation field shows decreased tracer uptake on bone marrow, bone and gallium scans. Transient intense accumulation of gallium in the salivary glands is seen immediately after radiation to the cervical region. Myocardial uptake of bone tracer may be seen after mediastinal irradiation. Lung and gallium scans may show evidence of restrictive lung disease and pneumonitis after radiation to the chest. There is decreased uptake of renal imaging agents and increased uptake of bone tracers in the irradiated segment of kidneys.

Chemotherapy induced pulmonary toxicity is best assessed with gallium scanning. The effect of cardiotoxic agents can be monitored by radionuclide left ventricular ejection fraction measurements. Renal problems, such as acute tubular necrosis, uric acid nephropathy, etc., are diagnosed by DTPA renal and bone scans.

Infective complications are imaged using gallium scanning in patients with nongallium avid tumors and by In-111 labeled white blood cells.

ADDITIONAL READING

Siddiqui AR: Nuclear Imaging in Pediatrics. Year Book Medical Publishers, Chicago 1985

Miller JH: Imaging in Pediatric Oncology. Williams and Wilkins, Baltimore 1985

DISCLAIMER