The Principles and Application of Gastrointestinal Scintigraphy in Children

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Radionuclide imaging techniques provide the capability to evaluate a number of congenital and acquired abnormalities of the gastrointestinal tract of children. They have replaced many invasive procedures and may be sequentially performed to evaluate the patient's response to various medical or surgical therapies (*1*). Although similar radiopharmaceuticals and instrumentation are utilized for both adults and children, the uniqueness of the latter requires certain adaptations.

THE PEDIATRIC PATIENT

Confusion, anxiety, and fear are truly representative of a child's mental and emotional status upon entering the nuclear medicine laboratory. It is imperative to explain to the child exactly what is going to occur. By establishing an initial rapport with the child one begins to gain his or her trust and cooperation, which are essential in obtaining good quality studies. Time is an agonizing aspect of pediatric imaging because children have no concept of time. Consequently, physical and mental immobilization techniques are necessary. Physical immobilization consists of wrapping the child in a sheet mummy-style (*19*). Use sandbags around the child's wrapped body and on the lower extremities. Mental immobilization is actually a distraction, and this may be accomplished through books, small plastic toys, or hand puppets. Make use of these tools, as they will aid in controlling the child's behavior during the procedure. Sedation is generally not required. Neonates and small infants need special attention because they are unable to maintain body temperature. The neonate's body should be swaddled in a blanket and the head covered, if necessary use heat lamps. Constant supervision, patience, careful attention to detail, and adequate image statistics are essential to obtaining accurate and good quality scintigraphic studies.

GASTROESOPHAGEAL REFLUX

Vomiting is a common problem experienced by infants from 6 wk of age up to 2 yr (*1*). Generally, it is a benign, self-limited condition which resolves with no clinical problems. Children who present with symptoms that may be attributed to the consequences of gastroesophageal reflux (GER) are of concern. Chief among symptoms is failure to thrive, others include aspiration pneumonia, recurrent episodes of acute respiratory distress, apneic episodes, as well as children with esophagitis, hematemesis, and neurologic disorders (*1*). The sensitivity of the common diagnostic procedures used to evaluate GER are: 50% for the barium swallow, between 60% and 90% for scintigraphic evaluation, and 97% for the acid reflux test (*2*). The latter procedure is the most reliable, but it is technically demanding and often requires sedation. The insensitivity of the conventional radiographic technique, the barium esophagram, combined with the invasive nature of other diagnostic procedures, such as the acid reflux test, esophageal manometry, and endoscopy, necessitate the use of scintigraphy in screening for reflux and pulmonary aspiration (*3*). GER scintigraphy is a practical, sensitive examination which can be used to detect and quantitate reflux, and it may be useful in evaluating response to a selected course of medical/surgical therapy, specifically Bethanechol, Reglan, or Nissen fundoplication (*4*). Additionally, radionuclide evaluation is more physiologic and permits imaging for an unlimited duration without increasing the radiation dose. Fisher et al. estimated that the total body radiation from 100 μCi of technetium-99m- (^{99m}Tc) sulfur colloid is less than 20 millirads, which is considerably less than that delivered during fluoroscopic examination (*5*).

Technical Considerations

Several radionuclide techniques have been devised to evaluate gastroesophageal reflux over the past two decades. All entail the use of ^{99m}Tc-sulfur colloid, with a dose range from 100 μCi to 1 mCi. The media used to accompany the tracer include formula, milk, fruit juice, or glucose water. The procedure requires that the patient be fasted. Infants should fast 2–4 hr, young children 4–6 hr, and children 10 yr and older 8 hr. Simulate the child's normal feeding pattern by administering his or her exact feeding medium and intake volume. To assure adequate radiopharmaceutical ingestion, initially administer 100 μCi–200 μCi of ^{99m}Tc-sulfur colloid in a small volume, ~15 ml to 30 ml. Continue to feed until the infant is satisfied or the child reaches his or her normal

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intake volume. The radiotracer may be administered orally or via nasogastric or gastrostomy tube.

The technologist should wear gloves and utilize absorbent protective materials when feeding and burping the child. A Chux absorbent pad, taped to the child's shoulders, protects clothing and skin from contamination during feeding. If contamination occurs, remove clothing and wash skin prior to performing the examination. Depending on the route of administration, one of the following should be done before imaging: after oral administration, burp the child; after nasogastric tube administration, remove the tube; after gastrostomy tube administration, tightly clamp the tube and secure its free end to the lower abdomen. Absorbent protective pads are placed under the child's head and neck area and on the chest in order to easily remove any vomitus contamination, which may occur during the examination. Layering of these pads allows for prompt removal from the field of view without disrupting the child's position. The child should be placed supine or in a lateral position either under or on top of a gamma camera detector, with a low-energy, high-sensitivity collimator, and positioned to include the thorax and upper abdomen. Images are obtained at one frame per min for 60 min and computer data acquired, using a 64 × 64 word mode matrix at one frame per 10–30 sec for 60 min. The word mode matrix should be used to avoid pixel saturation. Two to four hr postradiotracer ingestion, a 10-min static image of the thorax and upper abdomen should be obtained in the anterior and posterior projections to evaluate the lungs for aspiration. Special attention must be exercised not to confuse clothing or skin contamination with aspiration.

Computer Analysis

The data collected during GER scintigraphy are analyzed to detect reflux events and to quantitate gastric emptying (*1*). Computer contrast enhancement of acquired images allows one to appreciate subtle as well as prominent episodes of reflux (Fig. 1). To detect reflux, a region of interest (ROI) is selected superior to the cardioesophageal junction; an identical ROI for background is placed opposite the esophageal region. To graphically evaluate gastric emptying, an ROI is placed around the stomach, excluding the small bowel, (Fig. 2A). Time-activity curves are then generated. Reflux episodes appear as spikes of increased activity above background. The height of the spike is proportional to the amount of material refluxed from the stomach into the esophagus, and the width of the spike corresponds to the duration of the reflux episode (Figs. 2B-CD).

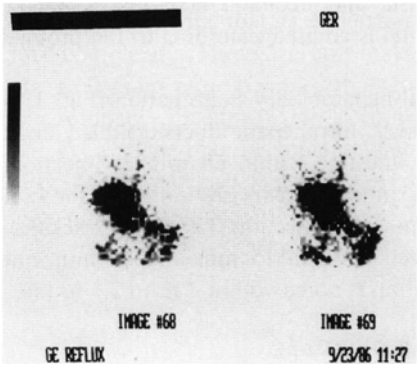

FIG. 1. Contrast-enhanced computer images of gastroesophageal reflux.

GASTRIC EMPTYING

It has been established that infants with severe gastroesophageal reflux have delayed gastric emptying (*6*). This observation supports the recommendation for combined gastroesophageal reflux and gastric emptying studies. The primary nutritional sources for infants are liquid meals, which empty significantly faster than solid meals (*7-8*). This difference in emptying is believed to be dependent on the pressure gradient between the stomach and duodenum that is largely controlled by the tone of the proximal part (fundus) of the stomach (*7*). Gastric emptying information is useful in the evaluation and subsequent medical management of children with failure to thrive, gastroparesis, gastroesophageal reflux, and pyloric stenosis. In infants, the gastric emptying rate at 1 hr varies and is directly dependent upon the degree of reflux. Hillemeier et al. have reported gastric emptying rates at 1 hr in infants with failure to thrive and in those with recurrent pulmonary disease, both attributable to severe GER, to be 21.3% ± 6.4% and 19.8% ± 5.4%, respectively. These rates were significantly lower than that of infants with mild reflux, adequate weight gain, and no pulmonary symptoms who emptied 44.3% ± 6.0% at 1 hr (*8*). The available data suggest that in many infants GER is part of a disturbance of motility of the stomach and distal esophagus (*1*). Gastric emptying scintigraphy is a diagnostic parameter which aids in clarifying the pathogenesis of gastroesophageal reflux.

Technical Considerations

The fasting criteria for patients undergoing gastric emptying scintigraphy are identical to those previously stated for GER imaging. The type of liquid meal and the volume administered will be governed by the child's age: formula for infants, milk or fruit juice for older children. Again, a small volume of the appropriate liquid to which 100 μCi to 200 μCi of ^{99m}Tc-sulfur colloid has been added is administered orally or via nasogastric tube. Additional volume is given until the infant/child is satisfied or when his or her normal intake volume is achieved. Imaging should begin within 5 min postinitiating ingestion of the radiotracer. The patient is then placed in the supine position above or beneath a gamma camera detector, interfaced with a dedicated computer, and the upper gastrointestinal tract is imaged for 60 min. A low-energy, high-sensitivity or a low-energy, all-purpose collimator may be used. Images are acquired at one frame per minute using a 64 × 64 word mode matrix. It is important to position the child so that the gastric emptying pattern can be completely appreciated and that no patient motion occurs. This can be readily achieved with a large-field-of-view camera and a proper immobilization technique.

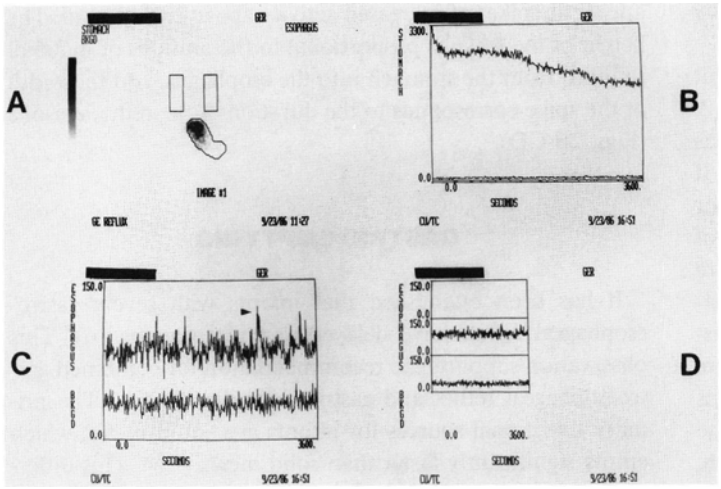

FIG. 2. Computer analysis technique: (A) Regions of interest for stomach, esophagus, and BKG. (B) Gastric emptying curve. (C) Esophagus/BKG curves demonstrating a reflux episode (arrow). (D) Stack presentation of esophagus/BKG curves.

Computer Analysis

The computer analysis consists of selecting an ROI that defines the stomach and excludes the small bowel. This ROI is used to obtain counts of ^{99m}Tc in the stomach as a function of time. Hillemeier et al. used a technique that expresses gastric emptying as a percentage

$$([CT_o - CT_t/CT_o] \times 100),$$

wherein CT_t is the count rate of ^{99m}Tc at any time in the stomach after correction for decay and CT_o is the initial count rate of ^{99m}Tc in the stomach (*6*). Another method to quantify gastric emptying, using a variation of the aforementioned technique, has been reported by Sty et al. (*1*). Their technique requires an area of interest to be selected from each of the first and last image frames. Again, the small bowel is excluded. Count data from each region are obtained and gastric emptying (GE) is expressed as a percentage:

$$GE = \frac{C_o - \frac{C_{60}}{0.89} \times 100}{C_o}$$

where C_o is the count rate from the first frame and C_{60} is the count rate from the last frame obtained at 60 min. Division by 0.89 corrects for decay during the 60-min period.

HEPATOBILIARY SCINTIGRAPHY

The diagnosis of biliary tract abnormalities in infants is difficult because many diverse conditions may affect the hepatobiliary system. Conventional biochemical tests are effective in diagnosing some very specific metabolic abnormalities, but do not always differentiate between the various other causes of hyperbilirubinemia (*11*). Generally, noninvasive diagnostic modalities are preferred, since invasive procedures, such as percutaneous transhepatic cholangiography, are difficult to perform and potentially hazardous to children (*1*). Currently the noninvasive modalities available to assess the biliary system include the oral cholecystogram, intravenous cholangiography, computed tomography, ultrasound, and hepatobiliary scintigraphy. In recent years the use of radionuclides in evaluating the biliary system has been motivated by the development of hepatobiliary agents based on iminodiacetic acid (IDA), a class of ^{99m}Tc-labeled complexes developed by Loberg and colleagues (*9*). The IDA compounds have high hepatocyte extraction efficiency, low extraction in other organs, short parenchymal transit time, and provide diagnostic information in jaundiced patients with direct serum bilirubin levels exceeding 10 mg/dl.

Technical Considerations

Infants and children referred for biliary scintigraphy are fasted for a minimum of 2 hr prior to radionuclide examination. An intravenous injection of 200 μCi/kg body weight of a ^{99m}Tc hepatobiliary agent is administered. Minimum doses of 500 μCi and 1 mCi are administered to nonjaundiced and jaundiced patients, respectively. The child is placed supine under the scintillation detector, and anterior images are acquired for 500,000 counts at 5-min intervals for 1 hr. Additional images are obtained at 2 hr, 4–6 hr, and 24 hr, or until activity is demonstrated in the biliary system and intestine. Electronic magnification may be used for neonates and infants. Oblique and lateral images aid in distinguishing low concentration gallbladder filling from right renal collecting system activity, the former being anterior and the latter posterior (*2*). A low-energy all-purpose or high-resolution collimator may be used. When the differential diagnosis is between biliary atresia and neonatal hepatitis, premedication with phenobarbital is advised according to the protocol described later.

A normal hepatobiliary examination (Fig. 3) will demonstrate the liver, intrahepatic ducts, gallbladder, extrahepatic ducts, and intestine within 60 min of injection. Most frequently maximum liver incorporation of the radiotracer occurs 5–10 min after injection. The biliary tract and gallbladder are visualized between 15 min and 40 min, and complete liver extraction is noted within 2 hr to 2.5 hr (*3*).

Clinical Applications

Hepatobiliary scintigraphy is useful in evaluating neonates with hyperbilirubinemia that can result from neonatal hepa-

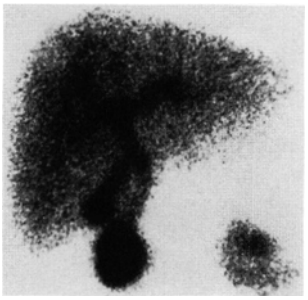

FIG. 3. Normal hepatobiliary image.

titis, biliary atresia, and metabolic abnormalities such as alpha-1-antitrypsin deficiency. Other clinical indications include the assessment of liver transplants, biliary cirrhosis, choledochal cyst, and bile leak secondary to trauma. According to Sty et al., between 60%–75% of the cases of prolonged jaundice in newborns fall into two categories: congenital obstructive biliary tract disease (biliary atresia) and congenital inflammatory liver disease (neonatal hepatitis) (*1*). Frequently, biliary scintigraphy is performed to establish a differential diagnosis between these two disease entities, as it is direct, noninvasive, and provides considerable morphologic and physiologic information. The appearance of radioactivity in the bowel excludes biliary atresia, but the absence of it is indeterminate. Some patients with hepatitis associated with severe intrahepatic cholestasis will not show bowel excretion even when followed for up to 96 hr (*2*). To aid in differentiating the aforementioned etiologies, it is essential to maximize biliary excretion of tracer. Phenobarbital enhances the biliary excretion of conjugated bilirubin. With phenobarbital premedication, an accuracy of 90% or greater in distinguishing biliary atresia from neonatal hepatitis can be achieved (*10*). The recommended dose of phenobarbital is 5 mg/kg/day, divided into two equal oral doses, for three to seven days (*11*).

Hepatocyte clearance is best evaluated by comparing liver activity to cardiac blood-pool activity at a selected time prior to the occurrence of biliary excretion. This ratio is not a precise measurement of hepatocyte clearance, but it is a reliable index. Neonates with severe hepatitis have poor hepatic extraction, and tracer accumulation in the liver is primarily due to hepatic blood-pool activity rather than polygonal cell extraction (*3*). The hepatic blood-pool activity will decrease at the same rate as does the cardiac blood-pool activity (Fig. 4). Technetium-99m-IDA images of neonates with hepatitis generally demonstrate poor hepatic uptake, nonvisualization of the gallbladder and biliary ducts, and delayed appearance of activity in the intestine (Fig. 5). Biliary atresia is characterized by good hepatic tracer uptake and by nonvisualization of the gallbladder, ducts, and intestinal activity, with prominent renal excretion of the radiotracer (Fig. 6A-B).

Postsurgical Evaluations

Portoenterostomies (Roux-en-Y jejunal conduits) are performed in children with disease entities such as biliary atresia,

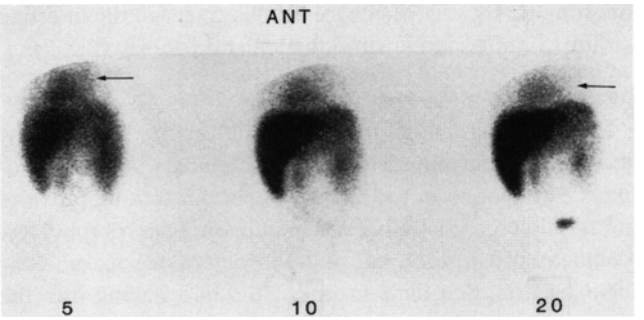

FIG. 4. Neonatal hepatobiliary images demonstrating severe hepatitis. Note linear decrease in hepatic and cardiac blood-pool activity.

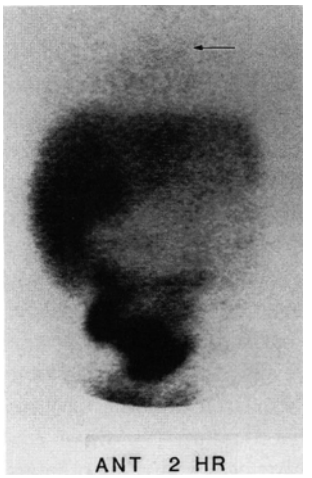

FIG. 5. 2-hr delayed image of neonate with severe hepatitis. Note nonvisualization of biliary ducts and gallbladder, delayed appearance of intestinal activity, and residual cardiac blood-pool activity.

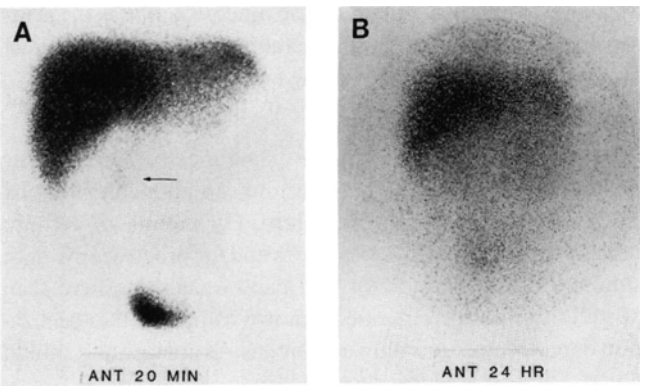

FIG. 6. (A) 20-min image of neonate with biliary atresia. Note good tracer uptake, nonvisualization of gallbladder, and prominent renal excretion (arrow). (B) 24-hr delayed image demonstrating no evidence of ductal, gallbladder, or intestinal activity.

choledochal cyst, sclerosing cholangitis, common bile duct stenosis, and posthepatic resection. A section of the small intestine, specifically the jejunum, is anastomosed to the hepatic ductal system to divert bile flow into the intestine (*12*). Hepatobiliary imaging is useful in evaluating conduit patency immediately postsurgery. Additionally, the integrity of the portoenterostomy may be assessed to detect dilatation, narrowing, or obstruction either within the liver or at the

anastomotic site. The evidence of radiotracer in the intestine within 1 hr after administration confirms patency (Fig. 7).

Hepatobiliary Trauma

Blunt trauma to the abdomen, child abuse, liver biopsy, and birth trauma may all result in hepatobiliary injury. Radionuclide evaluation of the biliary system posttrauma provides information representative of function as well as morphology. Technetium-99m-IDA imaging will detect bile leaks, show their location, and demonstrate if the bile leaking into the peritoneal cavity is greater than the bile flow into the intestine (Fig. 8). Scintigraphy can also determine the integrity of the liver capsule by showing confinement of the bile leak.

MECKEL'S DIVERTICULUM IMAGING

Meckel's diverticulum is a congenital anomaly located on the antimesenteric side of the small intestine resulting from incomplete closure of the omphalomesenteric duct, occurring in ~2% of the general population. Only 25%–40% of those affected are symptomatic. Meckel's diverticulum usually contains ileal mucosa, but may contain gastric, colonic or duodenal mucosa (*4*). Technetium-99m-pertechnetate is known to concentrate in gastric mucosa, and this fact justifies its use in this procedure. The pertechnetate anion is accumulated via active transport by the mucous surface cells in the gastric mucosa. Currently radionuclide imaging is considered to have an accuracy of 90%–98%, thus it is the examination of choice when searching for Meckel's diverticulum (*1*). Most frequently the patient is in the pediatric age group and presents with rectal bleeding as hematochezia (fresh blood in the stool) or melena, or with anemia. Approximately 50%–60% of all Meckel's diverticula contain gastric mucosa, and it is the acid-pepsin secretions that cause ulceration of the adjacent ileal mucosa with consequent bleeding (*1,13*).

Technical Considerations

Barium studies and proctoscopy should be performed after radionuclide imaging, because barium can attenuate photons and obscure Meckel's diverticulum. Hyperemia of colonic mucosa, attributable to bowel preps and/or proctoscopy, may simulate tracer localization and cause a false-positive scan (*1-3*). Potassium perchlorate is known to inhibit the localization of pertechnetate within ectopic gastric mucosa and should not be administered prior to the scan.

The patient should be fasted for several hours before imaging. It has been suggested that premedication with cimetidine indirectly increases the concentration of pertechnetate in gastric mucosa by inhibiting the secretion of pertechnetate from the cells into the lumen of the gastrointestinal tract (*3*). The cimetidine is administered orally or intravenously, at a rate of 5 mg/kg of body weight, in three equal doses over a 24-hr period. The patient should void just prior to the imaging procedure to avoid bladder interference. The child is placed in the supine position beneath the gamma camera detector. A low-energy all-purpose, high-resolution, or converging collimator may be used. Intravenously administer 200 μCi/kg, with a minimum of 2 mCi, of ^{99m}Tc-pertechnetate and acquire anterior images for 350,000 counts to 500,000 counts for infants or 750,000 counts to 1 million counts for older children and adolescents. Images should be obtained immediately and every 5 min for the first 30 min and at 45 min. Right lateral, oblique, and posterior projections are included at the 15- and 30-min intervals. If questionable findings or suspicious areas of tracer localization are seen, delayed images the appropriate projections should be acquired at 1.5 hr to 2 hr. Nasogastric suction may enhance the study when rapid gastric excretion of ^{99m}Tc occurs. Administer 6–8 mg/kg of potassium perchlorate post-imaging to decrease thyroid accumulation of pertechnetate.

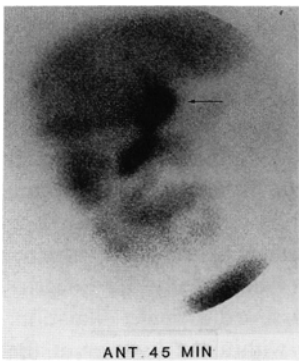

FIG. 7. Biliary atresia patient s/p portoenterostomy. Patency of conduit confirmed by appearance of radiotracer in intestine within 60 min.

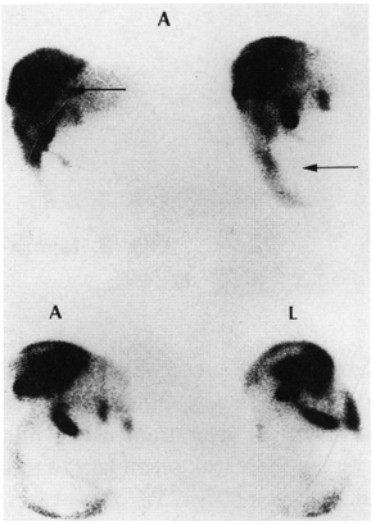

FIG. 8. Blunt trauma causing fracture of liver, leading to massive intraperitoneal bile leak. (Reprinted by permission from Dr. John Sty).

Clinical Application

Usually Meckel's diverticula are found in the right lower quadrant of the abdomen, but they can be located elsewhere and have been reported to move during the study (*3*). The appearance of activity within the ectopic gastric mucosa occurs simultaneously with that of the stomach. This important feature helps to differentiate ectopic gastric mucosa from inflammatory causes, which tend to accumulate the radiotracer later in time; it also helps to distinguish an extrarenal pelvis from Meckel's diverticulum (*2*). Abnormal localization of the radiotracer persists in multiple images during the study and may be appreciated in several projections (Fig. 9).

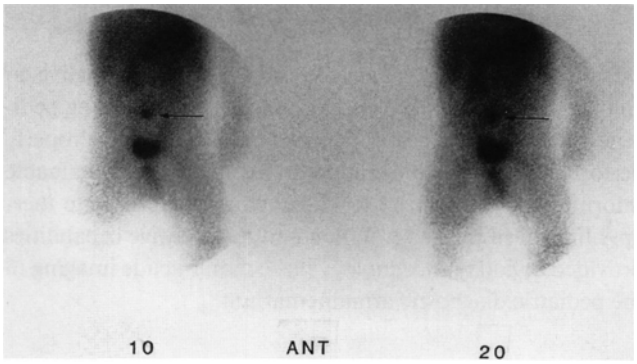

FIG. 9. Anterior 10-min and 20-min images of patient with Meckel's diverticulum. Focus of activity in periumbilical region (arrow).

SCINTIGRAPHY OF GASTROINTESTINAL BLEEDING

Localization of the bleeding site in patients presenting with acute gastrointestinal hemorrhage remains a serious diagnostic problem. Active rectal bleeding (hematochezia) and melena are frequently associated with Meckel's diverticulum, when encountered in children, but this is not always the case. The primary sources of upper gastrointestinal bleeding include esophagitis, esophageal varices, gastric ulcer disease, and as a consequence of gastric surgery (*4*). Lower gastrointestinal bleeding may result from colitis, angiodysplasia, and Crohn's disease and other inflammatory bowel diseases (*4*). In the past, angiography was the preferred diagnostic approach. However, this procedure is invasive and will demonstrate bleeding only when the injection of contrast coincides with active bleeding at a rate of 0.5 ml/min or greater (*2*). Endoscopy and barium studies are of limited value in the presence of active hemorrhage. Limitations associated with the aforementioned diagnostic techniques stimulated the development of radionuclide methods.

Successful radionuclide imaging is dependent upon tracer extravasation into the bowel lumen while the radiotracer is blood borne. Current scintigraphic evaluations utilize agents which may be categorized according to their rate of blood clearance. Agents may be rapidly extracted from the circulation or remain in the circulation for a prolonged period. Technetium-99m-sulfur colloid is representative of the former and labeled red blood cells of the latter.

TECHNETIUM SULFUR COLLOID IMAGING

The ^{99m}Tc-sulfur colloid technique developed by Alavi and colleagues is based on the following theory: when a radioactive agent cleared by a specific organ (e.g., the liver) is intravenously injected into a patient with active bleeding, a small fraction of the injected activity will extravasate at the bleeding site and will be eliminated from the circulation (*4*). This phenomenon will continually repeat itself as the blood recirculates and adds another, but smaller, fraction of activity to that already at the hemorrhage site. Due to continued clearance of the radiotracer from the vascular system by the target

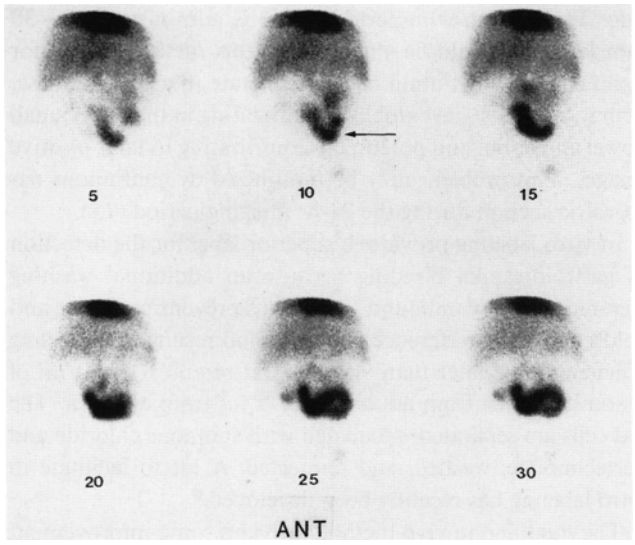

FIG. 10. Anterior image sequence of 3-mo-old infant with small bowel bleed (arrow).

organ, a high contrast is eventually reached between the site of bleeding and the surrounding background. Technetium-99m-sulfur colloid imaging has several distinct advantages: the radiopharmaceutical is readily available, easily prepared, and a diagnosis may be provided in less than 30 min (*14*). A disadvantage, associated with rapid vascular clearance by the reticuloendothelial system ($t_{½}$ = 2 min) is that bleeding can only be detected if it occurs at the time of tracer injection. Also, bleeding sites in the upper abdomen may be obscured by the activity in the liver and/or spleen (*15*). The recommended reinjection of radiotracer upon renewed hemorrhage is impractical for children, as the radiation exposure to the liver and spleen in such instances is substantial in comparison with a single administration of ^{99m}Tc-red blood cells (*16*).

TECHNETIUM-99M-LABELED RED BLOOD CELL IMAGING

Technetium-99m-labeled red blood cells (RBCs) remain in the circulation for a prolonged period and provide the opportunity to detect slow and intermittent bleeding over 24 hr. Clinical reports by many investigators support the superiority of this technique when the slow or intermittent bleeder is to be evaluated (*17*). Labeled RBCs continue to circulate and extravasate at the site of any bleeding. They can localize active hemorrhage within minutes (Fig. 10), and occult bleeding sites with bleeding rates as low as 0.1 ml/min can be detected on delayed images (*14*). In labeling RBCs with ^{99m}Tc, the in vivo, in vitro, or modified in vivo methods have been utilized. All of them require the initial administration of a reducing agent, stannous chloride, which reduces the surface membrane of the RBC so that ^{99m}Tc-labeling may occur. This process is often referred to as "pretinning" of the RBCs.

The in vivo method involves the pretinning of circulating RBCs by intravenously administered reconstituted "cold" pyrophosphate from a kit containing 1 mg of stannous chlo-

ride. Technetium-99m-pertechnetate is administered 20–30 min later. It should be stressed that this method allows for significant concentration of pertechnetate in gastric mucosa, with some activity eventually accumulating in the lower small bowel and colon and potentially contributing to false-positive images. This problem may be minimized by continuous nasogastric suction during the 24-hr imaging period (*15*).

In vitro labeling provides a superior label for the detection of gastrointestinal bleeding because an additional washing step removes any unbound ^{99m}Tc, thus preventing gastric and colon activity interference. This method results in a labeling efficiency of greater than 90% (*14*). It requires 10–20 ml of blood be drawn from adults and 2–5 ml from children. The red cells are separated, incubated with stannous chloride and pertechnetate, washed, and reinjected. A kit to facilitate in vitro labeling has recently been developed.*

The modified in vivo method provides some improvement in labeling efficiency when compared to the basic in vivo method. This is the most commonly used method and is recommended when in vitro labeling cannot be accomplished, since it reduces free pertechnetate interference (*18*).

Technical Considerations

The patient should be barium-free and fasted, if possible, prior to the imaging procedure. When using ^{99m}Tc-sulfur colloid, the radiopharmaceutical should be freshly prepared. The child is placed in the supine position beneath the detector with a low-energy, all-purpose or high-resolution collimator. Intravenously administer 200 μCi/kg, minimum 2 mCi, of ^{99m}Tc-sulfur colloid and imaging is begun immediately. An anterior dynamic sequence is acquired at one image per 2 sec for 30 images. Static images are then obtained immediately after the dynamic sequence and at 5 min, 10 min, 15 min, and 30 min for 500,000 counts/image. When utilizing red cells as imaging agents, pretinning of the RBCs is accomplished by intravenously administering stannous chloride in accordance to the child's weight, ~10 μg of Sn^{+2}/kg (*3*). For modified in vivo labeling of the RBCs, wait 20 min post-stannous chloride administration and, using a butterfly needle connected to a 5 cm extension port, withdraw 2–5 ml of blood in a 5 ml shielded syringe which has been anticoagulated with acid citrate-dextrose (ACD). The shielded syringe should contain 0.2–0.5 ml of ACD and 200 μCi/kg, minimum 3 mCi, of ^{99m}Tc-pertechnetate. Incubate for 15–20 min, with occasional gentle mixing. The butterfly/extension port may be maintained within the vein and kept patent by continual flushing with saline or a dilute mixture of ACD and saline. The patient is placed supine underneath the detector with a low-energy, all-purpose or high-resolution collimator and an anterior dynamic image sequence is recorded at one image per 2 sec for 30 images as the RBCs are reinjected. Anterior static images are acquired at 5-min intervals for 60 min for 500,000 counts/image. If the bleeding site is not visualized, delayed images should be performed at 4–6 hr and 24 hr or if renewed hemorrhage occurs. If the patient stools during the interim, the stool should be placed under the detector to monitor for the presence of radioactivity.

CONCLUSIONS

Scintigraphy offers a sensitive and specific alternative to conventional and invasive procedures when evaluating pediatric patients with gastrointestinal abnormalities. Properly performed scintigraphic studies afford the clinician valuable information with respect to diagnosis and appropriate therapy. Improved image resolution and quantitative capabilities provided by today's technology place radionuclide imaging in the pediatric diagnostic armamentarium.

NOTES

* Brookhaven National Laboratory, Upton, NY.

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Figure 8 courtesy of John R. Sty, MD, reprinted with permission from the textbook, *Pediatric Nuclear Medicine*, Appelton-Century-Crofts, Norwalk, CT. Figure 10 courtesy of Children's Hospital of Philadelphia, Department of Nuclear Medicine.

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