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Кафедра онкологии с курсом лучевой диагностики и лучевой терапии

Н. М. ЕРМОЛИЦКИЙ

ЛУЧЕВАЯ ДИАГНОСТИКА И ЛУЧЕВАЯ ТЕРАПИЯ

**Учебно-методическое пособие
для студентов 3 курса факультета по подготовке специалистов
для зарубежных стран медицинских вузов**

В двух частях

Часть 2

RADIOLOGY

**Teaching workbook
for 3rd year students of the Faculty of preparation of experts
for foreign countries of medical higher educational institutions**

In two parts

Part 2

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Учебно-методическое пособие подготовлено в соответствии с типовой программой по специальности «Лечебное дело», содержит необходимые для усвоения основные разделы по радиологии желудочно-кишечного тракта, радиологии мочевыделительной системы, а также по радионуклидной диагностике, лучевой терапии и рискам, связанным с медицинским облучением.

Материалы адаптированы к русскоязычному варианту изложения лучевой диагностики и лучевой терапии с учетом объема часов, могут быть использованы студентами старших курсов факультета по подготовке специалистов для зарубежных стран при изучении терапевтических и хирургических дисциплин.

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1. GASTROINTESTINAL IMAGING. RADIOLOGY OF ESOPHAGUS

Introduction

The esophagus, stomach, and small intestine are not well seen on plain x-ray films. In order to examine these organs well it is necessary to swallow a barium fluid that can be seen on a fluoroscope screen and on the x-ray films. The classical radiological imaging methods such as upper GI examination still play an important role whenever physiological motion plays a role (swallowing, peristalsis of the esophagus, gastric motility, etc.) and in postoperative patients, e. g., when the evaluation of an anastomosis has been requested. The oral administration of contrast is obligatory in these cases.

Examination techniques of gastrointestinal tract

Plain radiography

There is no routine use of plain radiography in the assessment of oesophageal disease, with the exceptions of suspected perforation or radio-opaque foreign bodies, when a preliminary chest radiograph is indicated. However, in general, plain radiographs add little useful information. With the proliferation over the past two decades of imaging techniques, such as CT and ultrasound (US), and other modalities, such as endoscopy, the role of plain abdominal radiography has decreased. The abdomen X-ray (AXR) is still a quite usually primary investigation in the patient with acute abdomen. A number of less-common indications will be encountered such as swallowed (or inserted) foreign body.

Luminal contrast barium studies

Principle: contrast is instilled into the organ that is being studied and x-rays are then taken.

Luminal contrast examinations of the gastrointestinal tract can be performed with a variety of contrast materials. Barium sulfate suspensions are the preferred material for most examinations. A variety of barium products are available commercially, and many are formulated for specific examinations depending on their density and viscosity. Water-soluble contrast agents, which contain organically bound iodine, are used less often, primarily to demonstrate perforation of a hollow viscus or to evaluate the status of a surgical anastomosis in the gastrointestinal tract.

These are simple to perform, inexpensive and have high sensitivity. Ideally, as in the rest of the alimentary tract, the best results are obtained with double-contrast studies, although these may be difficult to achieve because of the transient nature of oesophageal dilatation during swallowing. Good fluoroscopy is essential, aided by digital imaging for spot radiographs.

The examination starts with the patient erect and turned obliquely to the left, so that the body of the oesophagus is thrown clear of the spine. The initial

bolus is observed fluoroscopically, to ascertain if there is any obvious structural abnormality, followed by spot radiographs of the upper mid and lower oesophagus, including the cardia.

The table is then placed horizontally for a prone swallow accomplished with the patient in the right anterior oblique position. The purpose of this procedure is to assess motility in the body of the oesophagus and to fully distend the gastro-oesophageal junction. When assessing motility, only a single bolus of barium should be swallowed as repeated swallowing interferes with the assessment of normal motility. The passage of the bolus is marked by the primary stripping wave, which is a muscular contraction that propels the bolus downwards and collapses the lumen of the oesophagus. Any residual barium will then be cleared by a secondary wave.

A single-contrast study of a GI structure means that one contrast agent is used, such as a suspension of barium sulfate, an ionic water-soluble contrast agent such as diatrizoate meglumine (Gastroview/Gastrografin), or a nonionic water-soluble contrast agent such as iohexol (Omnipaque).

In a double-contrast study, the radiologist uses two contrast agents to examine the organs in question. A double-contrast upper GI series uses an effervescent agent that creates carbon dioxide to distend the luminal organs and high-density barium to “scrub and paint” the mucosa.

Patient preparation included: nil by mouth for a couple of hours. Contraindications of examination: bowel obstruction. A good examination requires an empty stomach and therefore you will not be able to have any food or fluids by mouth 10–12 hours before your exam. Chewing gum or other material or smoking will also create saliva to swallow which will make extra fluid in stomach and must be avoided.

Computed tomographic imaging

The major role of computed tomography (CT) in the assessment of oesophageal disease is mainly confined to the staging of oesophageal cancer. It performs two functions here: (A) the assessment of local spread of tumour; and (B) the assessment of metastatic disease, particularly to the liver and gastric lymph nodes. Thus, the whole of the thorax and upper abdomen should be examined. If the tumour is sited at the gastro-oesophageal junction or is primarily gastric in position, then a large bolus of water is usually given beforehand to obtain maximal distension of the stomach.

CT imaging of the chest and abdomen can portray the various hollow organs of the gastrointestinal tract. Mucosal disease, such as ulcers, and small neoplasms will not be shown with this imaging modality. Larger gastrointestinal neoplasms, thickening of the walls of the hollow organs, and extrinsic processes can be easily detected. Also, with the use of luminal distention and intravenous contrast material, a variety of gastrointestinal disorders are more readily evaluated.

Abdominal ultrasound

Abdominal ultrasound has had an increasing impact on evaluation of the hollow organs of the gastrointestinal tract, although in the United States, this modality

is used mainly to examine the solid organs of the abdomen and the biliary tract, including the gallbladder. The location of the hollow organs and the presence of gas interference remain technical problems; however, inflammatory disorders can be evaluated, such as acute appendicitis, especially in pediatric patients. Endoluminal ultrasound using blind probes or those attached to an endoscope has been used in the upper gastrointestinal tract to detect and stage malignancy; other indications include fine-needle aspiration (FNA) through the gastrointestinal wall.

Endoscopic ultrasound

The limitations of CT in assessing the oesophageal wall can be overcome by the use of endoscopic ultrasound (US). This technique utilizes an US probe that is mounted at the end of an endoscope and, depending on the manufacturer, is either of linear array or a radial sector arrangement. The endoscope itself may be forward-viewing or oblique-viewing so that a lesion can be observed and then the probe applied to it. The probe frequencies are in the range of 7–12MHz and this is high enough to delineate the five layers of the oesophageal wall: mucosa, muscularis mucosa, submucosa, muscularis propria and adventitia. These are demonstrated as alternating layers of reflectivity. In addition, small lymph nodes adjacent to the oesophageal wall can be visualized, and with certain probes fine-needle aspiration can also be performed.

Radionuclide radiology

The prime role here is in the assessment of motility disorders of the oesophagus and in the investigation of gastro-oesophageal reflux disease. For the former, the patient is placed in a horizontal position under a gamma camera and is given a standard radioactive meal, usually consisting of ^{99m}Tc -sulphurcolloid-labelled scrambled egg or equivalent. Similarly, patients with suspected reflux are examined in the horizontal position, having drunk water labelled with ^{99m}Tc -sulphurcolloid. This investigation may in addition demonstrate complications such as aspiration into the lungs.

Positron emission tomography is a physiological imaging technique that relies on the metabolism of ^{18}F -FDG to yield images. Because of this feature it has found a particular role in the staging and follow-up of tumours, including the oesophagus. The advent of hybrid PET/CT machines that combine the anatomical accuracy of CT with the physiological feature of PET have enhanced this function.

Magnetic resonance imaging

Magnetic resonance (MR) imaging is the newest modality developed for cross-sectional imaging of the body and nearly all organ systems can be evaluated with this technique. MR imaging of the hollow organs of the gastrointestinal tract is increasingly being used to evaluate a wide assortment of gastrointestinal tract disorders. As with CT imaging, mild mucosal diseases and small focal lesions are not well detected with this technique; however, malignancies can be similarly evaluated and staged. With the newer technologies, both CT

and MR imaging offer multiple options for viewing the gastrointestinal tract, including multiplanar viewing and 2-D and 3-D reconstructions.

MR imaging of the oesophagus is not widely used. There are no definite protocols for oesophageal imaging, but there are some basic necessities. Cardiac gating may be needed to reduce the problem of motion artefact. Both T1- and T2-weighted imaging is necessary, ideally using breath-hold (e.g. gradient echo) sequences. Images in coronal and sagittal planes may be helpful over and above the standard axial sequences.

Normal anatomy of the esophagus

The esophagus is a muscular tube that is normally 25-30 cm long and 2-3 cm wide. The esophagus is divided into three segments: the cervical, thoracic, and abdominal segments. The cervical portion is separated from the cervical vertebrae by only a few mm of prevertebral soft tissue. It is also in contact with the trachea and the left mainstem bronchus, separated only by connective tissue. There are several structures that are in close proximity to the esophagus and which make normal impressions on it. These structures are the aortic arch, the left mainstem bronchus, the left inferior pulmonary veins (figure 1.1).

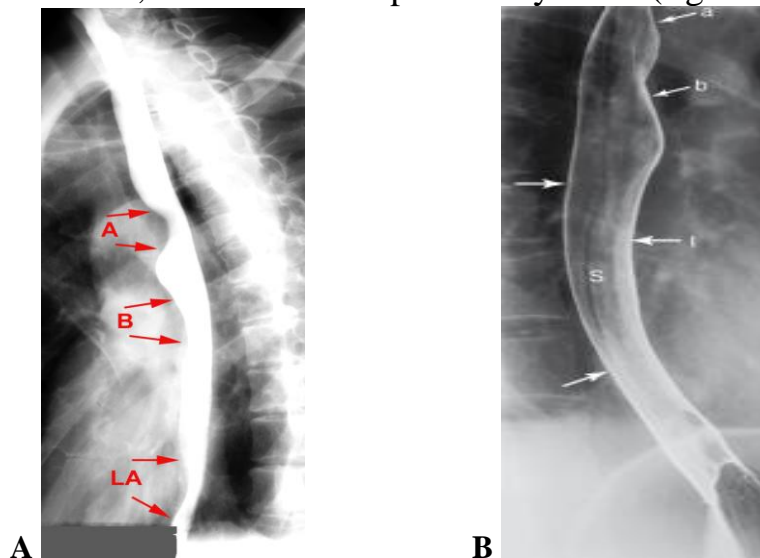


Figure 1.1 — (A) Is an example of a single-contrast image obtained with the patient swallowing barium while in a vertical position. This oblique view of a normal barium swallow shows the normal impressions made by the (A with arrows) aortic arch, (B with arrows) left mainstem bronchus, and (LA with arrows) left atrium on the esophagus.

(B) Radiograph shows a normal lower thoracic esophagus. The esophagus is a muscular tube within the mediastinum. The esophagus is usually collapsed unless distended by liquid or solid food; swallowed air; or, in this image, swallowed air and barium. These indentations are identified as the bottom of the aortic arch (a), the left main stem bronchus (b), and the left atrium (l).

In this patient, swallowed high-density barium coats the mucosa. The swallowed carbon dioxide (effervescent agent) and swallowed air distend the lumen of the esophagus. The mucosa of the esophageal tube seen in profile appears as a white line (arrows). The mucosal surface of the normal esophagus seen en face is smooth and varies from white to gray (mucosa identified by S). Normal structures in the mediastinum push on the distended esophagus, manifested as alterations of the normal straight tubular contour of the esophagus

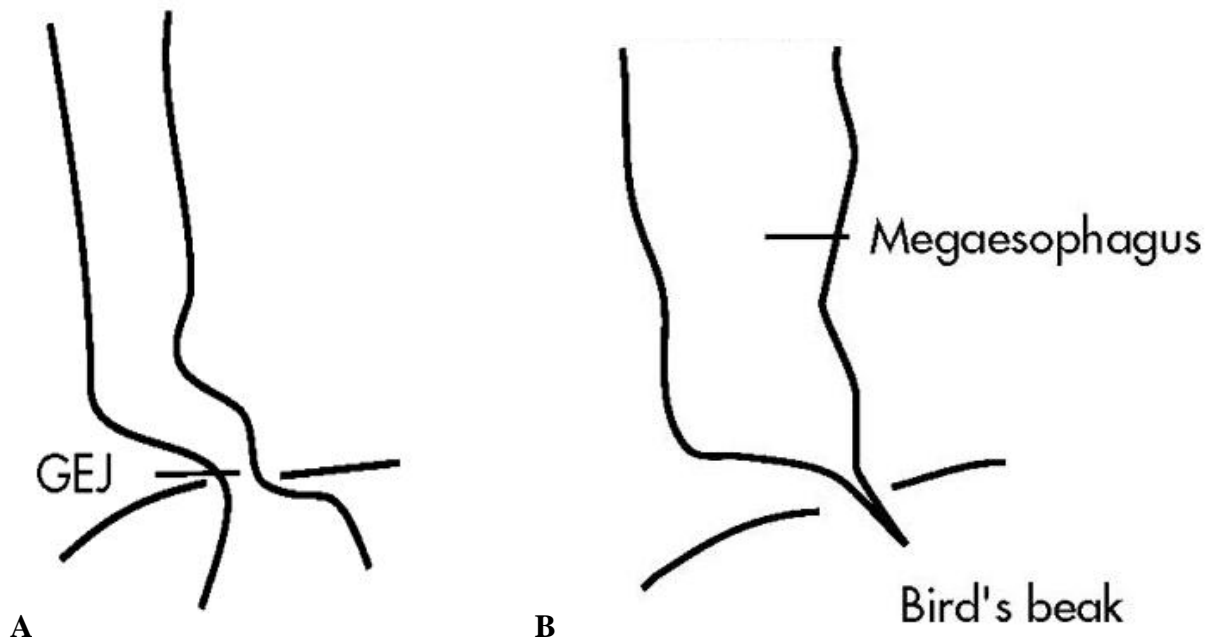
The wide spectrum of motility disorders ranges from the well-defined primary esophageal motility disorders to very nonspecific disorders that may play a more indirect role in reflux disease. Primary motility disorders include nonspecific esophageal motility disorder, achalasia, diffuse esophageal spasm and hypertensive lower esophageal sphincter. The classic finding in diffuse esophageal spasm, most commonly seen during a barium swallow study, is the “corkscrew” or “rosary-bead” appearance of the esophageal body during a simultaneous contraction.

Radiographical imaging diseases of the esophagus

Achalasia

Achalasia is a primary esophageal motility disorder characterized by aperistalsis and lower esophageal dysfunction. The gastroesophageal sphincter fails to relax because of wallerian degeneration of Auerbach's plexus. The sphincter relaxes only when the hydrostatic pressure of the column of liquid or food exceeds that of the sphincter; emptying occurs more in the upright than in the horizontal position.

Radiological findings: on plain films, achalasia can be recognized by massive esophageal dilatation with possible large amounts of retained food and fluid in the esophagus. Typically, the distal esophagus has a smooth, tapered appearance often likened to a "bird's beak" which reflects the dysfunction. Image depicts of the esophagus showing a massively dilated esophagus with retention of contrast in the distal portions of the esophagus, shows the "bird's beak" appearance of the dysfunctional lower esophageal sphincter (figure 1.2).



**Figure 1.2 — Schemes of distal esophagrams (GEJ — gastro-oesophageal junction).
(A) Normal, (B) achalasia of the esophagus**

Diverticula

Esophageal diverticula can be classified based on their location (i.e. cervical, midesophageal, epiphrenic, intramural, or intraluminal). The diverticula may fill with food or fluids and compress the true lumen of the esophagus causing dysphagia.

Radiological findings: Image depicts the frontal view of a large barium-filled sac. On double-contrast esophagograms, most of the outpouchings are still filled with barium. Diverticula are outpouchings of one or more layers of the intestinal wall that may occur at any level of the esophagus. Esophageal diverticula can be classified as traction diverticula, which are composed of all esophageal layers, and pulsion diverticula, which are composed only of mucosa and submucosa herniating through the muscularis. Traction diverticula often have a triangular or tented appearance resulting from traction on the diverticulum by the fibrotic process in the adjacent mediastinum. Pulsion diverticula appear on barium studies as rounded wide-necked outpouchings that fail to empty when the esophagus collapses.

Perforation

Untreated thoracic esophageal perforations have a near 100% mortality rate.

Radiological findings: on plain films, subcutaneous emphysema may be visible on AP or lateral films of the neck. Air may also dissect into the chest and produce a pneumomediastinum. Lateral films of the neck may reveal widening of the prevertebral space, anterior deviation of the trachea, or a retropharyngeal abscess with an air-fluid level.

If a cervical perforation is suspected on plain film, the study should be followed up with a water-soluble contrast study. On the esophogram, one would look for localized extravasation of contrast medium into the neck or mediastinum.

Foreign bodies/food impaction

80 % of pharyngeal or esophageal foreign body impactions occur in children, who accidentally ingest coins, toys, etc. In adults however, animal/fish bones or large boluses of meat cause most foreign body impactions. The risk of esophageal perforation in foreign body impaction is less than 1 %, however, the risk increases significantly if the foreign body remains lodged for greater than 24 hours.

Radiological findings: occasionally, the foreign object may be radiopaque and visualized. Contrast studies can also be performed. Animal/fish bones may be obscured by barium, but they can sometimes be visualized as linear filling defects.

If the food bolus is completely obstructing the esophagus, then contrast studies may reveal a polypoid filling defect outlining the superior aspect of the bolus. If the obstruction is incomplete, contrast may trickle around the bolus and continue downstream towards the stomach. After the food impaction is treated, an esophagram should be completed to look for abnormal esophageal strictures.

Esophagitis

Esophagitis may present with erosions, ulcers, and strictures and rarely with perforations and fistulas. Types esophagitis: infectious (herpes, candidiasis), chem-

ical (reflux esophagitis, corrosives), iatrogenic (radiotherapy, extended use of nasogastric tubes, drugs (tetracycline, antiinflammatory drugs, potassium, iron)).

Radiographic features: thickening, nodularity of esophageal folds; irregularity of mucosa (granularity, ulcerations); retraction, luminal narrowing, stricture.

Corrosive/caustic esophagitis

Ingestion of caustic or corrosive agents (i.e. lye, dishwasher detergents, alkali or acidic agents) causes acute and chronic inflammatory changes mostly in the distal two-thirds of the esophagus. There are three characteristic phases of injury in caustic esophagitis: 1) acute necrosis, 2) ulceration-granulation, 3) stricture formation. Chest and abdominal radiographs should be ordered routinely for patients who have ingested these agents. Chest films may reveal a dilated esophagus or evidence of esophageal perforation. Abdominal films may show pneumoperitoneum secondary to gastric perforation. If perforation is suspected, the study should be followed up by a water-soluble contrast study.

Radiological findings: in the acute phase, esophagrams may show abnormal esophageal motility with diffuse spasms and poor peristalsis.

On double contrast studies, shallow ulcers may appear as punctuate, linear, or serpiginous collections of barium. In severe cases, the esophagus may show diffuse narrowing with an irregular contour. The strictures typically appear as areas of smooth, tapered narrowing in the cervical or upper thoracic esophagus. Image depict irregular narrowing of the esophagus with ulcerations.

Leiomyoma

Leiomyomas make up approximately 50 % of all benign esophageal tumors. About 60 % of the lesions are located in the distal third of the esophagus, 30 % in the middle third, and 10 % in the proximal third. They appear as discrete submucosal masses ranging from 2–8 cm in size.

Radiological findings: on chest films, leiomyomas may be recognized as a soft tissue mass in the posterior mediastinum or by punctuate areas of calcification in the tumor. A calcified esophageal mass is pathognomonic of a leiomyoma.

In contrast studies, the leiomyomas appear as discrete submucosal masses with round or ovoid filling defects sharply outlined by barium. Larger leiomyomas may occasionally cause some compression of the lumen significantly enough to narrow the lumen. In image, the ovoid filling defects. The smooth surface and obtuse angles formed are of submucosal masses.

Adenocarcinoma

Radiological findings

Early: early esophageal adenocarcinoma may appear as plaques or flat, sessile polyps in the distal esophagus (figure 1.3–1.4).

Late: advanced esophageal adenocarcinomas appear as infiltrating lesions with irregular luminal narrowing or, nodularity or ulceration of the mucosa. Less frequently, adenocarcinomas can appear as a polypoid mass, ulcerative lesion.

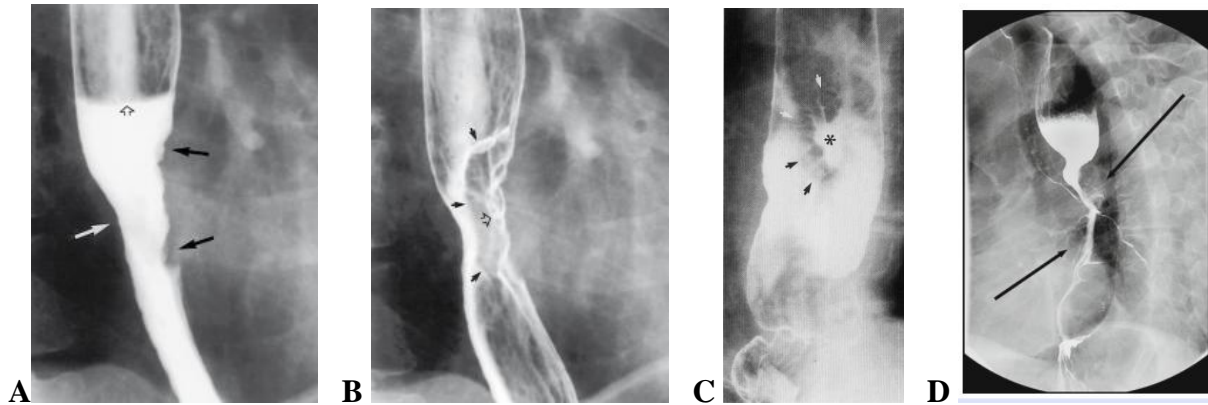


Figure 1.3 — Inflammatory polyp (A, B arrows) and oesophageal carcinoma (C, D).
(A) Spot radiograph of the esophagus performed while the patient stands and drinks high-density barium shows a column of barium (with an air-barium level, open arrow) in the mid-esophagus. A region of focal circumferential narrowing, 3 cm in length, is present. The narrowing appears smooth on one wall (white arrow) and has an irregular contour on the opposite wall (black arrows).

(B) Spot radiograph performed seconds later after the barium column has passed through the esophagus shows the same circumferential narrowing with a smooth contour on one side and an irregular contour on the other. The mucosal surface is now seen en face as well, however, revealing focal mucosal nodularity (open arrow) and barium-coated lines (arrows) that disrupt the normal smooth surface of the esophagus and outline the outer margin of a mass.

(C) Early oesophageal carcinoma. En face there is a central ulcer (asterisk) with a nodular margin (arrows).

(D) Esophageal carcinoma, malignant stricture. A squamous cell carcinoma of the mid-esophagus causes an abrupt narrowing with irregular mucosa. Note the irregularity and overhanging edges (arrows)

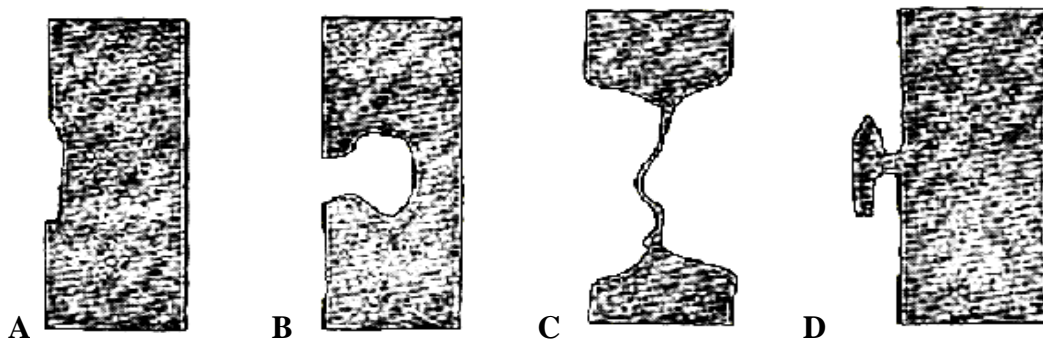


Figure 1.4 — Schemes of esophagograms variants of esophageal tumours.
(A) Infiltrative, **(B)** polypoid, **(C)** annular stenotic, **(D)** ulcerative

On contrast studies, esophageal cancer may appear as an infiltrating, polypoid, ulcerative. Infiltrating cancers show irregular narrowing of the lumen with an associated nodular or ulcerated mucosa with well-defined borders. Polypoid lesions are usually greater than 3,5 cm in diameter and appear as lobulated or fungating intraluminal masses with possible areas of ulceration. Ulcerative carcinomas appear as well-defined meniscoid ulcers with a radiolucent rim of tumor surrounding the ulcer.

2. RADIOLOGY OF STOMACH

Introduction

The stomach are not well seen on plain x-ray films. In order to examine well it is necessary to swallow a barium fluid that can be seen on a fluoroscope screen and on the x-ray films. To X-ray anatomy of stomach: fornix, cardial part, small curvature, large curvature, body of the stomach, angle of the stomach, antral part, pyloric canal.

Single-contrast radiographic study: the stomach is filled and distended with dilute barium or a water-soluble contrast agent. Water-soluble contrast should be used when perforation or post-operative anastomotic failure is suspected. The stomach is compressed either manually or by positioning to allow for adequate x-ray penetration in the evaluation of each anatomical segment. Single-contrast technique assesses thickness of the gastric folds and evaluation of gastric emptying. Large luminal defects can be detected.

Double-contrast radiographic study: the stomach is temporarily paralyzed by administration of glucagon, filled with dense barium, and distended with gas using effervescent granules. Hence both barium and air are used for contrast. Images are obtained as the patient rolls in various positions to coat the gastric mucosa with contrast. Double-contrast technique provides improved visualization of the gastric mucosa. Several films may be made during this time (figure 2.1).

Limitation: requires fluoroscopy and requires follow up endoscopy to biopsy lesions.

Patient preparation: the patient should have nothing orally after midnight or the next morning preceding the radiographic study (no smoking or chewing gum). Fluid and food in the stomach degrade the examination by interfering with good mucosal visualization and causing artifacts that may mimic disease.

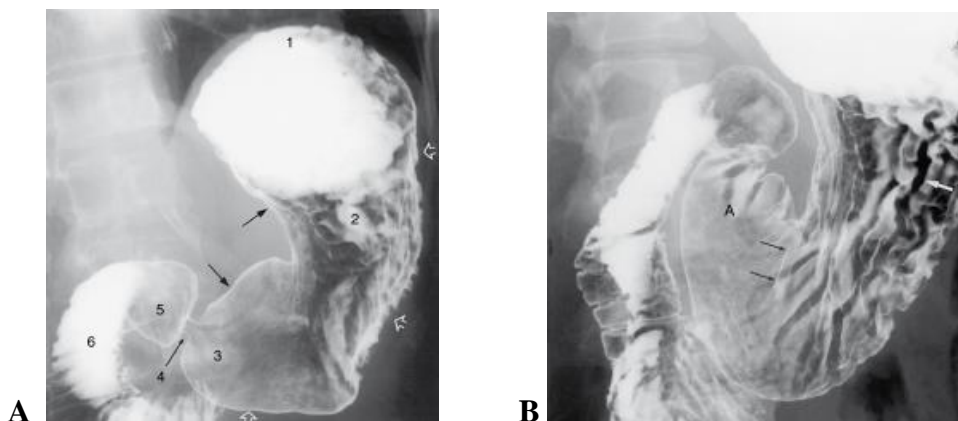


Figure 2.1 — (A) Normal stomach. 1 — gastric fundus, 2 — gastric body, 3 — gastric antrum, 4 — pylorus (pyloric channel), 5 — duodenal bulb, and 6 — second portion of duodenum. (B) is a double-contrast image of the distal stomach. Rugal folds are seen as radiolucent filling defects in the barium pool (white arrow) and as parallel barium etched lines (black arrows).

Rugal folds are composed of mucosa and submucosa and are most prominent along the greater curvature of the stomach. The normal gastric antrum (A) has few, if any, rugal folds in most patients

Magnetic resonance and CT imaging

Magnetic resonance (MR) imaging is the newest modality developed for cross-sectional imaging of the body and nearly all organ systems can be evaluated with this technique. MR imaging of the hollow organs of the gastrointestinal tract is increasingly being used to evaluate a wide assortment of gastrointestinal tract disorders. As with CT imaging, mild diseases and small focal lesions are not well detected with this technique; however, malignancies can be similarly evaluated and staged.

Inflammatory disorders

Gastritis

The appearance of a gastritis can vary. There may be oedema around small ulcers, thickened hyperaemic mucosa, or areas of atrophic mucosa. Islands of more 'normal' mucosa may stand proud from a sea of atrophic thinned mucosa, giving the polyps reported in the fundal type 'A' gastritis.

Perhaps as diverse as the underlying causes are the varied manifestations including erosions, rugal hypertrophy, rugal atrophy, and mucosal nodularity. Given that no single finding or combination thereof is specific for a particular etiology, gastritis is most commonly categorized as either acute or chronic.

Acute gastritis

Radiographic findings: thickened gastric rugae (> 5mm) secondary to edema mucosal nodularity, antral narrowing (indicative of *h. pylori*) (figure 2.2).

Erosions: manifest by small mucosal defects that collect contrast.

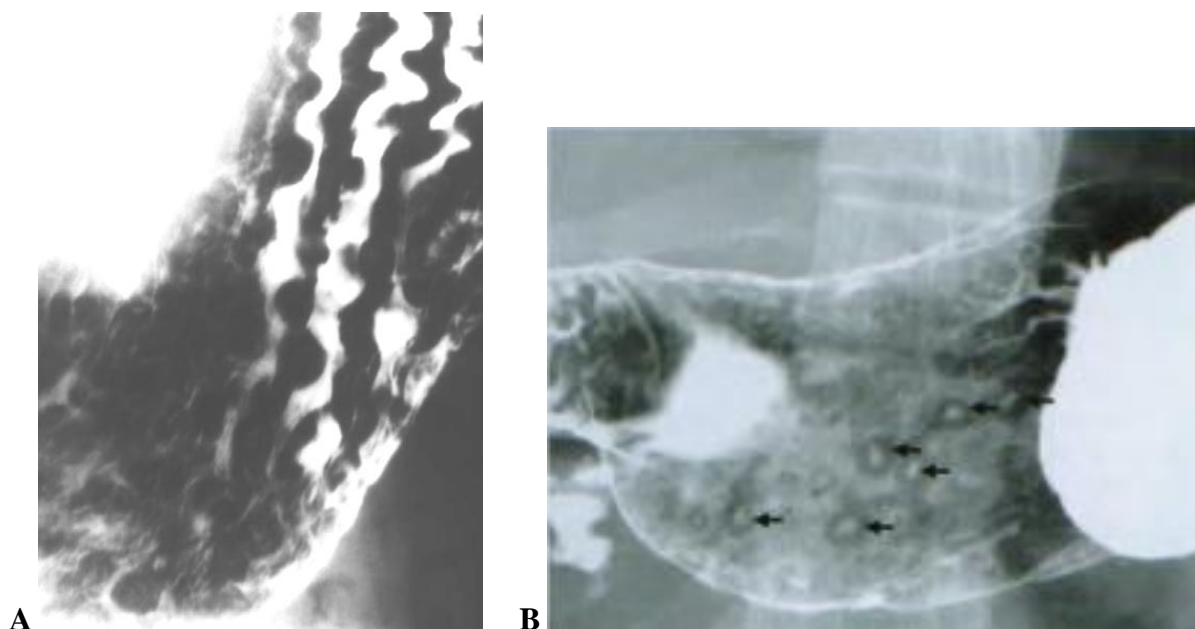


Figure 2.2 — (A) Acute gastritis. Diffuse erosive gastritis with thick nodular folds. Erosions are scattered along the folds.

(B) Acute erosive gastritis. There are numerous erosions in the stomach (arrows). Each erosion consists of a small central collection of barium surrounded by a translucent ring (a small 'target' lesion)

Chronic gastritis

Radiographic findings: thinning or loss of rugal folds (however, thickening may be seen in early chronic disease); widening or loss of the area gastricae; as in acute gastritis, erosive lesions may be appreciated; mucosal nodularity; antral narrowing.

Gastric polyps

Gastric polyps are the most common benign gastric tumor with an incidence of 1,5–5 %. They are typically solitary, but may be multiple or diffuse. Gastric classification is similar to other GI polyps:

1. Hyperplastic: most common; usually small in size and have no malignant potential. Radiographic findings:

– Shape: sessile or pedunculated. “Mexican hat sign” represents the stalk seen overlying the head of polyp.

– Size: usually < 2cm in diameter.

– Surface: sharply margined polyp with smooth circular border.

– Location: variable.

– Often multiple.

2. Adenomatous: tend to be larger and papillary in appearance. Are a malignant precursor. Radiographic findings:

– Shape: broad-based elliptical polyp +/- a pedicle.

– Size: usually > 2cm in diameter.

– Surface: contour is generally lobulated, but may be smooth.

– Location: antrum is most common.

Gastric ulcers

Gastric ulcers are disruptions of the mucosa that extend into or through the submucosa. The radiologic imaging study of choice in the clinical evaluation of suspected gastric ulcers is a double-contrast upper GI series. Features to evaluate include location, shape, penetration, mucosal folds, and the ulcer mound. Ulcers are generally classified as either benign or malignant depending upon their radiographic features and underlying etiology.

Radiographic findings: the distortion and uninterrupted mucosal folds that radiate from (pulled into) the ulcer crater.

Ulcer crater seen en face: distinct collection of barium that persists on different views; the collection is most often round but can be linear. Ulcer crater seen in profile: barium collection extends outside the projected margin of the gastric or duodenal wall. Double-contrast studies: the crater has a white center with surrounding black “collar.”

Benign ulcers

Benign ulcers constitute approximately 95 % of all gastric ulcers. Most benign ulcers heal in 3–4 weeks following treatment with complete resolution by 6 weeks. All gastric ulcers should be followed by repeat examination in 6 weeks to confirm healing. Surgery is rarely performed for benign gastric ulcers but may be indicated if outlet obstruction occurs.

Radiographic findings:

- Location: most commonly occur on the lesser curvature or posterior wall of the stomach.
- Shape: ulcer crater is smooth and round or oval (figure 2.3).
- Penetration: the ulcer projects beyond the normal margin of the gastric lumen.
- Mucosal folds: extension of smooth gastric folds to the ulcer crater margin.
- Ulcer collar: an edematous mucosal band across the ulcer neck.

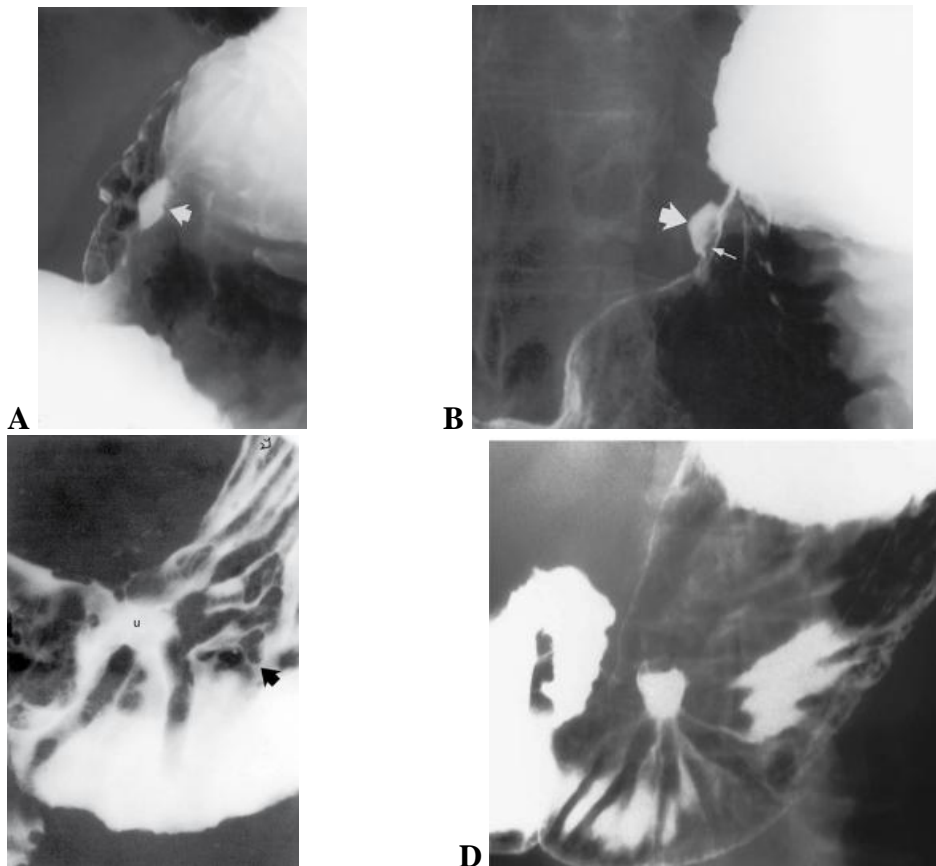


Figure 2.3— Variants of gastric ulcer crater at double-contrast radiographic examination.

(A) A 6-mm focal barium collection (arrow) is seen en face. No mass effect is seen.

(B) When the barium collection is viewed in profile, the collection protrudes from the expected luminal contour (large arrow). A thin lucency (small arrow) crosses the collection at its interface with the luminal contour. These are findings of a benign gastric ulcer. The ulcer niche (crater) is filled with barium (large arrow) and protrudes outside the expected contour of the stomach. No mass or mucosal nodularity is seen to indicate that a tumor is present. As the ulcer extends into the soft submucosal fat, it spreads laterally, burrowing under the mucosa. The undermined mucosa is manifested as the lucency (small arrow) crossing the edge of the ulcer, termed a Hampton line.

(C) Coarsely lobulated, nodular folds radiate toward a central barium collection (u). Compare a normal-sized fold (open arrow) with an enlarged, lobulated fold (black arrow).

(D) Benign gastric ulceration. Small posterior wall ulcer demonstrated en face. Radiating mucosal folds extend to the edge of the crater

Malignant ulcers

Approximately 5 % of gastric ulcers are found to be associated with malignancy. Of those, 90 % are due to adenocarcinoma, with the remaining 10 % di-

vided among lymphoma, sarcoma, and metastases. Radiographic imaging suggestive of malignancy warrants tissue biopsy.

Radiographic features:

– The interrupted mucosal folds and irregular raised edge of the tumour indicate carcinoma of stomach.

– Shape: the ulcer crater is irregular and nodular.

– Non-penetrating: The ulcer does not project beyond the expected normal stomach margin.

– Mucosal folds: do not radiate to the ulcer margin and are often nodular.

– Ulcer mound: irregular and mass-like with eccentric crater.

Benign tumors

Benign tumors of the stomach are usually submucosal (lipoma, fibroma, schwannoma, hemangioma, lymphangioma, carcinoid (malignant transformation in 20 %)). Leiomyoma: most common benign tumor; may ulcerate, 10 % malignant.

Gastric carcinoma

Gastric carcinoma is the third most common GI malignancy after colorectal and pancreatic cancer, and represents the 6th leading cause of cancer deaths. Although they may present anywhere within the stomach, gastric carcinomas are most commonly located in the antrum or pylorus (50 %); 60 % are on the lesser curvature and 30 % occur at the GE junction.

The diagnosis is usually suggested by endoscopic biopsy. CT is useful in defining the extent of disease as hepatic or peritoneal metastases may be present.

Radiographic findings:

– Gastric mass producing an irregular filling defect (figure 2.4)

– Possible tumor ulceration. If an ulcer is present, radiating folds may be blunted or fused.

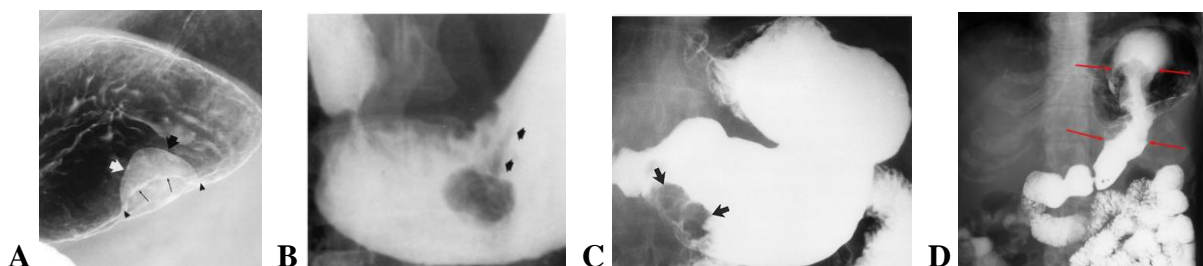


Figure 2.4 — (A) 4-cm, smooth-surfaced mass (large arrows) is protruding into the stomach. The mass has sharp angles to the luminal contour (arrowheads). There is a sharp line between the obliquely oriented tumor and mucosal surface (thin arrows). These are the classic findings of a mass arising in the submucosa or muscularis propria, variably termed a submucosal or extramucosal mass.

(B) Adenomatous polyp. A long, thin pedicle (arrows) extends from the head of the polyp to the stomach wall.

(C) Polypoid gastric carcinoma. Single-contrast technique upper GI series reveals a lobulated filling defect (arrows) in the antrum of the stomach.

(D) Single contrast study from the same patient showing the apple core appearance (arrows) of the stomach due to the invasive gastric adenocarcinoma

3. RADIOLOGY OF INTESTINE

Introduction

Decreased natural contrast between adjacent structures of roughly similar radiographic density mandates the use of contrast material. Barium suspensions, high-density compounds mixed with water, are commonly used in the examination of the gastrointestinal tract. Barium enema is useful to diagnose problems in the intestine and to identify abnormal growths, ulcers, polyps, diverticula, and intestinal cancer. A satisfactory barium examination depends on the colon being carefully cleansed and empty.

Limitation: discomfort to patient, requires fluoroscopy, time consuming.

Patient preparation: for small-bowel examination, the patient should have nothing orally after midnight or the next morning preceding the radiographic study. Fluid and food in the stomach and small intestine degrade the examination by interfering with good mucosal visualization and causing artifacts that may mimic disease.

Preparation for the barium enema examination must be performed properly to obtain an accurate evaluation of the colon by this method. Various colonic preparations have been recommended and usually combine the use of dietary changes, oral fluids, and several cathartics the day preceding the barium enema examination. The presence of even small amounts of residual stool in the bowel may mimic colonic disease, or a filling defect in the colon may be passed off as stool but be a neoplasm.

CT Imaging

CT imaging of the abdomen can portray the various organs of the gastrointestinal tract. Mucosal disease, such as ulcers, and small neoplasms will not be shown with this imaging modality. Larger intestinal neoplasms, thickening of the walls of the hollow organs, and extrinsic processes can be detected with CT imaging. A major role of CT scanning, especially in the esophagus and colon, is staging malignancy of these organs. In the colon, for example, CT examination is used for initial staging, especially of distant metastases, and for evaluation of recurrence following surgery.

Magnetic resonance imaging

MR imaging of the hollow organs of the gastrointestinal tract is being used to evaluate and stage malignancies, especially of the esophagus and rectum, and also to assess inflammatory and obstructive bowel disease.

Radiography small intestine

The normal dimensions of the small bowel can be remembered by the "Rule of 3's": 1) bowel wall < 3mm thick, 2) bowel folds < 3mm thick, 3) bowel diameter < 3cm wide. Patterns that should be assessed when evaluating the small

bowel include the location of the abnormality, the caliber of the lumen, the mucosal contour, the fold pattern (figure 3.1).

The small bowel generally lies centrally within the abdomen, “framed” by the large bowel. On imaging, the small bowel can be differentiated from the large bowel based on the presence of plicae circulares (circular folds), which traverse the entire diameter of the lumen. The large bowel does not possess these circular folds, but rather has saccular dividers called haustra.

Inflammatory diseases

Duodenal ulcer

Duodenal ulcers are two to three times more common than gastric ulcers. All bulbar duodenal ulcers are considered benign. Postbulbar or multiple ulcers raise the suspicion for Zollinger-Ellison syndrome.

Radiographic features of duodenal ulcers: persistent round or elliptical collection of the barium, radiating folds, spasm (figure 3.1).

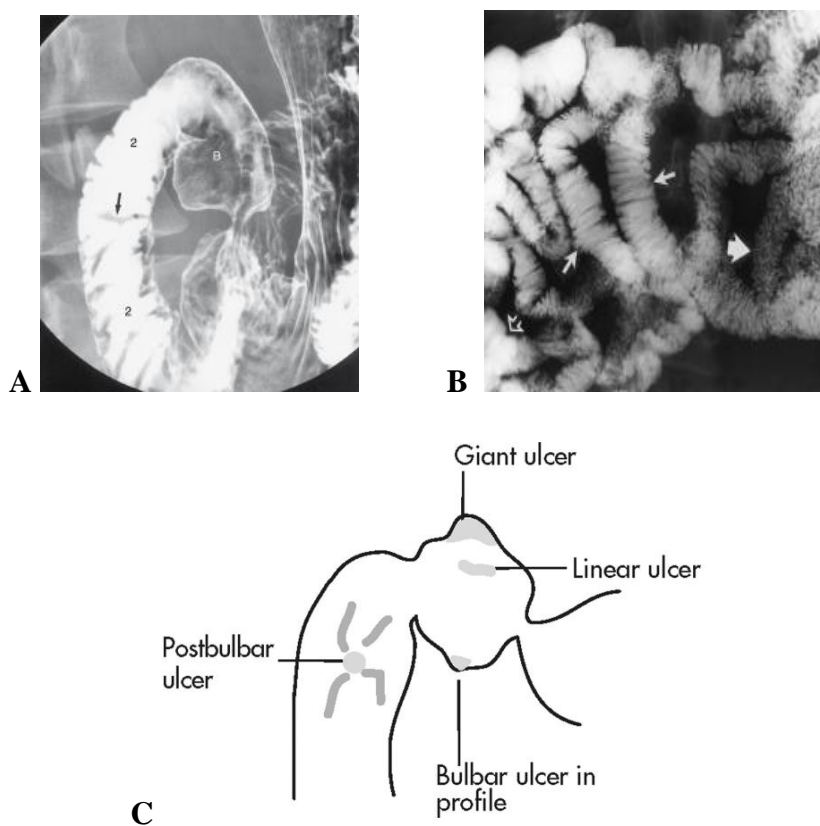


Figure 3.1 — (A) Spot radiograph of the duodenal bulb (B) and second portion of the duodenum (2) obtained during a double-contrast upper GI series. The folds of the duodenum (folds of Kerckring) (arrow) cross the duodenum except at the level of the papilla of Vater.

(B) Close-up from an overhead view obtained during a normal small bowel follow-through examination demonstrates the normal anatomy. Many loops of small intestine are visible. Two loops are well distended (thin arrows) and show that the valvulae conniventes lie perpendicular to the longitudinal axis of the small bowel.

(C) Scheme variants of duodenal ulcers

Ulcer largely replaces the duodenal bulb. A large ulcer crater may be mistaken for a deformed bulb but does not change shape during fluoroscopy. Duodenal ulcers often heal with a scar; this can lead to deformity and contraction of the duodenal bulb: cloverleaf deformity, or hourglass deformity. Postbulbar ulcers: any ulcer distal to the first portion of the duodenum should be considered to have underlying malignancy until proven otherwise (only 5 % are benign ulcers, mostly secondary to Zollinger-Ellison syndrome).

Crohn's disease (regional enteritis)

Early findings represent active inflammation, while late findings represent chronic inflammation and/or fibrosis. Fluoroscopic findings include:

- mucosal ulcers (punctate collections of barium surrounded by radiolucent mounds of edema)
- luminal narrowing from edema, spasm.
- fold thickening.
- strictures, manifest by the “string sign”.

Ulcers

Fluoroscopy, using either single or double contrast, is the imaging study of choice for evaluating small bowel ulcerations. Barium pools in the ulcer base, seen as a radiopaque collection outside the confines of the small bowel. Ulcers can have a variety of appearances, ranging from aphthoid to linear to “punched-out” to “bull’s-eye,” depending on the etiology. In addition, pancreatic pseudocysts and diverticula may mimic the appearance of ulcers.

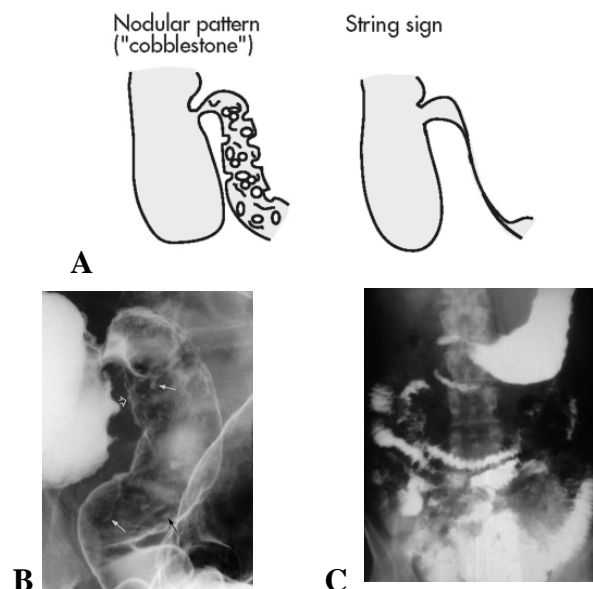


Figure 3.2 — (A) Schemes variants Crohn's disease of the small bowel. (B) Spot radiograph of the terminal ileum shows numerous aphthoid ulcers en face as 2- to 5 mm punctate or slightly elongated collections of barium surrounded by radiolucent halos (thin arrows). In profile, the aphthoid ulcers appear as 2- to 4mm punctate barium collections (open arrow) protruding outside the expected luminal contour. (C) Crohn disease of intestine (luminal narrowing from edema, spasm, fold thickening) with stomach involvement

Solitary mass

Masses projecting into or occurring with the small intestine appear as filling defects on radiographic studies. These filling defects may represent intraluminal, mucosal, intramural, or extrinsic masses (figure 3.3).

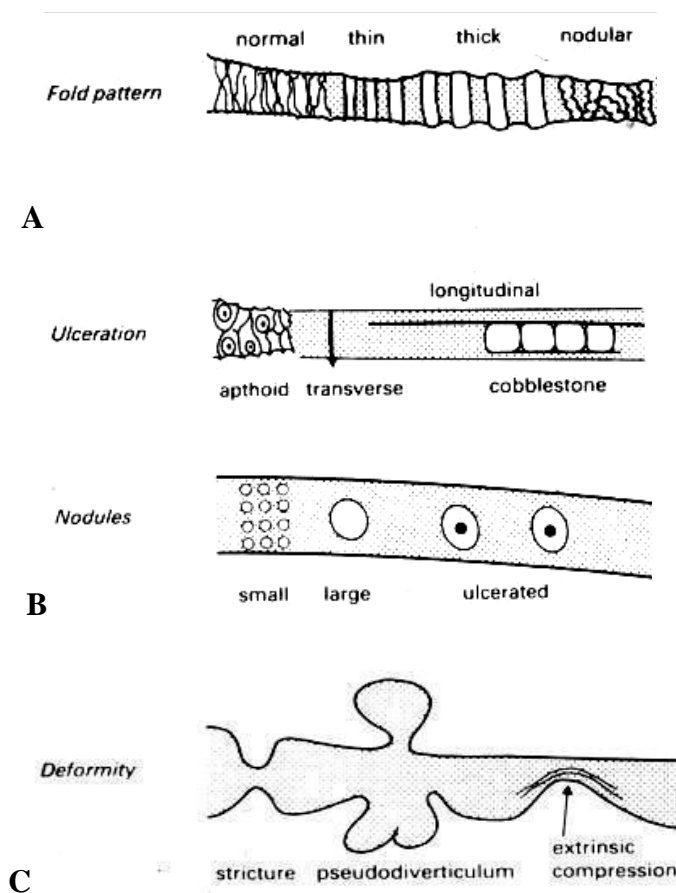


Figure 3.3 — (A-C) Schemes of variants lumen, mucosal and fold patterns of small bowel

Radiography colon Inflammatory diseases

Crohn's disease

Crohn's disease is an idiopathic inflammatory disease of the GI tract that is characterized by ulcerations, erosions, noncaseating granulomas, and full-thickness bowel wall inflammation. The disease may affect any portion of the gastrointestinal system from the esophagus to the anus. The course is progressive in nature, with frequent remissions and relapses. The radiographic hallmarks of Crohn's disease are aphthous erosions, thickened and distorted folds due to bowel wall edema, "cobblestone" pattern of deep ulcerations (figure 3.2–3.3), fibrosis with thickened walls, contractures, and stenosis resulting in the "string sign," fistula and sinus tract formations, stranding in mesenteric fat due to inflammation, and "skip" lesions with intermittent areas of normal bowel between diseased segments (figure 3.2).

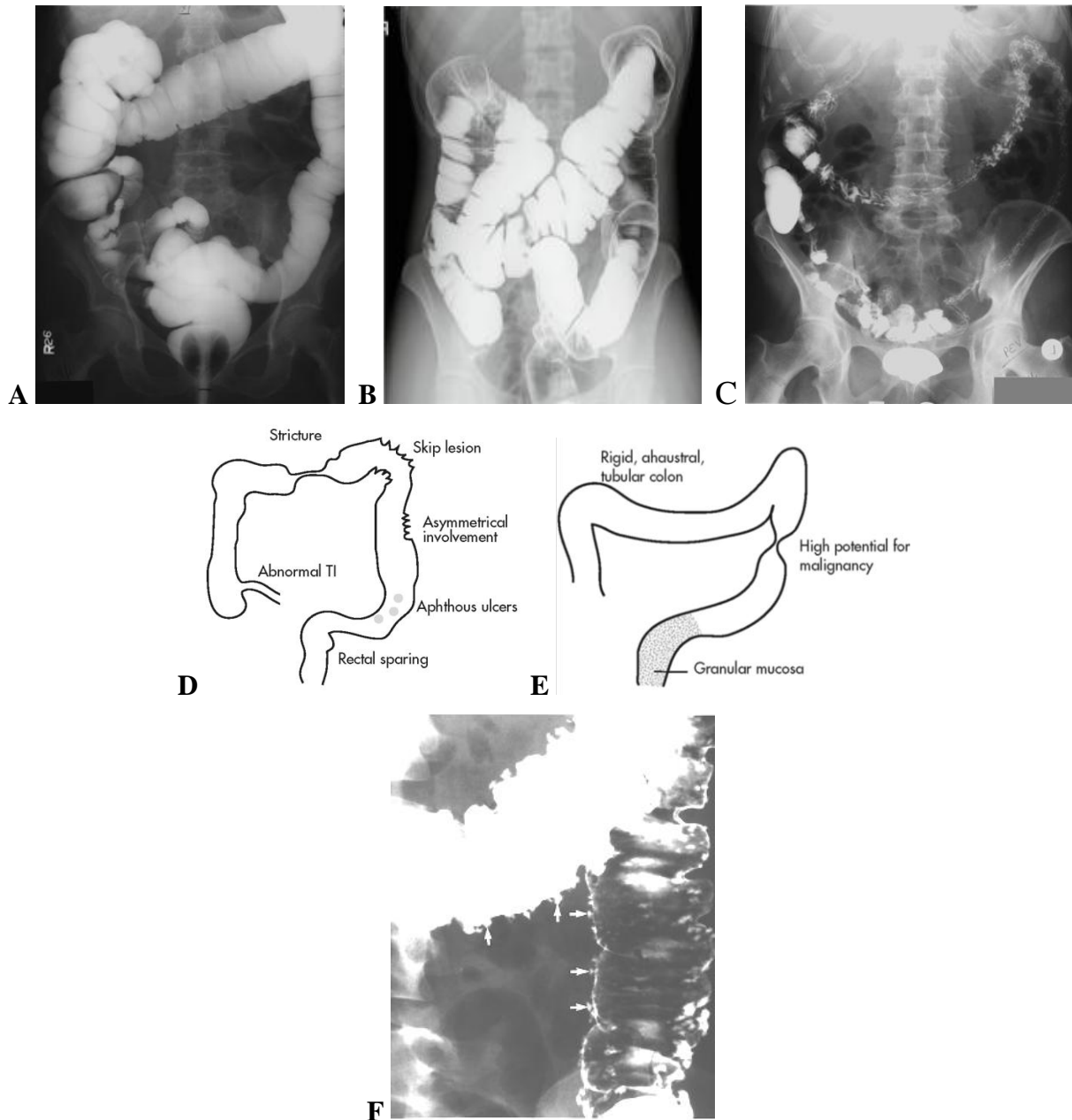


Figure 3.4 — (A) Single-contrast barium enema and (B) double-contrast barium enema of the normal colon. Although a single contrast study may be easier to perform, mucosal detail is better seen on the double contrast study.

(C) Post-evacuation radiograph of abdomen and pelvic.

(D, E) Schemes variants Crohn's disease of the large bowel. There is a stenosis of the descending and tranverse colon. The haustral pattern is lost. Numerous deep fissured ulcers can be seen and there is irregular mucosal thickening at the hepatic flexure with a cobblestone appearance. This portions of bowel is affected asymmetrical. The bowel involvement is thus asymmetrical with skip lesions.

(F) Ulcerative colitis (spot radiograph of the colon with marked multiplies of ulcers craters)

Colitis

Radiographic features of bowel inflammation (any etiology) depend mainly under of the process. Ulceration shallow: granularity of mucosa, aphthoid. Ulce-

ration deeper: flasklike collections of barium: collar button. Edema: displacement of barium (translucent halo around central ulcer). Spasm: localized persistent contraction/narrowing of bowel lumen.

Ulcerative colitis

Ulcerative colitis is an idiopathic chronic inflammatory disease that is characterized by superficial ulcerations, edema, and hyperemia of the colonic mucosa and submucosa. The disease usually begins in the rectum and extends proximally in a continuous pattern.

The radiographic hallmarks of ulcerative colitis are confluent, circumferential, shallow ulcerations of the colon, granular mucosa, collar button ulcers, and "thumbprinting" (figure 3.4).

Structural abnormalities

Diverticulosis

Diverticulosis is a condition in which the mucosa and muscularis mucosae herniate through the muscularis propria of the colon wall and produce a saccular outpouching. Approximately 70 % of diverticula occur in the sigmoid colon and 25 % in the ascending colon. Plain films and barium studies reveal diverticula as gas/barium-filled sacs parallel to the lumen of the colon. Most are 5–10mm in diameter, but may range from tiny spikes to 2 cm.

Hallmarks on barium enema include distorted diverticular sacs, evidence of abscess, and leakage of barium outside the bowel lumen (figure 3.5).

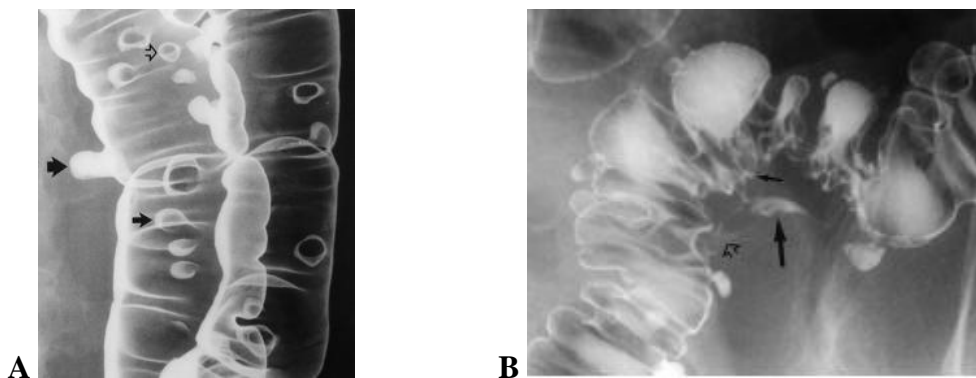


Figure 3.5 — (A) Diverticulosis of the colon. Coned-down image of the splenic flexure from a left-side-down decubitus overhead from a double-contrast barium enema reveals numerous diverticula. Some barium-filled diverticula are seen in profile (thick black arrow). Most diverticula seen en face have a small pool of barium on their dependent surface resembling a meniscus (thin black arrow). Other diverticula are devoid of a barium meniscus and are depicted only as barium-coated ring shadows (open arrow). The normal haustral sacculations and interhaustral folds are preserved.

(B) Diverticulitis. Spot radiograph of the sigmoid colon from a double-contrast barium enema shows several small barium-filled tracks (open arrow) forming a flame-shaped collection (large arrow) in the pericolic space. The wall of the adjacent sigmoid colon has a spiculated contour (spicule represented by small arrow). There is an extrinsic mass impression on the inferior wall of the sigmoid colon. Compare the asymmetric inflammatory changes with the normal contour of the opposite colonic wall

Neoplasms

Polyps

Polyps are focal masses that protrude from the mucosa into the bowel lumen. In general, polyps less than 1cm in diameter have a 1 % risk of cancer, 1–2 cm have a 10 % risk, and those greater than 2cm have up to a 50 % risk. Thus, barium studies are often indicated to detect colon polyps (figure 3.6).

Radiographic finding: benign polyps are small in diameter, stable in growth, spherically shaped, have normal mucosa, long stalks, and a smooth surface. Malignant polyps on the other hand are large in diameter, sessile, irregularly shaped, may exhibit sudden growth, and have a broader base and puckered mucosa.

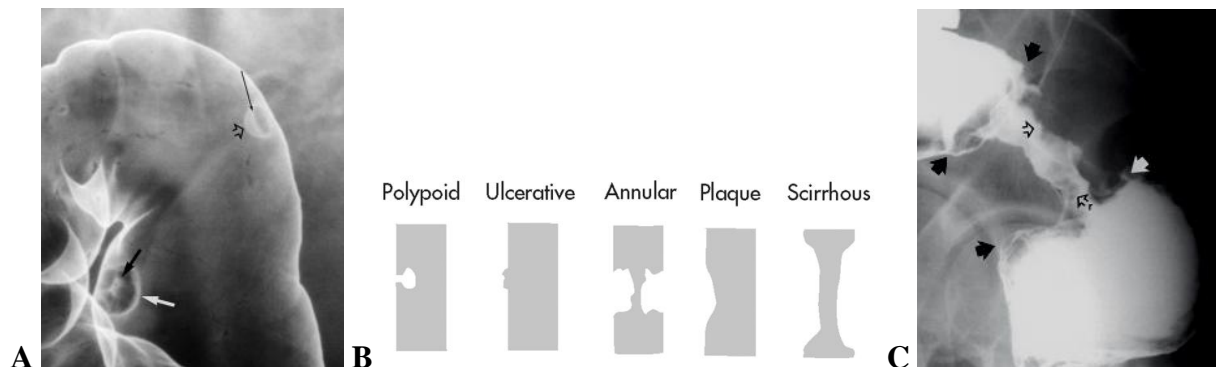


Figure 3.6 — (A) Spot radiograph of the splenic flexure shows two polyps. The small polyp resembles a hat. The top of the hat (open arrow) is the top of the polyp. The brim of the hat (thin black arrow) is barium trapped between the mucosa and the polyp as it is retracted by its stalk. This was a tubular adenoma. The second polyp has a more worrisome morphology—that of an umbilicated, sessile polyp. A small barium collection (thick black arrow) fills a central umbilication or ulceration. The edge of the polyp is coated by barium (or “etched in white”) (white arrow). This polyp was a tubulovillous adenoma.

(B) Schemes variants of the colorectal cancer.

(C) Annular adenocarcinoma of the rectum. Spot radiograph from the single-contrast phase of a double-contrast barium enema shows a 5-cm-long, circumferential narrowing of the proximal rectum. The lesion has abrupt shelf-like margins (large black and white arrows) and an irregular surface (open arrows). This has been called an “apple core” lesion, but this is a misnomer because the tumor represents the part of the apple that has been eaten away, and the lumen would be the “apple core”

Colorectal cancer

Colorectal adenocarcinoma is the most common GI malignancy and is the second most deadly cancer in the United States. Signs and symptoms depend on the location of the tumor. Approximately 50 % of these malignancies develop in the rectosigmoid area and 25 % in the cecum and ascending colon. Many likely arise from a malignant transformation of an adenomatous polyp. These tumors tend to form annular constricting lesions or bulky exophytic masses, with raised everted edges and ulcerated mucosa, ranging from 2–6 cm in diameter. They spread by direct invasion into the pericolonic fat and adjacent organs, through

lymphatic vessels to regional nodes, and hematogenously via systemic and portal circulation.

Apple-core constricting lesions, tumor masses, nodal involvement, and metastases may be visualized (figure 3.6).

X-ray diagnostics of some urgent abdominal conditions **Intestinal obstruction**

The main sign of intestinal obstruction — Kloiber's cup and arches (air-fluid levels). The small bowel obstruction — the width of horizontal fluid level is more than height of a gas bubble above it; on a background of gas the mucosal folds reminding a spring can be visible; the localization of Kloiber's cups is more often in medial parts of the abdomen. Arches — the intestinal loops, filled gas and limited by horizontal fluid levels.

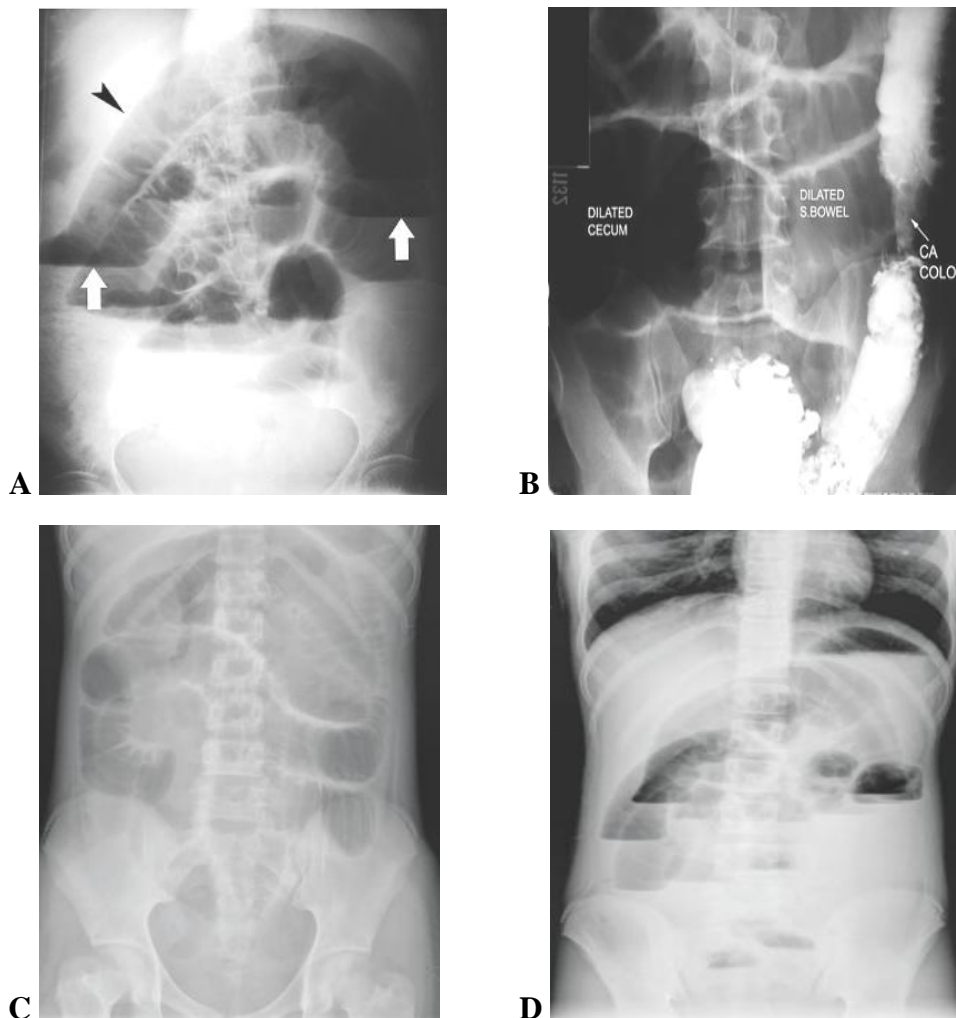


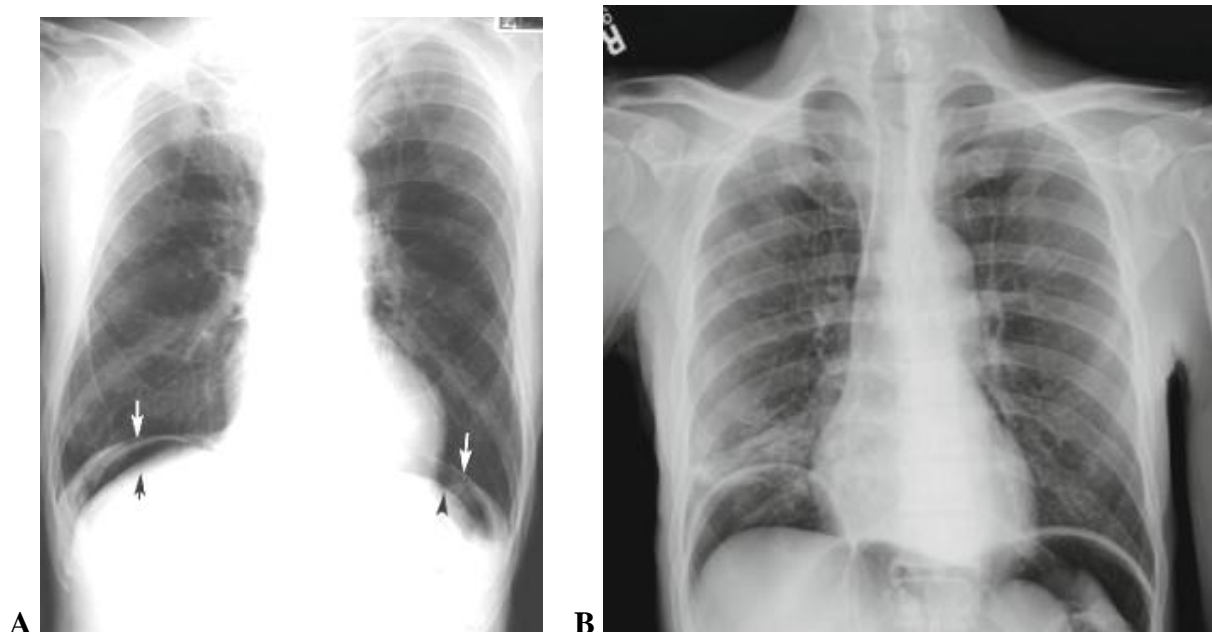
Figure 3.7 — (A) Small bowel obstruction (black arrow – dilated small bowel, white arrows – air-fluid levels). (B) Large bowel obstruction.

(C) Supine and (D) upright abdominal radiographs same patient demonstrate a “stacked” appearance of multiple segments of markedly dilated small bowel with numerous air-fluid levels at high-grade distal small bowel obstruction

The large bowel obstruction — the width of a horizontal level is less than height of a gas bubble above it; the localization of Kloiber's cups is more often in lateral parts of the abdomen; on a background of gas colic haustrae sometimes are visible (figure 3.7). For more exact determination of a level of an intestinal obstruction it is necessary to give a patient the barium sulfate per orally and to perform dynamic X-ray. The stopping of barium mass will show the localization of an obstruction. The mechanical obstruction - at a roentgenoscopy there's detected «migration» of a fluid from one loop of an intestine to another, fast motions of fluid levels. The dynamic obstruction - at a roentgenoscopy no motions of fluid levels, barium meal passes very slowly.

Free gas in an abdominal cavity

The free gas in an abdominal cavity — can be the result of perforation of hollow organs (stomach, intestine), penetrating wounds of an abdominal wall; after operations on the organs of an abdominal cavity, or owing to injection of gas in an abdominal cavity with the diagnostic purpose (diagnostic pneumoperitoneum). In a vertical position of a patient there's detected a falciform accumulation of gas under the right dome of a diaphragm (at presence of a much amount of gas — under the right and the left also) (figure 3.8), in a latero-position — under a lateral wall of an abdominal cavity.



**Figure 3.8 — (A) Free gas of abdominal cavity (arrows).
(B) This upright chest radiograph demonstrates crescent shaped lucencies under both hemidiaphragms. This is free intraperitoneal gas, or “free air,” which rises up to the top of the peritoneal cavity when the patient is upright**

Pneumoperitoneum is commonly due to recent surgery, but it may also indicate a ruptured abdominal viscus, such as a perforated duodenal ulcer.

4. NUCLEAR MEDICINE

Introduction

Nuclear medicine imaging (also called radionuclide, radioisotope scanning) is an excellent diagnostic tool because it shows not only the anatomy (structure) of an organ or body part, but the function of the organ as well. This additional "functional information" allows nuclear medicine to diagnose certain diseases and various medical conditions much sooner than other medical imaging examinations which provide mainly anatomic (structural) information about an organ or body part. Nuclear medicine can be valuable in the early diagnosis, treatment and prevention of numerous medical conditions and continues to grow as a powerful medical tool.

Plain films, US, CT, and MRI produce anatomic images with very high spatial resolution. A viewer can see anatomy very well, but function generally is not assessed. Nuclear medicine studies sacrifice spatial resolution, but in return offer information about organ function. Nuclear medicine studies, in general, are very sensitive, but relatively nonspecific in the detection of pathology.

Principles and methods

How it is done:

- Radionuclides are injected into the body.
- The nuclide concentrates in the organ that is being tested.
- The imaging is done by tracing the distribution of radiopharmaceuticals within the body.
- The radioactive gamma rays are emitted through the body as the natural decaying process of these isotopes takes place. The emissions of the gamma rays are captured by detectors that surround the body. This essentially means that the human is now the source of the radioactivity.
- Scanning of body or organ follows.
- A radionuclide can be a pure element (e. g. iodine-131) or a biological agent labeled with radioisotopes.
- All radionuclides are expelled from the body with an associated half life.

Useful for:

- Primarily useful to evaluate the function of the organ studied.
- Nuclear imaging detects functional (vs. anatomical) properties of human tissues.

Advantage:

– Highly sensitive. For example, early osteomyelitis may not be visible on plain films for 7-10 days, while scintigraphy will be positive at the time of presentation. Skeletal metastatic spread can frequently be detected significantly earlier by scintigraphy than by radiography.

– Radionuclide imaging is safe since it does not carry the risk of allergic reaction encountered with contrast.

– Radiation exposure is minimal.

The principal benefit of radionuclide imaging is that it is able to detect physiologic abnormalities within a given tissue.

Limitation and disadvantages

The main disadvantage of scintigraphy is its non-specificity (to take a common example, an isolated 'hot spot' on a bone scan could be due to infection, trauma, or neoplasia and correlation with clinical history and other imaging studies is of paramount importance).

Nuclear medicine applications

Radioactivity

A radioactive nucleus is one that is unstable and will spontaneously disintegrate or decay at some time. The reason for the instability is either that the nucleus is too large or because there is an imbalance between the protons and neutrons. Unstable nuclei have an excess of energy. When a nucleus disintegrates, it will emit radiation either as photons (gamma rays) or as high-velocity particles.

The particular nature and energy of emissions are characteristic of each radionuclide. The radiation generally is ionizing, meaning that it is highly energetic. Radionuclide imaging uses ionizing radiation. However, the radiation is emitted from within the patient and subsequently detected in the imaging device.

A radionuclide is an unstable atom that undergoes radioactive decay. In imaging, the most common radionuclide used is technetium, which is a gamma emitter. Pure gamma emitters (e. g. ^{99m}Tc = technetium-99m) are preferred whenever possible because beta particles give patients very much higher doses of radiation without contributing to the image. Technetium-99m is the most frequently used radionuclide in nuclear medicine today, which combines the advantages of optimum radiation properties (emission of exclusively γ -radiation with suitable energy, short half-life of 6 hours) and general availability as a generator nuclide.

Principles of nuclear medicine

In nuclear medical diagnostics, unsealed radioactive substances are used to image organ functions non-invasively. In contrast to other imaging diagnostic modalities (ultrasound, X-ray, to some extent also magnetic resonance tomography), the nuclear medical examination approach is primarily function-oriented. In this case vital processes such as blood circulation, metabolism and viability of organs or tumors can be displayed as “functional images”. Nuclear medicine provides physiological images, i.e. the metabolic activity of the organs process the radiopharmaceutical and concentrate it in the target organs for imaging.

Radiopharmaceuticals

Nuclear medical examinations are based on use of radiopharmaceuticals. Radiopharmaceuticals (radiotracers) are the possible for clinical use radionuc-

lides (radioisotopes) and labelled medias. Nuclear medicine imaging examinations are performed by administering various radiopharmaceuticals to the patient and subsequently recording in vivo distribution. Radiopharmaceuticals consist of two main components: (1) the main component that is distributed to various organs via a number of different mechanisms, and (2) the radionuclide that is tagged to the main component, which emits gamma rays, permitting detection of the compound in the body.

Technetium-99m is the most frequently used radionuclide in nuclear medicine today because it is widely available, easily prepared, and has a relatively short half-life (6 hours) with an acceptable whole-body radiation dose. Its parent nuclide, molybdenum-99 (^{99}Mo), can be produced in either a reactor or a cyclotron. ^{99}Mo has a half-life of 66h and therefore $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ generators can conveniently be supplied weekly to nuclear medicine departments, providing a fresh daily supply of the radionuclide. The 6-h half-life of $^{99\text{m}}\text{Tc}$ is sufficiently long for most imaging applications and its 140 keV gamma radiation has reasonable tissue penetration but can still be easily collimated. $^{99\text{m}}\text{Tc}$ can be administered in free form as the pertechnetate ion (TcO_4^-); however, owing to its diverse chemistry, it can also be incorporated into various pharmaceuticals for visualization of different organ systems.

The amount of radiation that is taken up and then emitted by a specific body part is linked to the metabolic activity (cellular function) of the organ or tissue. For example, cells which are dividing rapidly (like cancer tissue cells) may be seen as "hot spots" of metabolic activity on a nuclear medicine image, since they absorb more of the radionuclide.

A radionuclide that has desirable imaging properties can usually be used to make a variety of radiopharmaceuticals. This is done by coupling the radionuclide with various stable compounds that are localized by organs or disease states. Different radiopharmaceuticals are used for displaying blood circulation, blood volume, lung ventilation, gastrointestinal passage, absorption and secretion, phagocytosis, cell kinetics, antigen or receptor binding as well as metabolism and thus viability.

Common adverse, nonspecific reactions such as vasovagal reactions with syncope, hypotension and diaphoresis can occur with the intravenous administration of any drug and are not specific for radiopharmaceuticals.

Nuclear medicine can image and/or show the function a variety of organs and body parts to diagnose a number of medical conditions including:

- abdomen (example given, to check for gastrointestinal bleeding);
- brain (e. g., to look for tumors or aneurysms (blood vessel disease) or evaluate stroke);
- blood (e. g., to test for various blood cell disorders);
- breast (e. g., to image breast cancers);
- hepatobiliary system (e. g., to check gallbladder and bile duct function);

- heart (e. g., to look for coronary artery disease, myocardial infarction, valve disease or heart attack; to detect heart transplant rejection; check the effectiveness of bypass surgery; to select patients for angioplasty);
- kidneys (e. g., to check renal function; to detect renal tumors; to test for renal transplant rejection);
- liver/spleen (e. g., to check for cirrhosis or metastatic cancer);
- lung (e. g., to check for pulmonary embolism (blood clot), check for lung transplant rejection);
- lymphatic system (e. g., to detect if cancer has spread to the lymph nodes);
- skeletal system (e. g., to check for metastatic cancer or to test for hidden bone trauma in sports injuries);
- stomach (e. g., to check for stomach function and to confirm ulcers or cancer);
- thyroid and parathyroid (e. g., to check for tumor or abnormal function).

Methods of nuclear medical routine diagnostics are today used most frequently for examinations of the thyroid gland, skeleton, heart, kidneys, lungs and brain as well as of oncological and inflammatory diseases.

Nuclear medicine is used mainly to allow visualization of organs and regions within organs that can not be seen on conventional x-ray images. Space occupying lesions (injury or abnormality), especially tumors, may stand out on nuclear medicine images. Generally, these lesions are seen as areas of reduced radioactivity (called a "cold spot"); however, in some instances, like bone scanning, areas of increased activity (called a "hot spot") represent disease or injury (pathology).

Methods of radionuclide examinations

Radiometry — the method of nuclear examination with use of a single detector placed above the certain area of a patient's body to determine the percentage of radiotracer intake in the organ (figure 4.1).

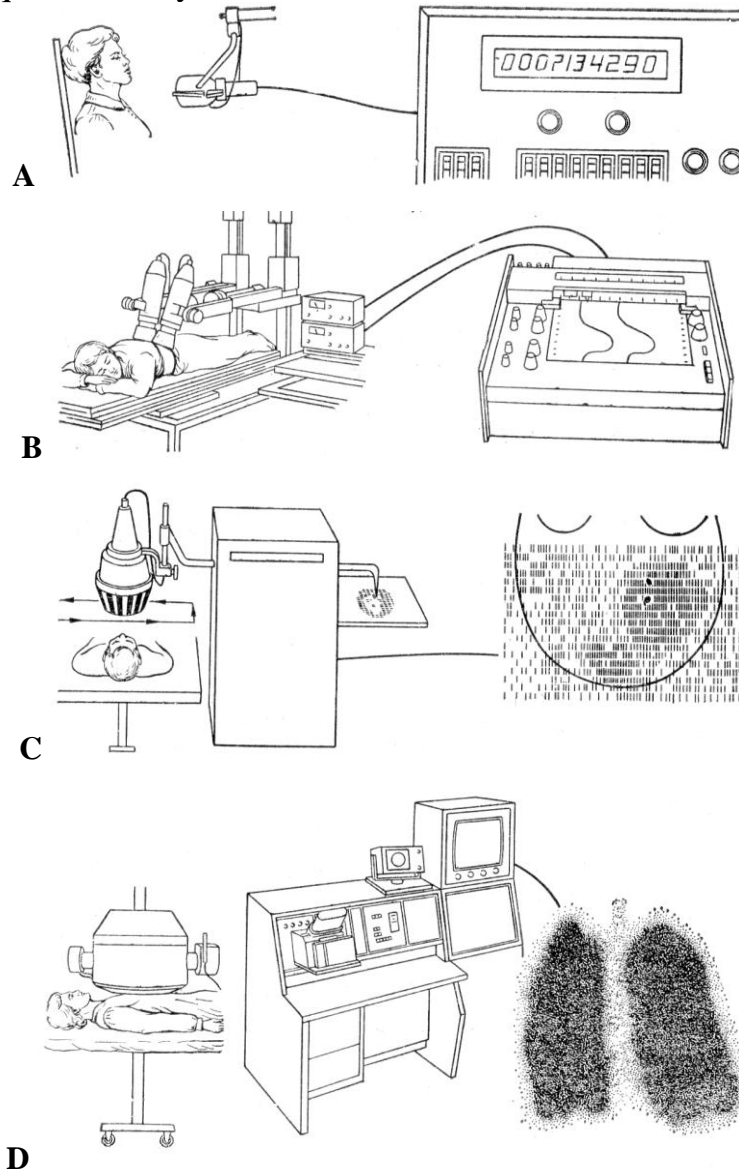
Radiography (radionuclide, not X-ray) - the method of nuclear examination with use of a single detector placed above the certain area of a patient's body to determine the intensity and speed of radiotracer's uptake and excretion from the organ. The result is presented as a time-activity graph.

Radionuclide scanning — the old method of nuclear imaging with use of rectilinear scanners, systems which have a single pencil-like detector. By moving this detector over a body region of a patient in a meandering fashion, and printing the local gamma-ray intensity, images of the distribution of radioactivity could be obtained.

(Radionuclide) scintigraphy — the method of nuclear imaging with the use of gamma-cameras, systems which detect the radiation at a large area of a patient's body, transfer gamma photons energy to light flashes (scintillations) and electric signals with subsequent computer digitalization and image creation.

Radioimmunological examinations (RadioImmunoAssays — RIA) — the group of nuclear laboratory examinations which are used to measure minimal quantities of biological substances with the help of radioactively labelled mole-

cules. Based on the reaction between an antibody and an antigen whose concentration has to be quantified. Radioimmunoassays are very sensitive and able to detect nano- or picomoles of substances. For this purpose uptake and kinetics of the tracers are quantitatively evaluated from measurements with external probes.



**Figure 4.1 — Schemes of methods radionuclide examinations (nuclear medicine).
 (A) Radiometry. (B) Radiography (radionuclide, not X-ray radiography).
 (C) Radionuclide scanning. (D) (Radionuclide) scintigraphy**

Techniques of image acquisition and processing

A major strength of nuclear medicine imaging is its ability to show and quantify physiological function. This capability is supported by a range of acquisition protocols and image processing software. This section introduces the main types of study.

Static image is the basic image; other acquisitions consist of a series of such images. This determines the number of pixels there will be in the image. Each gamma ray that is accepted by the camera is saved as a count in the pixel

corresponding to its location. A typical image may contain between 100 000 and 1 million counts, and take up to several minutes to acquire.

Dynamic imaging consists of a sequence of basic images or frames acquired over time. The frame rate is chosen according to the rate of change of the radionuclide distribution, and may be as rapid as 40 frames per second. The number of counts acquired in a short time can be increased by the use of a high-sensitivity collimator which has larger holes and therefore poorer resolution than a general purpose collimator. Processing can generate time–activity curves of selected organs (e.g. the kidneys in a renogram).

Whole body imaging. Most modern cameras allow whole body imaging in which either the camera or the patient is moved slowly longitudinally during acquisition. The result is an extended image that can include the whole patient. With a dual-headed camera it is possible to acquire anterior and posterior whole body images simultaneously and to allow, for example, a whole body survey for bone metastases to be acquired in less than 20 min. For quantitative measurements, a series of static images is preferable. In nuclear imaging the radiation exposure is determined by the injection of the tracer and additional images take time but do not otherwise expose the patient to risk. Radionuclide imaging is a particularly powerful method to search the whole body for disease, the distribution of which is unknown. Examples are bone scans done to detect metastases, tumor scans (for example with ¹⁸F-fluoro-deoxyglucose [FDG]) and scans with labeled white cells to detect occult infections.

Abnormal biodistribution due to disease can comprise either increased or decreased uptake of radiopharmaceutical, depending on whether the pathological process concerned results in loss of the mechanism of uptake. Some radiopharmaceuticals have highly specific uptake mechanisms and failure to demonstrate a site of disease may be due to absence of the uptake mechanism in that particular case. Such instances may not represent diagnostic failures because demonstrating the lack of uptake can have important implications for subsequent clinical management. The nuclear medicine image can either be in gray scale (shades of black and white), for instance in a bone scan, or they can be color coded to clearly show functional activity.

Areas of high uptake of pharmaceutical and therefore of the radionuclide to which it is bound show resultant high emission of gamma rays, These areas are referred to as "hot" spots. Areas of low uptake are referred to as photon-deficient or "cold" spots.

The radiation dose to the patient is determined by the amount of radioactive material initially injected into the body. Therefore once the radiopharmaceutical has been given, additional images can be obtained without increasing the radiation dose. Images are usually obtained as planar images that, like plain x-rays, display three-dimensional data in two dimensions. These images are labeled as anterior, lateral, and so forth.

Detection scintillation systems

Any detection scintillation system included:

- Scintillator NaI (sodium iodide crystal-scintillator, may be activated of thallium): emits light whenever hit by gamma ray. Amount of single light is proportional to energy level of gamma-photon.

- Photomultiplier tubes: read the light signals and translate them into electrical signals. The photomultipliers translate the information from the raw (light) form to electric signals.

- The electric signals are fed into an acquisition system for corrections, generation of image and further processing.

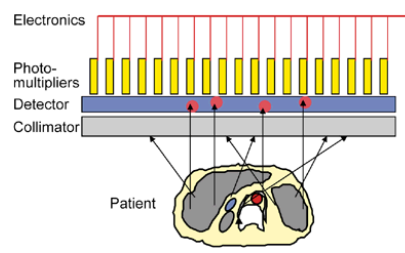
- The detector acts as the "film" of the photographic camera, it detects the gamma rays.

Scintillation detectors give off light immediately when hit by x-ray photons. They do not need to be heated. Sodium iodide (NaI) are commonly used scintillation crystals. In front of each detector is a collimator, which projects an image of the radioactive distribution onto the crystal. The scintillation crystal is connected to a photomultiplier tube, which converts the light from the crystal into an electric signal. Scintillation crystals are used in CT scanners. The crystal converts the incoming gamma-ray signal to a light signal, which is detected by an array of photomultiplier tubes (PMTs). The PMT signals are processed to form the image which is used. Collimator are needed in nuclear medicine because the gamma rays are emitted from the patient in all directions. Collimator limited of irradiation and allows only gamma rays perpendicular to the detector.

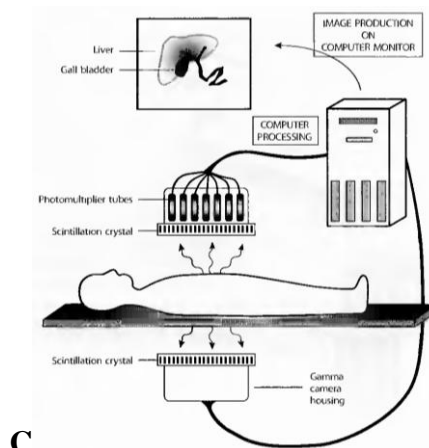
Gamma (scintillation) camera



A



B



C

Figure 4.2 — (A) A gamma camera. This model has two detectors mounted on the circular gantry ring to the left of the picture. (B) Components of a head gamma camera with scintillation crystal (detector) and photomultiplier tubes.

(C) Standard two-head gamma-camera and production of nuclear medicine scintigraphy images shown schematically

Most nuclear medicine studies are performed with gamma cameras, which provide planar (2D) images. A radiopharmaceutical agent, which is a radioactively tagged compound, is administered to a patient. Many radiopharmaceutical agents act like analogues of natural biologic compounds and localize to specific organs. Photons are emitted from the radiopharmaceutical agent in the patient, and a gamma camera is used to detect the tracer distribution. An image is created by a computer system (figure 4.2).

The gamma camera has a large crystal detector (called a scintillation crystal). The collimator collimates (focuses) the incoming gamma rays. The collimator in the imaging system makes the image coherent much as the lens in a camera focuses light. These crystals detect the emitted radiation signal and convert that signal into faint light. The light is then converted by an array of photomultiplier tubes to an electric signal, which is then digitized (converted into a computer signal) and reconstructed into an image by a computer. The resulting image is viewed on the system monitor and can be manipulated (post-processed) and filmed.

Modern high-performance gamma cameras are equipped with two detector heads, and, moreover, are able to perform dynamic and static scintigraphy and in two imaging modes: whole-body scanning, where the data is acquired along the entire length of the patient's body; and SPECT, where the detectors rotate around the patient acquiring data that is reconstructed into tomographic images.

SPECT

SPECT (single positron emission computed tomography) is another type of nuclear medicine examination. Most current gamma cameras can be used for both planar and tomographic imaging. SPECT is a 3D tomographic technique that uses gamma camera data from many projections and can be reconstructed in different planes.

SPECT uses a gamma camera which can rotate, and computer reconstruction. These have made it possible to reconstruct sectional body images in CT, MRI, SPECT and PET. Sectional images avoid the superimposition of structures and reveal inner structure just as the slices of a loaf of bread reveal structure not apparent from merely looking at the loaf. The images can be presented in coronal, sagittal, and axial projections that can provide enhanced spatial localization, superior to conventional radionuclide imaging. Applied to nuclear medicine the sectional imaging method is called SPECT and is used almost invariably in brain and cardiac imaging and often in bone and tumor imaging. The detector system in SPECT usually consists of two or three rotating gamma-camera heads. When not used for SPECT these are then available for other imaging methods (whole-body imaging, static imaging, etc.). The sensitivity of a SPECT system is proportional to the number of its detectors which typically range from one to three.

PET

Positron emission tomography (PET) is another unique technique that creates tomographic images by detecting gamma rays produced when positrons interact with electrons. PET imaging (scanning) is a type of nuclear medicine scanning that involves cross sectional data acquisition and reconstruction much like computed tomography (CT) scanning (figure 4.3).

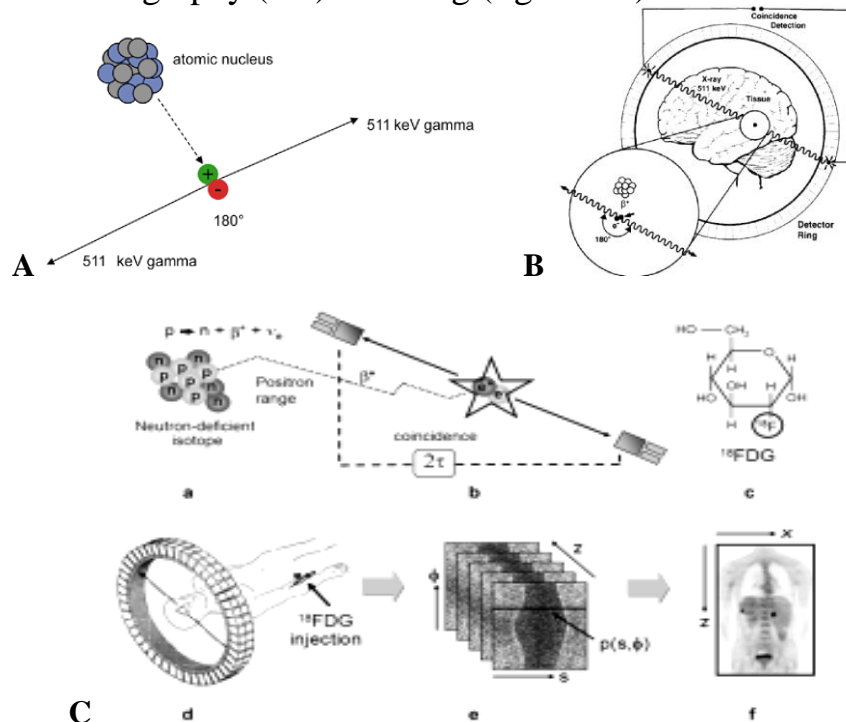


Figure 4.3 — (A) Positron decay (+ positron, - electron).

(B) The principle of positron emission tomography. The positron, after a short path and scattering off negative electrons, interacts with such an electron. As both annihilate, their rest mass results in two photons detected as coincidental events in the detector ring.

(C) Basic principles of PET imaging shown schematically: (a) the decay of a neutron-deficient, positron-emitting isotope; (b) the detection in coincidence of the annihilation photons; (c) the glucose analogue deoxyglucose labeled with the positron emitter 18F to form the radiopharmaceutical FDG; (d) the injection of the labeled pharmaceutical and the detection of a pair of annihilation photons in coincidence by a multiring PET camera; (e) the collection of the positron annihilation events into sinograms wherein each element of the sinogram contains the number of annihilations in a specific projection direction; and (f) a coronal section of the final, reconstructed whole-body image mapping the utilization of glucose throughout the patient

Through positron-emitting radionuclide labeling, PET allows the in-vivo imaging of physiologically and pathologically important molecules containing basic organic chemical elements such as carbon, hydrogen, and oxygen. Such data provide molecular and/or metabolic information essential to the diagnosis and evaluation of disease and thus to the effective management of patient care.

Biologically active molecules can be radiolabeled with positron-emitting radioisotopes. The positron-emitting radionuclide decays by emitting a positron from its nucleus that eventually collides with a nearby electron, resulting in an annihilation event where two 511,000 eV photons in the form of gamma rays are

emitted 180° apart. The two emitted photons travel extracorporeally and are detected nearly simultaneously as they interact with a ring of detectors (composed of scintillation crystals and photomultiplier tubes) surrounding the subject.

Within the gantry, photomultiplier–scintillator detectors record the locations of emitted gamma rays. This information is assessed by mathematical algorithms over many iterations and many different angles around the patient to map an image detailing where the radioactive substance has accumulated. The intensity detected at any point in the patient directly relates to the concentration of the radiotracer in the tissue.

Detection of a single annihilation event results in the “activation” of detectors opposing one another, which is recorded as a “coincident event.” The recording of multiple detector pair combinations yields a large number of these coincident lines. Sophisticated mathematical analyses of the coincident lines yields the location of cell populations or tissues that contain the molecule labeled with the positron emitter. Tomographic images of relative probe concentration can be reconstructed in the conventional sagittal, coronal and transverse imaging planes or, actually, in any arbitrary plane. The resultant image depicts the distribution and concentration of the radiolabeled tracer.

A small amount of the labeled compound is intravenously injected into the patient. After an appropriate amount of time, the patient is scanned. This process measures and spatially localizes the radionuclide within the target tissue. The images can be displayed as cross-sectional, coronal, or sagittal sequences. Three-dimensional images also can be constructed.

On casual review, the PET scanner appears similar to either a CT or MRI unit (figure 4.4).

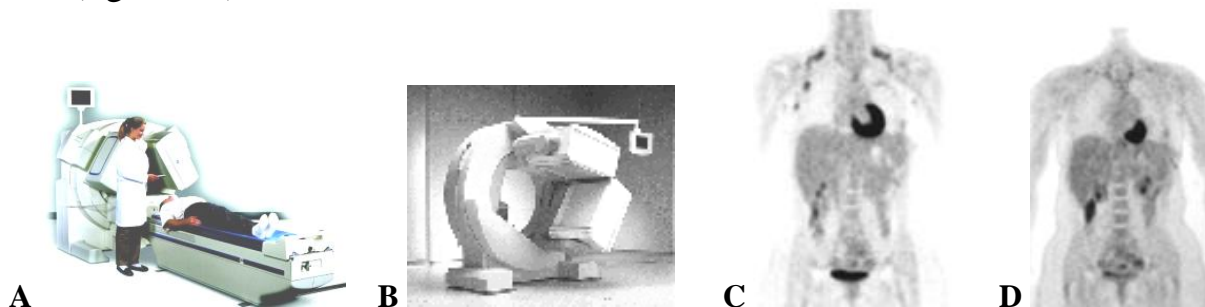


Figure 4.4 — (A, B) Variants of PET-systems and (C, D) frontal normal PET-tomograms

An advantage of PET is that the atoms that have been “labeled” to become positron emitters also reside naturally in the body and include such elements as oxygen. Also, the labeled compounds can be introduced in trace quantities so that they do not interfere with normally occurring metabolic activity. PET imaging requires positron emitters, which are typically produced in a cyclotron by irradiating a target material with a beam of charged particles. Radionuclides routinely produced for PET imaging studies include of short-lived O-15 (2-min half-life), N-13 (10 min), C-11 (20 min), and F-18 (110 min). The most widely used radiotracer is

2-[fluorine 18]-fluoro-2-deoxy-D-glucose (FDG), which is commonly used to evaluate brain function and malignancy. This compound is similar to naturally occurring glucose with the addition of a radioactive fluorine atom (F-18).

In some cases, PET may be more sensitive than SPECT, but PET scanners are much more costly than SPECT scanners and are often only available in the largest medical centers.

5. NUCLEAR MEDICINE (CLINICAL APPLICATIONS)

Introduction

Nuclear medicine studies were first performed in the 1950s using special devices called "gamma cameras." Nuclear medicine studies require the oral or intravenous introduction of very low-level radioactive chemicals (called radionuclides, radiopharmaceuticals or radiotracers) into the body. Radiopharmaceuticals are specially formulated to be collected temporarily in the specific part of the body to be studied. The radionuclides are taken up by the organs in the body and then emit faint gamma ray signals which are measured by a gamma camera.

Nuclear medicine provides physiological images, i.e. the metabolic activity of the organs process the radiopharmaceutical and concentrate it in the target organs for imaging. In an x-ray or CT examination, the radiation comes out of the x-ray or CT system and then passes through the patient's body before being detected and recorded onto film or by a computer. Nuclear medicine uses the opposite approach: a radioactive material is introduced into the patient, and is then detected by a machine called a gamma camera. The radiation which is emitted by the body during nuclear medicine imaging are gamma rays. These gamma rays are similar to x-rays but have a shorter wavelength.

The radionuclide substances used in nuclear medicine imaging are usually either synthesized radioactive substances, like technetium, or radioactive forms of elements that are naturally found in the body, such as iodine. The levels of radiation involved in nuclear medicine studies is usually considerably lower than a patient would receive in a conventional x-ray study or CT scan.

The nuclear medicine image can either be in grayscale (shades of black and white), for instance in a bone scan, or they can be color coded to clearly show functional activity, like in a cardiac study. The patient is positioned by the technologist on an examination table. Some nuclear medicine studies allow the patient to be seated. The nuclear medicine camera is then positioned over the area of interest, for example, the heart. Some nuclear medicine cameras have a patient aperture ("doughnut hole") like a CT scanner and the patient is positioned inside of this aperture for the study. The patient is simply required to relax and stay calm during the examination.

Space occupying lesions (injury or abnormality), especially tumors, may stand out on nuclear medicine images. Generally, these lesions are seen as areas of reduced radioactivity (called a "cold spot"); however, in some instances, like

bone scintigram, areas of increased activity (called a "hot spot") represent disease or injury (pathology).

Thyroid imaging and uptake

The use of iodine-131 (^{131}I) for measuring thyroid functional parameters and imaging the gland has historically served as the nucleus of the evolution of the field of nuclear imaging.

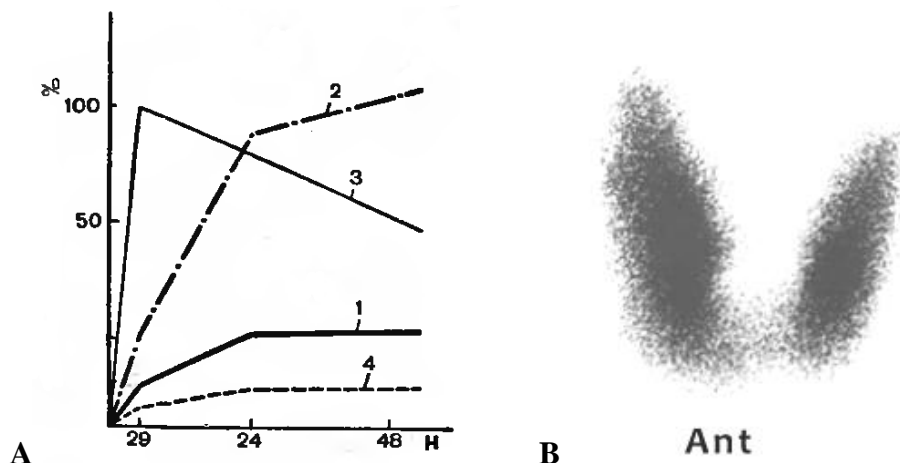
Most thyroid imaging techniques capitalize on some phase of hormone synthesis within the thyroid gland. Iodides or iodide analogs are actively transported into the thyroid gland, a process called trapping. Technetium-99m pertechnetate does not undergo organification to form thyroid hormone; instead, after trapping, it slowly "washes" from the gland.

The major advantages of ^{131}I are its low price and ready availability. The high thyroid dose makes ^{131}I undesirable for routine imaging of the thyroid. Technetium-99m pertechnetate is trapped by the thyroid in the same manner as iodides but is not organified; therefore, it is released over time as unaltered pertechnetate ($^{99\text{m}}\text{TcO}_4^-$) ion. The low absorbed dose to the thyroid permits administration of higher doses and therefore allows for more rapid imaging of the gland.

Iodine uptake test

The diagnosis of hyperthyroidism or hypothyroidism, however, is not made by using radioactive iodine uptake but should be made by serum measurements of thyroid hormone and thyroid-stimulating hormone (TSH). However, the thyroid uptake can be used to differentiate Grave's disease from subacute thyroiditis or factitious hyperthyroidism.

Thyroid uptake is based on the principle that the administered radiopharmaceutical is concentrated by the thyroid gland in a manner that reflects the gland's handling of stable dietary iodine and therefore the functional status of the gland. The higher the uptake of the radiopharmaceutical, the more active the thyroid; conversely, the lower the uptake, the less functional the gland. Uptake is conventionally expressed as the percentage of the administered activity in the thyroid gland at a given time after administration (usually at 4 to 6 hours and 24 hours) (figure 5.1). Normal range is about 10 to 30 % for 24-hour uptake determinations. The normal range for a 4- to 6-hour uptake is about 6 to 18 %. To begin the test, about 5 μCi (0.2 MBq) of ^{131}I -sodium in either liquid or capsule form is administered.



**Figure 5.1 — (A) Thyroid uptake (radiometry) types:
1 — normal, 2–3 — hyperfunction, 4 — hypofunction.**

(B) Iodine-123 anterior scan (scintigram) of the thyroid. The normal bilobed gland with an inferior isthmus is easily appreciated

Primary hyperthyroidism

Primary hyperthyroidism (Grave's disease or toxic nodular goiter) and secondary hyperthyroidism commonly produce elevated iodine uptakes. On the other hand, hyperthyroidism produced by toxic nodular goiters may yield uptake values in the high, normal, or mildly elevated range. Therefore, a normal or borderline elevated radioiodine uptake alone cannot be used to exclude the diagnosis of hyperthyroidism when it is clinically suspected.

The radiotracer uptake by this patient's hyperplastic and hyperfunctioning gland is uniform and intensely increased in the right lobe, left lobe, and isthmus. Therefore, the clinical manifestations and abnormal thyroid function tests correlate with the scintigraphic imaging findings.

Hyperthyroidism

On examination, there were no specific signs of thyroid disease and the thyroid was normal in size. Images obtained from technetium-99m-pertechnetate ($^{99m}\text{TcO}_4$), thyroid scintigraphy show abnormally increased homogeneous radiotracer uptake throughout the thyroid, which is normal in size. The intensity of thyroid gland uptake exceeds the uptake in both salivary glands, background activity is markedly decreased, and the pyramidal lobe is clearly visible. All of these findings indicate a hyperfunctioning gland. There is no focal photopenic or focal hot area to suggest a nodule.

Thyrotoxicosis

Although the diagnosis of thyrotoxicosis is established by clinical and biochemical means, radioiodine uptake and thyroid scintigrams are very useful in the differential diagnosis of the various causes of thyrotoxic states. Radioiodine uptake and scintigrams in thyrotoxic patients may be obtained at 4 to 24 hours post administration iodine-131 uptake together with ^{99m}Tc -pertechnetate scintigram is effective.

Reduced radioiodine uptake

Primary or secondary hypothyroidism may produce decreased radioiodine uptake.

Thyrosциntigraphy

Although ^{131}I may be used for obtaining thyroid uptakes, $^{99\text{m}}\text{Tc}$ -pertechnetate remain the agents of choice for obtaining maximum morphologic detail of the thyroid gland with the gamma camera. Either radionuclide, however, provides images of excellent quality (figure 5.1).

The indications for scintigraphic thyroid imaging include:

- To relate the general structure of the gland to function, in differentiating Grave's disease from toxic nodular goiter.
- To determine function in a specific area, for example, to see if a palpable nodule is functional.
- To locate ectopic tissue, such as a lingual thyroid.
- To assist in evaluation of congenital hypothyroidism (uptake in the gland is low and visualization is poor).

Technetium-99m-pertechnetate (TcO_4) radiotracer provides a lower radiation dose per unit administered than any of the radioiodines (I-131 and I-123) that are used for thyroid imaging. The thyroid is imaged 20 minutes after the intravenous administration of 5 mCi (185 MBq) of $^{99\text{m}}\text{Tc}$ -pertechnetate. On a $^{99\text{m}}\text{Tc}$ -pertechnetate scintigram, the salivary glands are usually well seen in addition to the thyroid. Technetium-99m pertechnetate is preferred over radioiodine when the patient has been receiving thyroid-blocking agents.

The normal thyroid gland is a bilobed organ with reasonably homogeneous distribution of activity in both lobes. Slight asymmetry in the sizes of the lobes is common, with the right lobe generally dominating.

Grave disease

Uniformly increased activity in the both lobes of the enlarged thyroid gland. There is no evidence of nodular increased activity to suggest a toxic nodular goiter, nor decreased uptake to suggest thyroiditis (figure 5.2).

Hyperfunctioning thyroid adenoma

Thyroid scintigraphy with $^{99\text{m}}\text{Tc}$ -pertechnetate demonstrates intense uptake of the radiopharmaceutical (*hot thyroid nodule*) corresponding to the palpable nodule in the left lobe of the thyroid. There is also suppression of uptake in the remainder of the left lobe as well as the entire right lobe. The scintigraphic findings in conjunction with the patient's history and elevated thyroid function tests are most consistent with an autonomous toxic nodule (figure 5.2).

Cold thyroid nodules are nonspecific and have both benign and malignant causes. 75 % of cold nodules are secondary to colloid cysts or adenomas. Although the incidence for carcinoma is more common in cold nodules than hot nodules, the incidence is still low and ranges from 15 to 25 %. Factors suggesting a benign etiology include older, female patients as well as multiple nodules. A nodule that decreases in size while on thyroid hormone is suggestive of a benign etiology.

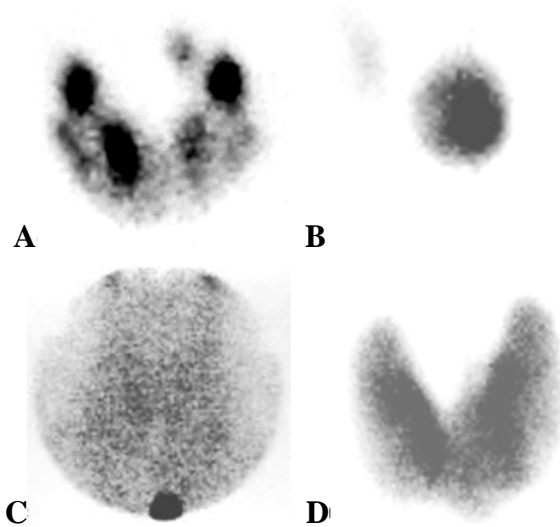


Figure 5.2— Scintigraphic images in four types of hyperthyroidism show:
(A) multinodular goiter, (B) solitary hyperfunctioning thyroid nodule,
(C) thyroiditis, (D) Graves' disease

Bonescintigraphy

Skeletal radionuclide imaging is performed with 99m-technetium tagged to methylene diphosphonate ($^{99m}\text{Tc-MDP}$) 10 mCi. Increased uptake of the radiopharmaceutical is seen in conditions producing both an increased metabolic activity and blood supply, including tumors, infections, fractures, metabolic diseases, and joint diseases. Radionuclide bone imaging is sensitive to early pathologic processes but is not as specific in defining anatomy as most other imaging systems. A major advantage of radionuclide imaging is that the entire skeleton can be imaged in a single examination.

Images are most commonly obtained 2 to 3 hours after injection, which allows clearance of the isotope from the blood supply and incorporation into bone. The imaging device in radionuclide scintigraphy is the gamma camera. After the injection, the gamma rays emitted from the patient's body. The data are manipulated by a computer, and the information concerning location and level of activity is portrayed on a computer monitor. The degree of image darkening reflects the degree of radionuclide activity. Images of both the whole body and specific collimated regions of interest are obtained.

In addition, it is important on the posterior view to examine the scintigram for the presence and location of renal activity; on the anterior view, for bladder activity. Asymmetric renal activity is not uncommon. Increased uptake is also found in the kidneys secondary to the excretion of the radioisotope, affording the radiologist an opportunity to also evaluate kidney anatomy and function.

Bone scintigram with nuclear medicine, for example, can be an important step in diagnosing of various kinds of cancer, including breast cancer, because it

can reveal if the cancer has metastasized beyond its primary site and developed secondary cancer growths in the bones. On an x-ray one might see that the bone is not broken, but on a bone scintigram, physicians can see metabolic changes caused by fine fractures, small tumors, or degenerative diseases such as arthritis.

Example indications: metastatic disease, tumor, malignant bone tumors, trauma, arthritis, osteomyelitis.

The normal scintigram varies significantly in appearance between children and adults. Nonpathologic increased uptake is noted in the most metabolically active regions of the body (e.g., epiphyses, costochondral junctions, sacroiliac joints, sternoclavicular joints). In children, areas of growth in the region of the epiphyses show intense uptake. In adults usually is good visualization of the skull, with relatively increased accumulation of activity in the region of the nasopharynx, which may be secondary to the high proportional blood flow in this region (figure 5.6). Because the human skeleton is symmetric, any asymmetric osseous activity should be viewed with suspicion.

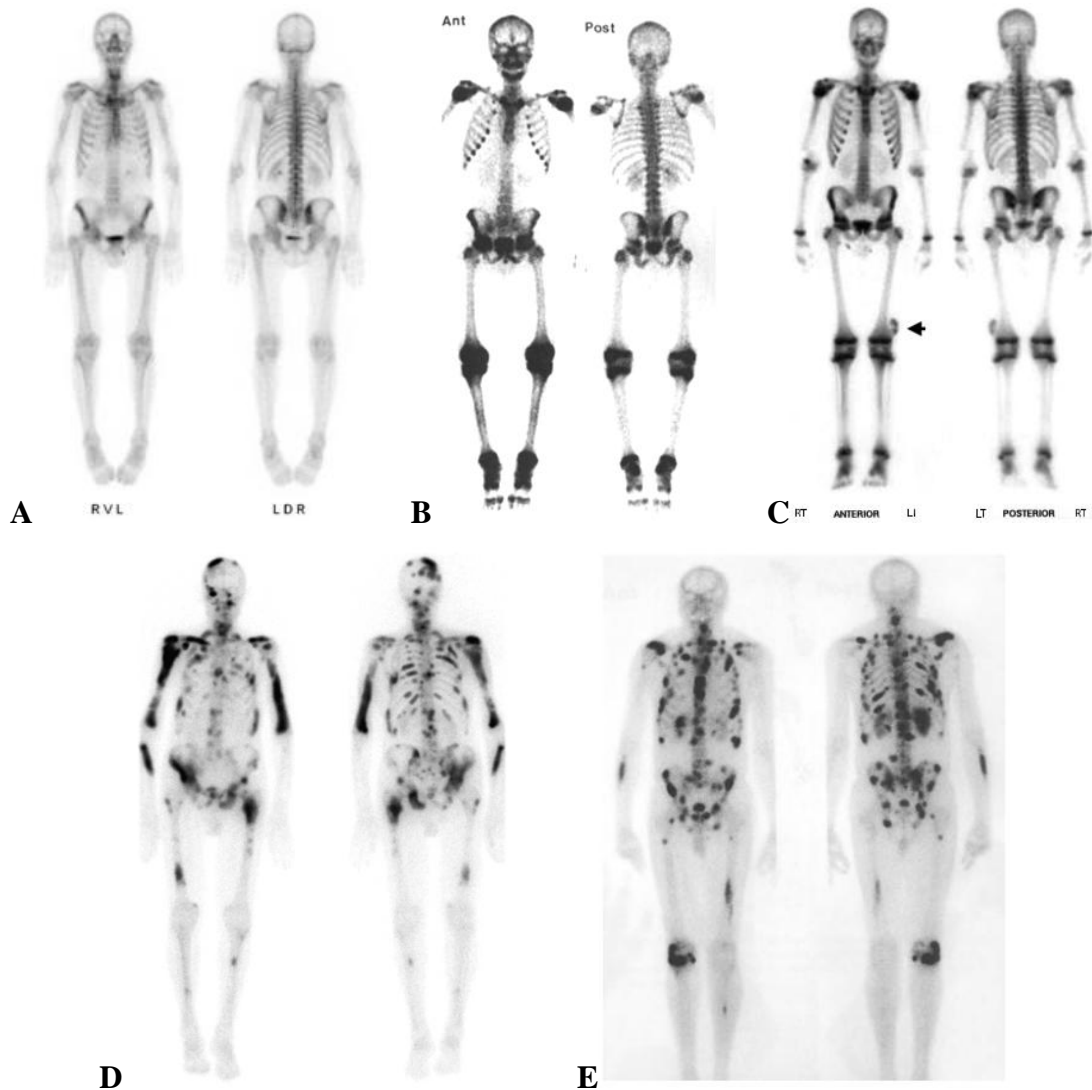


Figure 5.6 — (A) Normal adult bone scan (bone scintigraphy), anterior and posterior images. There is normal distribution of radiopharmaceutical in the bones and normal physiologic excretion of Tc-99m MDP by the kidneys into the urinary bladder. (B) Normal bone scintigrams. This scan was performed on a 15-year-old boy. Anterior (left) and posterior (right) images demonstrate markedly increased activity around the epiphyseal plates. This is usually best seen around the knees, ankles, shoulders, and wrists. (C) Osteochondroma. Fourteen-year-old male with pain and swelling of the left distal thigh for 1 week. The patient was referred to rule out trauma or heterotopic bone formation. The scintigrams shows increased pool activity in the lateral aspect of the distal left femur (arrow) representing the typical pattern of pedunculated osteochondroma. (D, E, different patient) Skeletal metastases from prostatic carcinoma. Anterior and posterior whole-body technetium-99m methylene diphosphonate bone scans show multiple focal sites of intense uptake (areas of increased activity) involving both the axial and appendicular skeleton. The scintigrams shows the typical pattern of metastatic bone diseases of randomly distributed foci of increased uptake of radiopharmaceutical

At any variants inflammatory and tumor diseases of bones scintigraphically there is a focal area of increased flow, increased blood pool activity and increased delayed uptake.

Scintigraphy of respiratory system

Example indications: diagnosis of pulmonary embolism, split lung function/preoperative assessment for lung resection.

Limitations: perfusion scintigrams are highly sensitive for the detection of small defects. However, this high sensitivity is not matched by a high specificity for the diagnosis of pulmonary embolism. Various conditions can cause mismatched defects on ventilation-perfusion scintigram including emphysema, tuberculosis, previous irradiation etc.

Perfusion imaging agents

Technetium-99m (^{99m}Tc) + macroaggregated albumin (MAA) is the radiopharmaceutical used for pulmonary perfusion imaging. It localizes by the mechanism of capillary blockade. In general, fewer than 1 in 1000 (< 0,1 %) of the capillaries are blocked. 95 % of the particles are removed from the circulation on the first pass through the pulmonary capillary bed. The normal administered activity in adults is 5 mCi (185 MBq).

Ventilation imaging agents: radioactive inert gases

The use of radioactive inert gases to evaluate ventilation permits sequential imaging of both lung ventilation and perfusion in conjunction with ^{99m}Tc -MAA because of the rapid clearance of the gases from the lungs.

Xenon-133 (^{133}Xe) is the primary isotope used for assessment of ventilation. It is relatively inexpensive and has a half-life of 5.3 days and a principal gamma ray energy of 81 keV. Xenon-133 allows for the assessment of all phases of regional ventilation: initial single breath, washin, equilibrium, and washout. This complete characterization of ventilation renders ^{133}Xe imaging the most sensitive ventilation study for detection and assessment of airways disease.

Ventilation examinations are generally performed either to assess regional ventilation or to improve the specificity of a perfusion scintigram. Inhale 10 mCi (370 MBq) of ^{133}Xe .

Normal perfusion scintigram

In the anterior view, the cardiac silhouette and the aortic knob are commonly identified (figure 5.7). The left lateral view may show a substantial anterior defect due to the heart. Oblique projections are often helpful but may be confusing to the uninitiated observer and frequently demonstrate prominent hilar defects. In general, defects suspected on the oblique projections should be confirmed on one of the four standard views.

Normal ventilation scintigram

A relatively homogeneous distribution of activity should be seen throughout both lungs; the initial breath image reflects regional ventilatory rate if there is maximum inspiratory effort.

Pulmonary thromboembolism (figure 5.8)

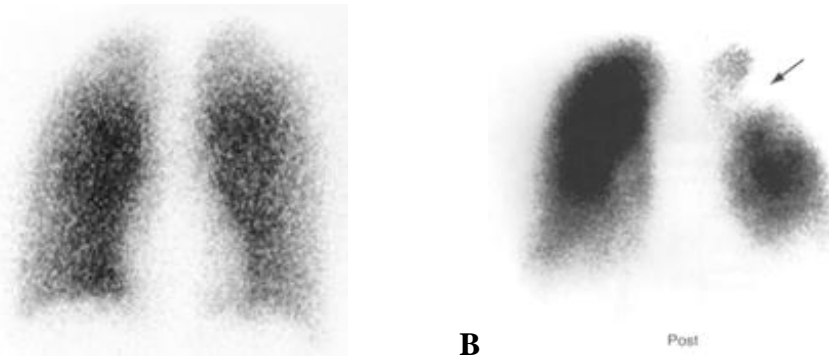


Figure 5.7 — (A) Normal perfusion study. A ^{99m}Tc -MAA perfusion scintigram (anterior view). The perfusion study reveals uniform perfusion throughout both lungs with no defects. Note the nonuniform uptake with homogeneous distribution of radiopharmaceutical and the sharp delineation of the costophrenic angles. In the anterior view, the cardiac silhouette and the aortic knob are commonly identified. (B) Tuberculosis. Posterior image from the perfusion lung scan shows decreased perfusion (arrow) in the upper area left lung (a matched defect).

Pulmonary thromboembolism is a potentially fatal complication of deep vein thrombosis. Although anticoagulation and thrombolytic therapies are effective, they are not without potential morbidity. Thus, before the institution of treatment, determination of the reasonable likelihood of the presence or absence of pulmonary emboli is needed.

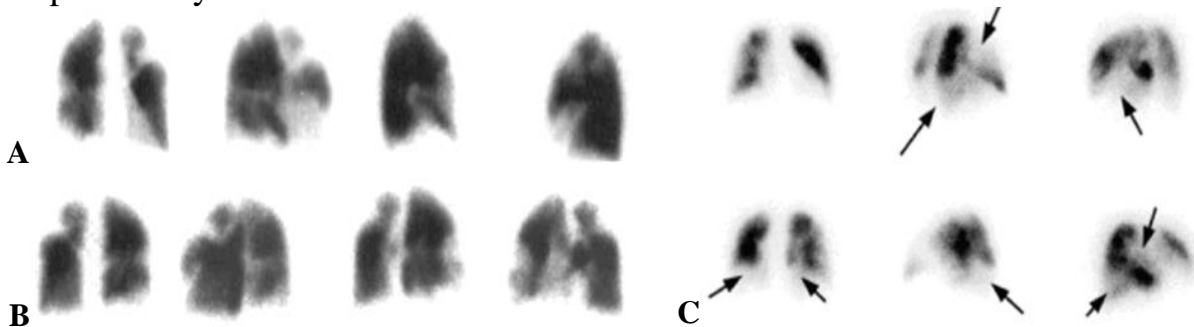


Figure 5.8 — (A, B, same patient) Perfusion MAA polipositions scans. Perfusion study shows multiple perfusion defects equivalent to more than two segments with no matching abnormalities on ventilation study and no corresponding changes in the chest X-ray, which was normal. This illustrates a typical pattern of high probability of pulmonary emboli. (C) ^{99m}Tc -MAA perfusion images demonstrate multiple segmental and subsegmental perfusion defects (arrows) in regions which are ventilated normally (V/Q mismatch). The findings indicate a high probability of acute pulmonary embolism

The clinical diagnosis of pulmonary embolism is often difficult. Chest radiographic findings alone are nonspecific for the diagnosis of pulmonary embolism. Radionuclide ventilation-perfusion imaging, when properly performed and interpreted, is an effective noninvasive procedure for the detection of pulmonary embolism. In addition, a normal scintigram essentially excludes the diagnosis. Lung scintigrams are often preferred over CT-angiography for patients who have contrast allergies, are in renal failure, or who are too large for the CT-gantry.

Hepatosplenoscintigraphy

Computed tomography (CT) and ultrasound offer better anatomic display of liver and spleen architecture than does radionuclide liver-spleen imaging, which is seldom performed. However, there remain some indications for technetium colloid liver-spleen scintigram, such as the confirmation or evaluation of suspected hepatocellular diseases, hepatomegaly or splenomegaly, and the confirmation of specific space-occupying lesions such as hepatic focal nodular hyperplasia.

The liver and spleen are organs of widely differing functions, but radionuclide colloid imaging capitalizes on a function common to both: phagocytosis.

The most commonly used agent is technetium-99m sulfur colloid, with an average particle size of 0.5 μm , which is larger than a true colloid. The uptake and distribution of $^{99\text{m}}\text{Tc}$ -colloid in the liver reflect both the distribution of functioning reticuloendothelial cells and the distribution of hepatic perfusion. In normal patients, most particles are rapidly accumulated by the phagocytes of the reticuloendothelial system of both the liver (Kupffer cells) and the spleen, allowing simultaneous imaging of both organs. Technetium colloid agents are cleared from the bloodstream with a half-time of 2 to 3 minutes. Under usual circumstances, 85 % of the dose accumulates in liver, 10 % in the spleen and the remainder in bone marrow.

Planar imaging

Imaging is performed using 5 mCi of $^{99\text{m}}\text{Tc}$ sulfur colloid. Adequate accumulation of $^{99\text{m}}\text{Tc}$ sulfur colloid in the liver requires about 5 to 10 minutes in normal patients. Routine gamma camera images for liver-spleen scintigram consist of anterior and posterior views as well as both lateral views. SPECT scintigrams of the liver occasionally adds additional information.

Normal hepatosplenoscintigram

In the normal liver, there is a homogeneous distribution of $^{99\text{m}}\text{Tc}$ sulfur colloid throughout the organ (figure 5.9). The liver usually consists of a dominant right and a smaller left lobe, which may occasionally be absent.

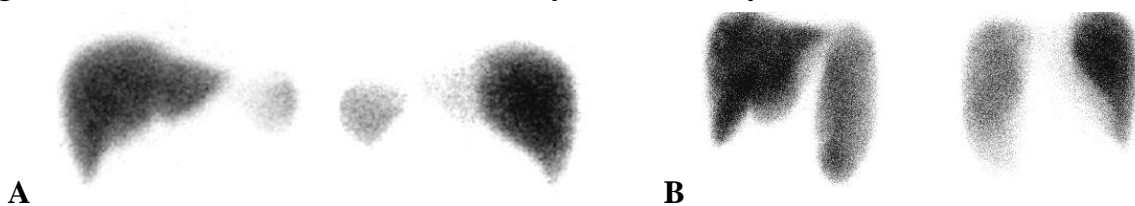


Figure 5.9 — (A) Normal planar $^{99\text{m}}\text{Tc}$ -sulfur colloid liver spleen imaging (anterior and posterior projections). Activity throughout the liver and spleen are uniform. Splenic activity is less than liver activity. The bone marrow is only faintly seen.

(B) A anterior and posterior images from a technetium-99m colloid liver-spleen scintigrams. The basic findings are marked colloid shift, splenomegaly, and an enlarged liver

Evaluation of a liver-spleen scintigram should include (1) the size, shape, and position of the liver and spleen; (2) the homogeneity of activity within the organs; (3) the presence of any focal defects in activity; and (4) the relative distribution of colloid among the liver, spleen, and bone marrow.

Abnormal liver scintigram

Any localized space-occupying process in the liver may present as a focal area of decreased activity (commonly referred to as a defect) on a technetium colloid scintigram, provided that it is of sufficient size to be detected. Radionuclide imaging simply confirms the presence or anatomic location of focal lesions (figure 5.10). Metastases, cysts and abscesses all displace normal Kupffer cells and appear as “cold” defects. Some benign focal liver lesions contain Kupffer cells and the benign nature of the mass can be confirmed by showing colloid uptake within it.

Differential of focal hepatic lesions with decreased uptake on technetium-99m colloid scintigrams: metastasis, cyst, hepatoma, adenoma, hematoma, hemangioma, abscess.

Defects in the hepatic parenchyma are nonspecific. Solitary intrahepatic defects may be produced by various lesions, any of which may also be multiple. In any patient with several liver defects, however, metastatic disease must be a prime consideration, particularly when accompanied by hepatomegaly or a known primary lesion. In most instances, particularly in cases of equivocal liver scintigram findings, ultrasonography or CT should be performed.

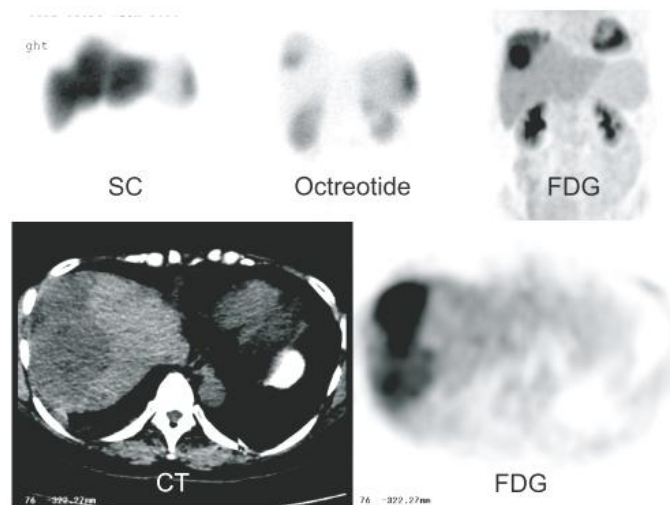


Figure 5.10 — Forty-eight-year-old female with history of pancreatic carcinoid tumor metastatic to liver. Anterior ^{99m}Tc-sulfur colloid image demonstrates a defect in the superior aspect of the liver. Focal uptake is noted on ¹¹¹In-octreotide anterior planar image and ¹⁸F-FDG anterior MIP image, consistent with metastatic carcinoid tumor. On the lower panels, axial PET-CT images illustrate FDG uptake corresponding to a low-density liver metastasis

In addition to primarily intrahepatic lesions, peripheral defects in the liver are frequently produced by adjacent extraparenchymal pathology, including subdiaphragmatic fluid accumulations or renal tumors, or by peripheral lesions of a primary hepatic origin, including subcapsular hematoma.

Increased radiocolloid concentration by the spleen and bone marrow compared with the liver (colloid shift) may be found in patients with diseases that

cause derangement of hepatic function and/or portal hypertension. Hepatic cirrhosis is the most common abnormality presenting in this fashion.

Other entities that may cause apparent focal areas of increased hepatic activity are Budd-Chiari syndrome (hepatic vein obstruction), focal nodular hyperplasia, and cirrhosis (regenerating nodules).

Hepatobiliary scintigraphy

Historically, liver imaging using radionuclides focused on the detection of liver masses. Solid masses may nevertheless have a nonspecific appearance on anatomic imaging requiring the use of radiopharmaceuticals that identify certain cell lines, metabolic properties or surface characteristics of specific lesions. The modern technetium-99m labeled hepatobiliary agents retain a pivotal role in studying biliary flow and dynamics.

The ^{99m}Tc -labeled hepatobiliary agents enable accurate and convenient imaging in acute and chronic biliary disease.

Analogues of technetium-99m labeled iminodiacetic acid (^{99m}Tc -IDA) first became available for clinical use in the 1970s and remain the most widely used radiopharmaceuticals for hepatobiliary imaging. After intravenous injection, these organic anions are taken up by hepatocytes in a manner similar to bilirubin. They are secreted into bile without conjugation. ^{99m}Tc -IDA uniformly mixes with bile, thereby becoming a marker of bile flow to the gallbladder and bowel.

Common indications are for acute (calculous or acalculous) cholecystitis, biliary patency, identification of biliary leaks, and, in neonates, differentiation of biliary atresia from neonatal hepatitis. Less common uses are for evaluation of biliary dyskinesia and sphincter of Oddi dysfunction. Limitation: none.

For elective studies, patients are given nothing by mouth beginning at midnight the night before the examination. Subsequent to the intravenous injection of 3 mCi (111 MBq) of ^{99m}Tc -labeled IDA, sequential anterior gamma camera images of the abdomen are obtained with the patient in the supine position.

The IDA material is taken up by the liver and excreted into the biliary tract. In a healthy person, IDA will pass through the bile ducts and into the cystic duct to enter the gallbladder. It will also pass into the common bile duct and enter the small intestine. IDA imaging is done by a nuclear scintigrammer, which takes pictures of the patient's biliary tract over the course of about two hours.

The patient is required to fast for at least 4 hours, but not longer than 24 hours. If the test is performed after a recent meal, the gallbladder may still be contracted, and this could lead to false-positive test results. After a prolonged fast, the gallbladder may be filled with concentrated bile, and this may also lead to false-positive test results by preventing tracer accumulation in the gallbladder. Tc-99m IDA is injected into a peripheral vein, followed by immediate imaging of the right upper quadrant.

Normal scintigram

In the normal patient, sufficient ^{99m}Tc -IDA is present in the liver in 5 minutes to allow good visualization of that organ. If for any reason additional

views of the liver are sought, they should be obtained in the first 10 or 15 minutes of the examination. After this time, there is progressive clearance of the radiopharmaceutical from the liver, and it becomes less apparent. As the radiopharmaceutical is excreted into the biliary tree, the major hepatic ducts and common duct are visualized first. Next, the gallbladder is filled as labeled bile flows through the cystic duct. About two thirds of biliary flow bypasses the gallbladder and enters the duodenum, and about one third enters the gallbladder (figure 5.11).

The amount and timing of entry into the gallbladder depends on a number of factors, including the nutritional state of the patient, administration of various drugs, and the tone in the sphincter of Oddi. In the presence of a patent common duct, activity flows promptly into the duodenal sweep and proximal small bowel.

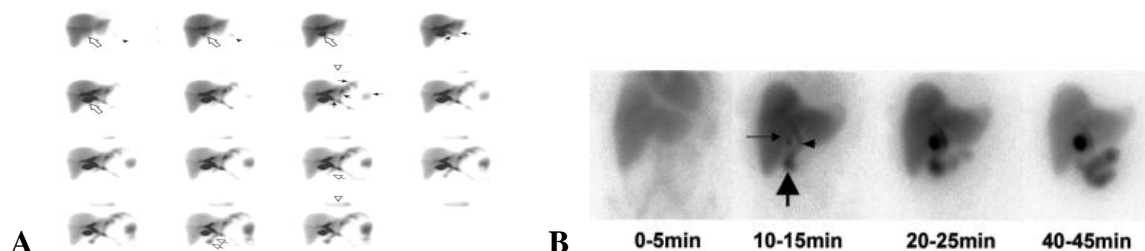


Figure 5.11 — (A) Normal hepatobiliary scans. Hepatic uptake is prompt. The CBD (short arrow), gall bladder (long arrow), and duodenum (thick arrow) are visualized within 15 min following intravenous administration of Tc-99m-IDA. (B) Normal hepatobiliary scintigrams. The common bile duct (thick and short arrows), gall bladder (long arrow)

Because the tracer behaves similar to bilirubin, it should be taken up by hepatocytes and excreted into the bile ducts. The liver should be visualized first, followed by visualization of the bowel and gallbladder. The appearance of tracer in the bowel and gallbladder by 60 minutes after administration is defined as normal. Nonvisualization of the gallbladder by 60 minutes is diagnostic of acute cholecystitis because this implies a functional obstruction of the cystic duct. False-positive results can be caused by chronic cholecystitis, hepatic insufficiency, and fasting for less than 4 hours or more than 24 hours as previously described.

Acute cholecystitis

Hepatobiliary imaging has proved to be of greatest value in the diagnosis of acute cholecystitis. More than 95 % of patients with acute cholecystitis have cystic duct obstruction. In this group of patients, radiopharmaceuticals excreted into the bile by the liver cannot enter an inflamed gallbladder through the obstructed cystic duct.

In the proper clinical setting, the diagnosis of acute (calculous or acalculous) cholecystitis in a fasting patient may be reliably made in the presence of normal hepatic uptake and excretion of the radiopharmaceutical through the common duct, but without visualization of the gallbladder over a period of 4 hours after injection.

A normal hepatobiliary scintigram with gallbladder visualization almost always excludes a diagnosis of acute cholecystitis.

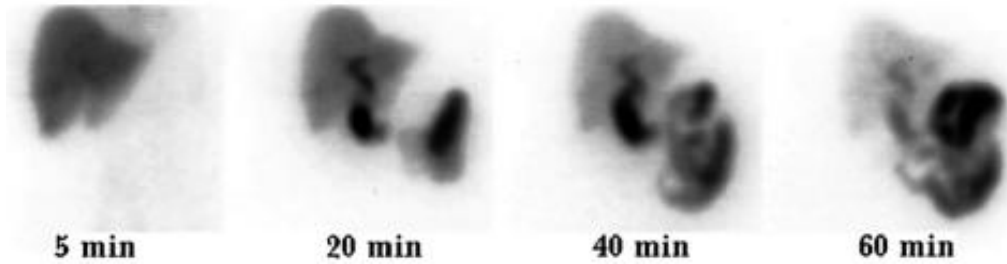


Figure 5.12 — The CBD and small bowel are promptly visualized in this study with Tc-99m-IDA, but the gall bladder is not visualized up to 60 min (cystic duct obstruction)

PET/CT and image fusion

Computed tomography (CT) has a high diagnostic ability by visualizing lesion morphology and by providing the exact localization of sites, but it is unable to provide information about functional status. In contrast, positron emission tomography (PET) with fluorine-18 fluorodeoxyglucose (FDG) provides information about the metabolism and viability of the lesions but fails to provide precise topographic localization.

The development of SPECT-CT and PET-CT systems allows the superimposition of nuclear medicine and CT images, a technique known as functional-anatomical mapping (figure 5.13). In a range of clinical scenarios, interpretation of images obtained using these hybrid devices has proved to be more diagnostically accurate than evaluation of the two sets of images separately. This combined imaging approach also allows functional data to be incorporated into the selection of radiation fields during radiotherapy planning.

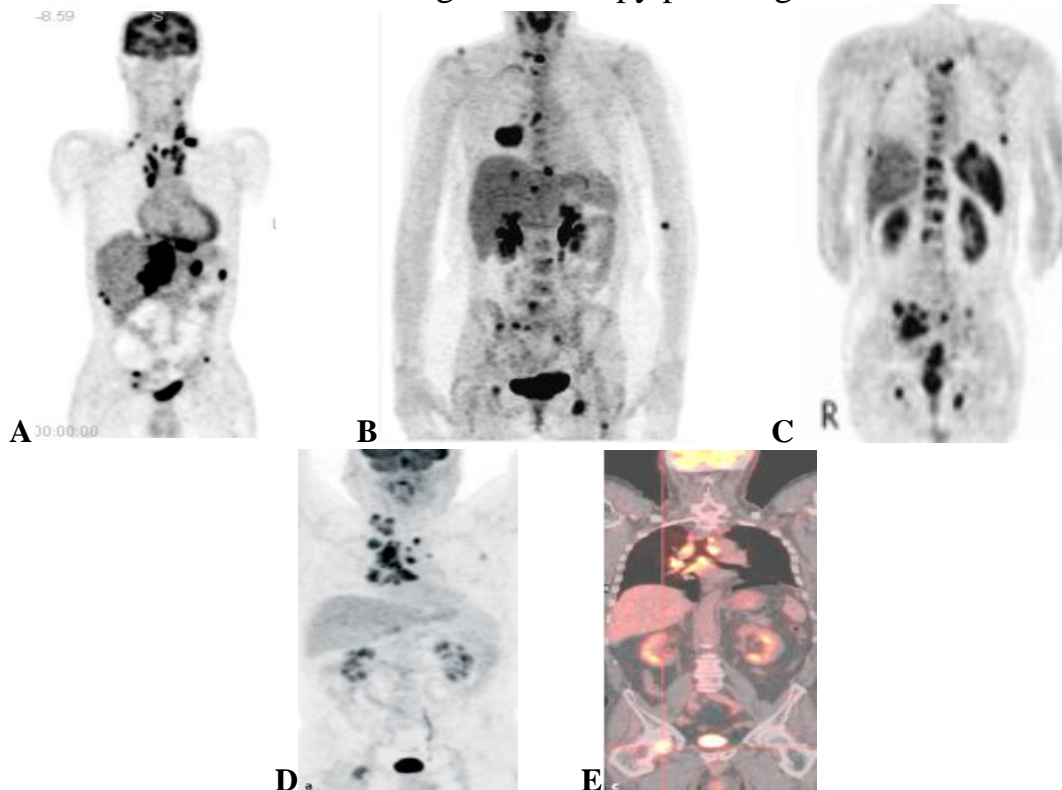


Figure 5.13 — (A, B, C, different of patients) PET tomograms and (D) PET, (E) PET/CT (same patient) fusion tomograms demonstrated of multiplies metastasis (hot spots)

Technical and clinical advances in medicine have led to the understanding that one modality cannot be a substitute for the other; they are complementary to each other. A fused image of PET and CT overcomes the inherent limitations of both modalities, resulting in a precise topographic localization of valuable physiologic information. The development of the new technology of PET/CT that allows for combined functional and anatomic data acquisition sequentially has the potential to make fusion an everyday clinical tool.

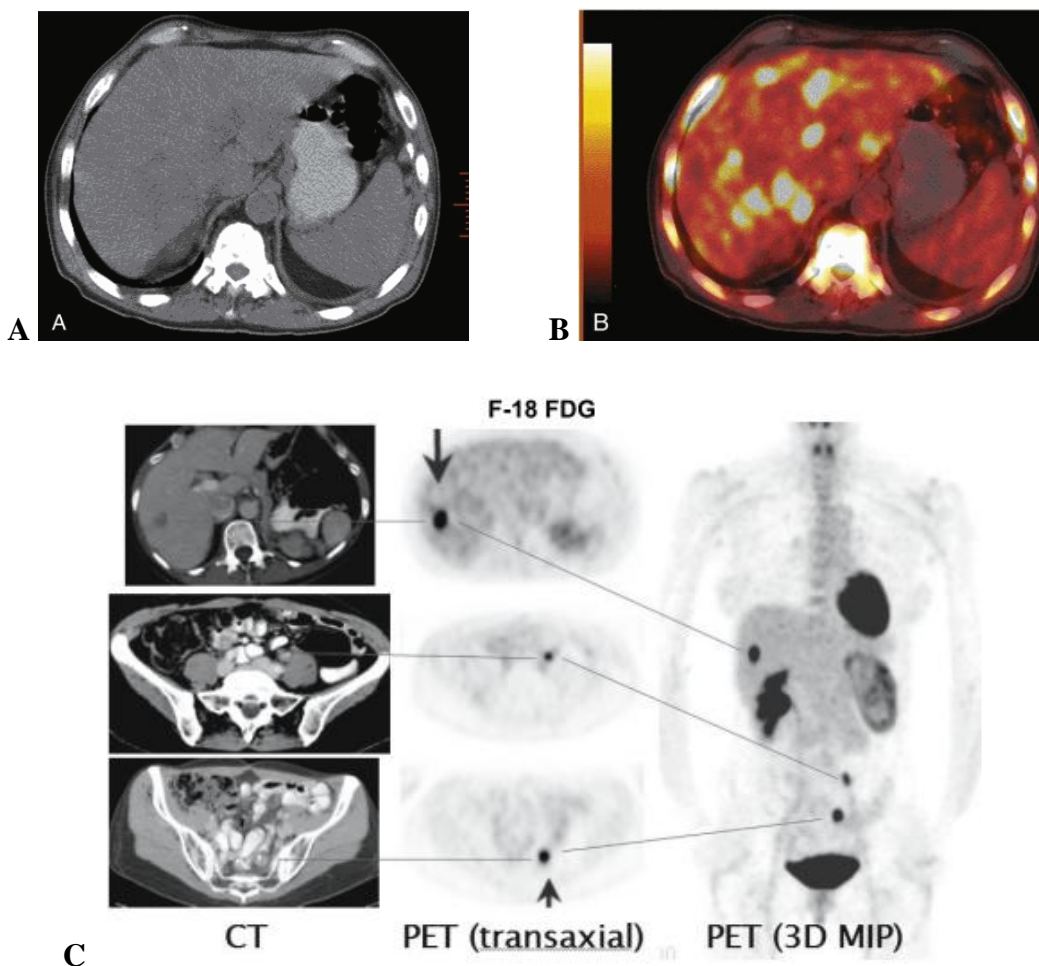


Figure 5.14 — (A) Axial noncontrast computed tomography (CT) image vaguely shows low attenuation bilobar hepatic lesions. (B) These lesions display abnormal increased uptake on transaxial fusion positron emission tomography (PET)/CT image consistent with hepatic metastases. Also noted are hypermetabolic osseous metastases. (C) An CT and FDC study shows metastases to the liver and abdominal lymph nodes (arrows)

Output from PET/CT imaging includes separate CT and PET images, as well as the coregistered fused images that overlay the anatomic CT and metabolic data. The combined PET/CT is more sensitive and specific for detecting otherwise occult malignancy, tumor staging, and detecting disease recurrence and/or metastasis (figure 5.14).

Table 5.1. — Examples common used of the radiopharmaceuticals

Study	Agent	Normal dosage introduced activity
Bone, Skeletal imaging	^{99m} Tc-MDP	25 mCi
Cardiac, Perfusion	²⁰¹ Tl-Chloride	3 mCi
Hepatobiliary	^{99m} Tc-IDA	5 mCi
Infection	⁶⁷ Ga-Citrate	5 mCi
Liver-Spleen scan	^{99m} Tc-Sulfur colloid	5 mCi
Lung, Ventilation	¹³³ Xe-Gas	20 mCi
Lung, Perfusion	^{99m} Tc-MAA	5 mCi
Renal, Cortical agents	^{99m} Tc-DMSA	4mCi
Renal, Glomerular agents	^{99m} Tc-DTPA	3 mCi
Thyroid, Scan	^{99m} TcO ₄ (pertechnetat)	10 mCi
Thyroid, Uptake	¹³¹ I-Sodium	7 μCi
Thyroid, Uptake and Scan	¹²³ I-Sodium	300 μCi
Tumor imaging	⁶⁷ Ga-Citrate	10 mCi
Tumor imaging	¹⁸ F-deoxyglucosa	10 mCi

(DTPA = diethylenetriaminepentaacetic acid, MAA = macroaggregated albumin, MDP = methylene diphosphonate, IDA = iminodiacetic acid)

Radiology of urinary tract

Introduction

Uroradiology remains a discipline that utilizes all imaging techniques to provide answers to specific clinical questions. The required information can be obtained most efficiently by using the correct test or tests performed in the correct order.

Currently ultrasound (US) and computed tomography (CT) are the most important imaging techniques in uroradiology. Renal US is a very important and frequently performed investigation, hence you should be familiar with the fundamentals of this modality. Renal tumors are mainly diagnosed by US, CT, and magnetic resonance imaging (MRI). Renal calculi can be demonstrated on US, renal and ureteric calculi on CT. The intravenous urogram (IVU) or pyelogram (IVP), once the mainstay of imaging of the genitourinary (GU) tract has lost much of its importance. Diseases of the lower urinary tract are mostly diagnosed by endoscopy.

Computed tomography

Computed tomography (CT) has high sensitivity for detection of small renal cell carcinoma, urinary tract stones and transitional cell carcinoma. CT is rapidly replacing IVP in the assessment of renal colic and haematuria.

Magnetic resonance (MR) urography

The unique advantage of MR urography (MRU) is the absence of ionizing radiation. The exact clinical role of MRU has not yet been defined and remains under evaluation. There are two basic methods for modern MRU. The first technique uses unenhanced, heavily T2-weighted turbo spin-echo sequences to obtain static-water images of the urinary tract. It is used in poorly functioning hydro-nephrotic kidneys. The second technique is similar to conventional intravenous urography and is known as excretory MR urography. A gadolinium-containing contrast agent is given intravenously. Following renal excretion, the gadolinium-enhanced urine is visualized using fast T1-weighted gradient echo sequences. MR imaging now plays an important role in the staging of pelvic malignancy, and the appearance of bladder and ureters is critical.

Ultrasound

Ultrasound (US) is an exceedingly useful technique for examination of the urinary tract. The advantages of using a non-invasive test, which is painless and does not involve irradiation to either patient or operator, are obvious. When a renal mass is found at IVU, then an ultrasound examination will easily and rapidly differentiate a tumour from a cyst. Combining a limited IVU, with its ability to demonstrate the pelvicalyceal system in detail, and ultrasound, which will show abnormalities of the renal outline, is a very efficient method of imaging the urinary tract accurately.

One of the most frequently performed urological ultrasound examinations is the estimation of residual urine in the bladder of patients with outflow obstructive symptoms. This can be combined with measurements of urinary flow rates, giving vital information to the urologist. A normal flow rate with no residue is reassuring to patient and clinician alike. Slow flow with a large bladder residue, on the other hand, may indicate a decompensated bladder due to outflow obstruction.

US provides information about renal length which is used to estimate renal mass and the presence or absence of hydronephrosis. The normal length in the adult ranges between 11 and 14 cm. Women tend to have smaller kidneys than men. The normal adult renal length approximates to the height of three lumbar vertebral bodies (nearly four in children). A difference in renal size of over 2 cm is usually significant.

Plain abdominal radiographs

A plain radiograph of the abdomen should be obtained before any contrast examination because calcification may later be masked by the contrast medium. As small renal calculi may be hidden by bowel shadows, at least two views of the renal area may be required. If there is doubt about the presence of a calculus, an oblique view or tomography of the kidneys may be required.

The perirenal fat gives a lucent outline to the kidneys and allows an assessment to be made of their position. Any mass related to them may be suspected by careful scrutiny of the plain radiographs. The loss of outline of a psoas

muscle may point to retroperitoneal pathology but it is a notoriously inaccurate sign. The full-length radiograph should include the bladder base and, in male patients, the prostatic urethra, particularly when there are lower tract symptoms, in order not to miss a urethral calculus. The outline of the bladder can be appreciated and for this reason the patient should empty the bladder before investigation: a large bladder residue may then be recognized.

Intravenous pyelogram (IVP)

Preliminary films are taken mainly to identify the kidneys and diagnose any area of renal tract calcification. This is particularly important in renal colic where a ureteric stone is being sought. Intravenous contrast is then injected. Films are taken to show the kidneys, the collecting systems, ureters and bladder. When overlying bowel gas obscures the kidneys, tomography and/or oblique projections are used to outline the collecting system. This is especially important in patients with haematuria where a small transitional cell carcinoma (TCC) of the collecting system may be the cause. A postmicturition film confirms drainage of both ureters and emptying of the bladder. For conditions, such as urinary tract infection and renal cell carcinoma, other imaging techniques, especially ultrasound (US), CT and scintigraphy, have replaced IVP. The number of intravenous urograms (IVUs) performed over the last 15 years has decreased as the use of other imaging techniques, particularly US and CT, has increased. The IVU is still a valuable procedure for examination of the urinary tract. It gives excellent anatomical images of the pelvicalyceal systems and, to some extent, an indication of renal function.

Retrograde pyelogram

This procedure is usually performed in conjunction with formal cystoscopy. The ureteric orifice is identified and a catheter passed into the ureter. Contrast is then injected via this catheter to outline the collecting system and ureter. In my experience better images are attained by performing the contrast injection in the X-ray department after the patient has left the recovery ward, rather than obtaining mobile films in theatre. Retrograde ureteropyelography is indicated mainly in those patients suspected of having a urothelial tumour of the upper urinary tract and in whom excretion urography is normal or equivocal.

Ascending urethrogram

A small catheter is passed into the distal urethra and contrast-injected. Films are obtained in the oblique projection. The posterior urethra is usually not opacified via the ascending method. Should this area need to be examined, a micturating cysto-urethrogram will be required.

Micturating cysto-urethrogram (MCU)

The bladder is filled with contrast via a urethral catheter. The catheter is withdrawn and films are taken during micturition. The particular indication will dictate the type and number of films performed. The micturating cystourethrogram (MCU) is the most accurate method of demonstrating vesicoureteric reflux, and is important in children with urinary tract infection and reflux nephropathy.

Renoscintigraphy

A renal scintigram is a nuclear medicine examination that measures the function of the kidneys. Renal scans are helpful in evaluating blood flow to the kidney, glomerular filtration, tubular function (resorption and secretion), and drainage of the collecting systems. Functional information is provided as well as anatomical, as well as renal size and drainage of the collecting systems.

Example indications: renal function; renal artery stenosis; obstructive uropathy, hypertension acute renal failure.

The preferred agents renal parenchymal static imaging are technetium-99m DMSA. Optimal parenchymal imaging can be obtained 1–3 hours after injection. By this time, collecting system activity will usually not be present. At a minimum, both posterior and posterior oblique views should be obtained.

^{99m}Tc-diethylenetriaminepentaacetic acid (^{99m}Tc-DTPA)

This tracer is a nearly ideal agent for assessment of glomerular filtration. It is a small chelate with a molecular weight of 500, and its only mode of excretion is glomerular filtration. It is neither secreted nor reabsorbed by the kidneys. Its renal extraction reflects the filtration fraction of plasma.

¹³¹I-hippurate

Hippurate is mainly excreted by tubular secretion (80 %) and, to a lesser extent, by filtration (20%).

^{99m}Tc-dimercaptosuccinic acid (^{99m}Tc-DMSA)

^{99m}Tc-DMSA is used for cortical imaging because about 50% of the injected dose is retained in the renal cortex, bound to sulfhydryl groups in the proximal convoluted tubules. Peak renal activity is seen at 4-6 hours after injection. It is the favored tracer for assessment of renal morphology and is used in the assessment of pyelonephritis and renal scarring.

Typically, the gamma camera is placed posterior to the patient. Used of activity Tc-99m DTPA: 5 mCi, Tc-99m DMSA: 5 mCi.

Renal perfusion can be assessed with the various ^{99m}Tc-labeled tracers with the camera set to take rapid sequence dynamic images at a rate of 1-3 seconds per frame during the first minute of the acquisition. The remaining 20–30 minutes of the study is usually performed at a framing rate of 20-60 seconds to evaluate the uptake and excretion phases (figure 5.15–5.16).

Acute renal obstruction

Decreased blood flow with decreased function and minimal excretion is noted in the kidney, suggesting an acute obstruction. An acute high-grade outflow obstruction can decrease excretion, overall function and blood flow to the affected kidney. A chronic obstruction will eventually lead to absence of function of the kidney.

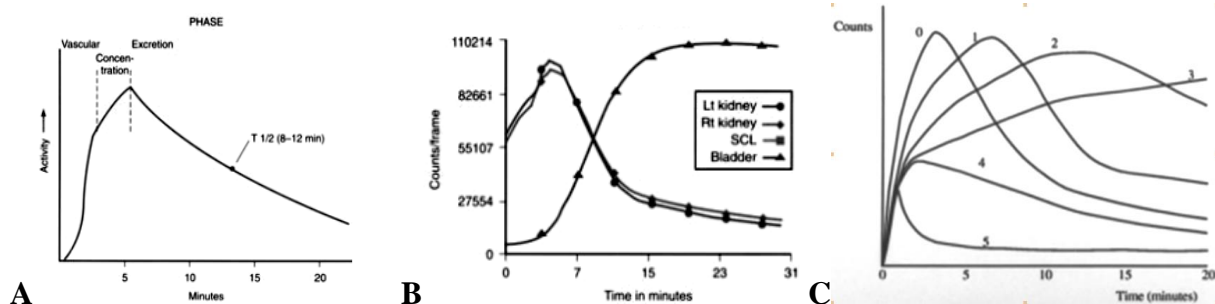


Figure 5.15 — Typical renogram curves. (A) Schematic drawing demonstrates the conceptual portions of the time-activity curve within the kidney.

(B) An actual renogram shows symmetric activity between right and left kidney, rapid drop off after the peak, and a long tail extending to the right. The curve also shows increasing activity within the bladder after about 4 minutes.

(C) Common renogram patterns used for the visual interpretation of renography.

Type 0: normal. Type 1: time to peak (T max) is >5 min.

Type 2: There are more exaggerated delays in time to peak and in parenchymal washout.

Type 3: Progressive renal accumulation (obstruction type, no washout detected).

Type 4: Renal failure pattern, but with measurable renal uptake.

Type 5: Renal failure pattern, representing blood background activity only (non functional type)

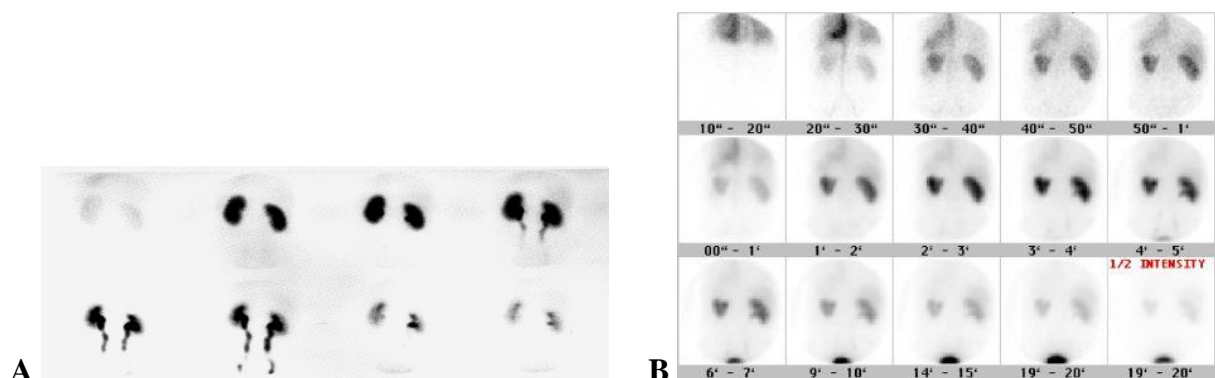


Figure 5.16 — Variants of normal dynamic renoscintigraphy. After administration of radiopharmaceutical, maximal kidney activity is seen at about 3 to 5 minutes, and by 4 to 5 minutes, the bladder can be identified at the bottom of the images.

By about 8 to 12 minutes, most of the activity has cleared the parenchyma and is seen in the collecting systems, making the kidneys appear slightly smaller than on the early images. The temporal sequence here is similar to that identified on intravenous pyelogram

Obstructive uropathy (figure 5.17)

Interpretation of a diuretic scintigram relies both on visual examination of the dynamic scintigram and on inspection of time-activity curves derived for each kidney using the regions of interest (ROIs) method. Curves represent obstruction with a continuous rise or plateau following diuresis. On images there is progressive accumulation in the collecting system which is unaffected by furosemide injection, is present residual hypotonia or dilatation of the pelvis and (or) calices. Can is present progressive accumulation of the tracer in both ureters and delayed renal washout.

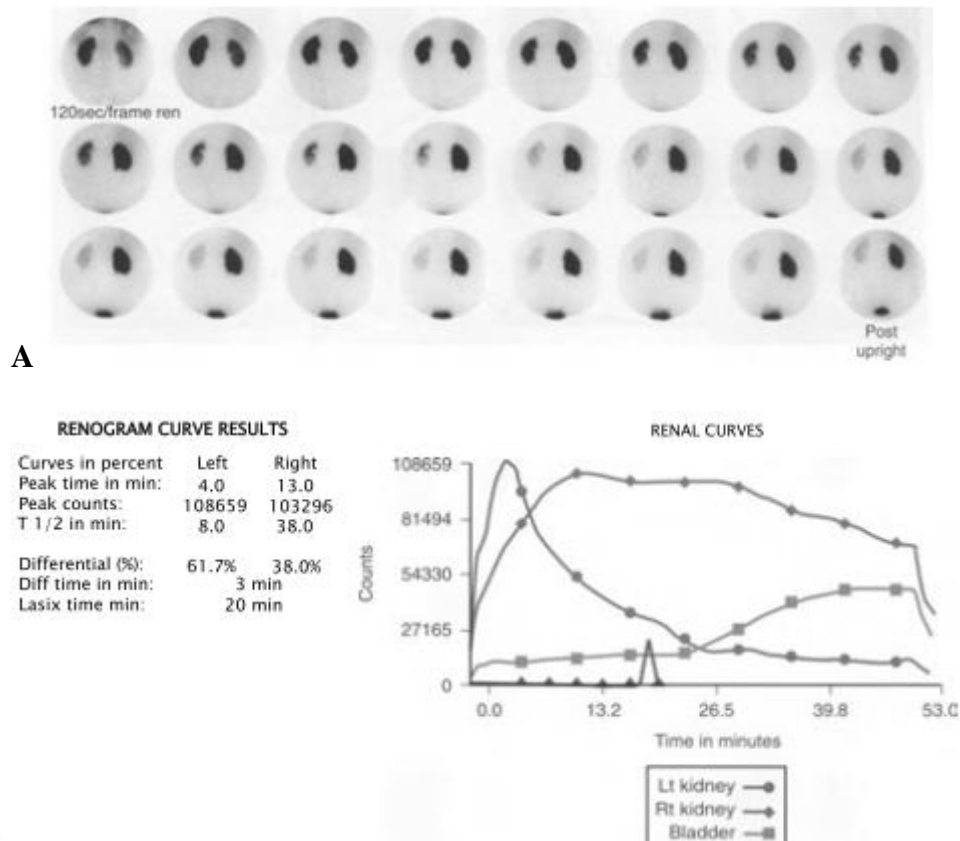


Figure 5.17 — (A) After intravenous administration of technetium-99m DTPA, the posterior 2-minute sequential images show a dilated collecting system of the right kidney. (B) Abnormal diuretic renogram with obstruction

Acute pyelonephritis

On imaging of the renal parenchyma with ^{99m}Tc -DMSA a cortical defect due to pyelonephritis is characterized by preservation of renal contour, whereas scarring (from a previous infection) typically results in volume contraction, although the two may be indistinguishable.

Renovascular hypertension

With a filtered agent such as ^{99m}Tc -DTPA, the drop in glomerular filtration results in moderate to severe reduction of tracer uptake by the affected kidney which in extreme cases can be complete with only background activity and no appearance of tracer in the collecting system.

Sequence of radiographic imaging

Contrast films are usually taken at 1, 5 and 15 minutes after injection. In order to obtain a good demonstration of the renal outlines, a radiograph coned to the renal area should be taken immediately after the injection of contrast medium (the 1-min film). This will coincide with the highest concentration of contrast medium in the nephrons and from this nephrogram the size and outline of the kidneys will be seen.

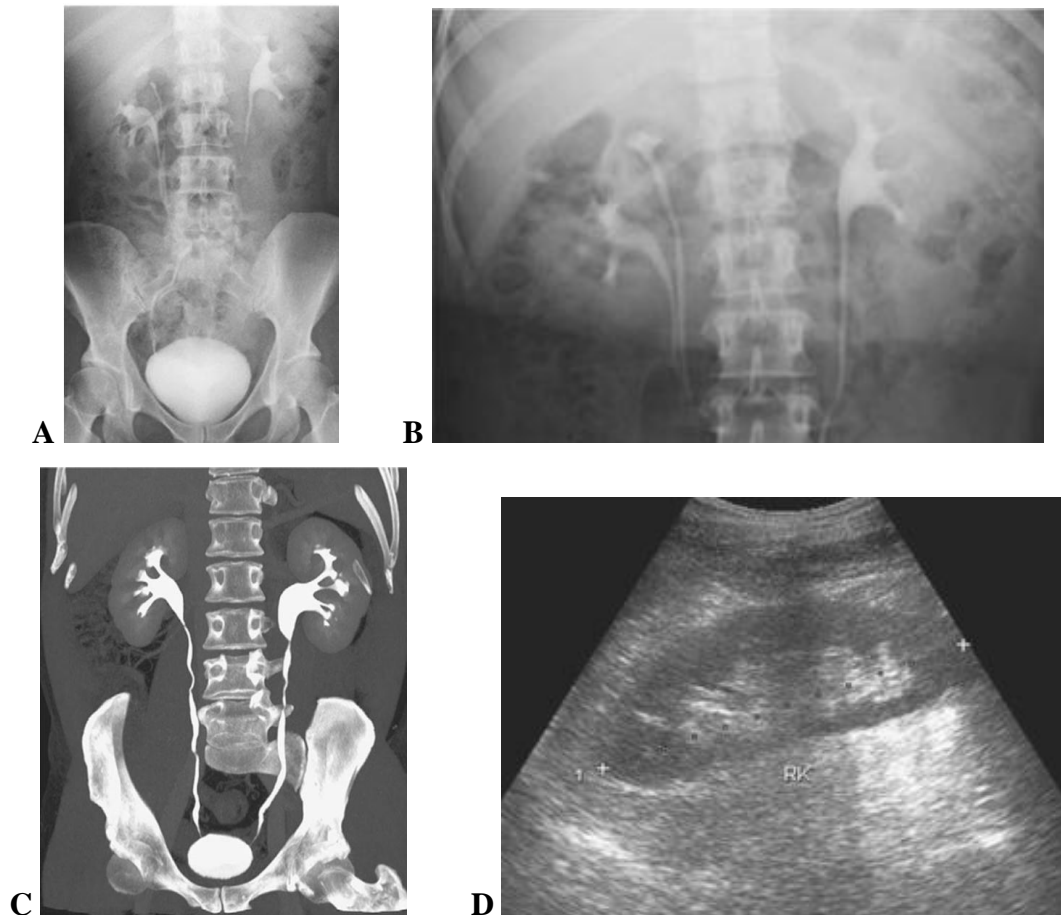


Figure 5.18 — Intravenous normal urogram (A-C). (A) Duplex right ureters on a 15-minute full length radiograph. (B) Designated renal area radiograph for improved visualization of duplex (right) and normal (left) collecting system. (C) CT urography. Coronal maximum intensity projection (MIP) acquired 10–12 minutes following intravenous contrast medium masking the location of a stone in the upper left ureter but demonstrating there is no obstruction and normal in all other respects. (D) Ultrasound of the kidneys. Normal right renal sonogram

An image at 5 min coned to the renal area will show early filling of the pelvicalyceal system and the relationship of the calyces to the renal outline. Again, tomography or oblique images may be useful. Some advocate abandoning the immediate 1-min nephrogram image, as the 5-min tomogram will give an equally good demonstration of the renal outlines, allowing the number of films in the IVU series to be reduced. This decreases the total radiation dose to the patient, the importance of which is now well understood. If there is any doubt about the renal outlines, ultrasound is far better than urography (figure 5.18).

Hydronephrosis and hydroureter

This situation is analogous to an obstructing ureteric stone (pebble) or a tumor encasing the ureter (pinching). On the IVP present signs of obstruction. Radiographic features:

1. Delayed nephrogram and delayed contrast excretion.

2. Hyperdense nephrogram: the affected kidney becomes too white.

3. Dilation of the collecting system and dilatation of the ureter before the obstruction.

Initial films may not show the site of obstruction since it takes longer to outline a blocked system with contrast. Therefore, to locate the site of obstruction, one must ask for delayed films. When there is no delayed nephrogram and no delayed contrast excretion, there is no obstruction.

Renal ectopia

Abnormally positioned kidney that can be found in various locations. The ectopic kidney usually functions, though the nephrogram and pelvocalyceal system may be obscured by overlying bone and fecal contents. Includes pelvic kidney, intrathoracic kidney, and crossed ectopia (the ectopic kidney lies on the same side as the normal kidney and is usually fused with it). Whenever only one kidney is seen on excretory urography, a full view of the abdomen is essential to search for an ectopic kidney.

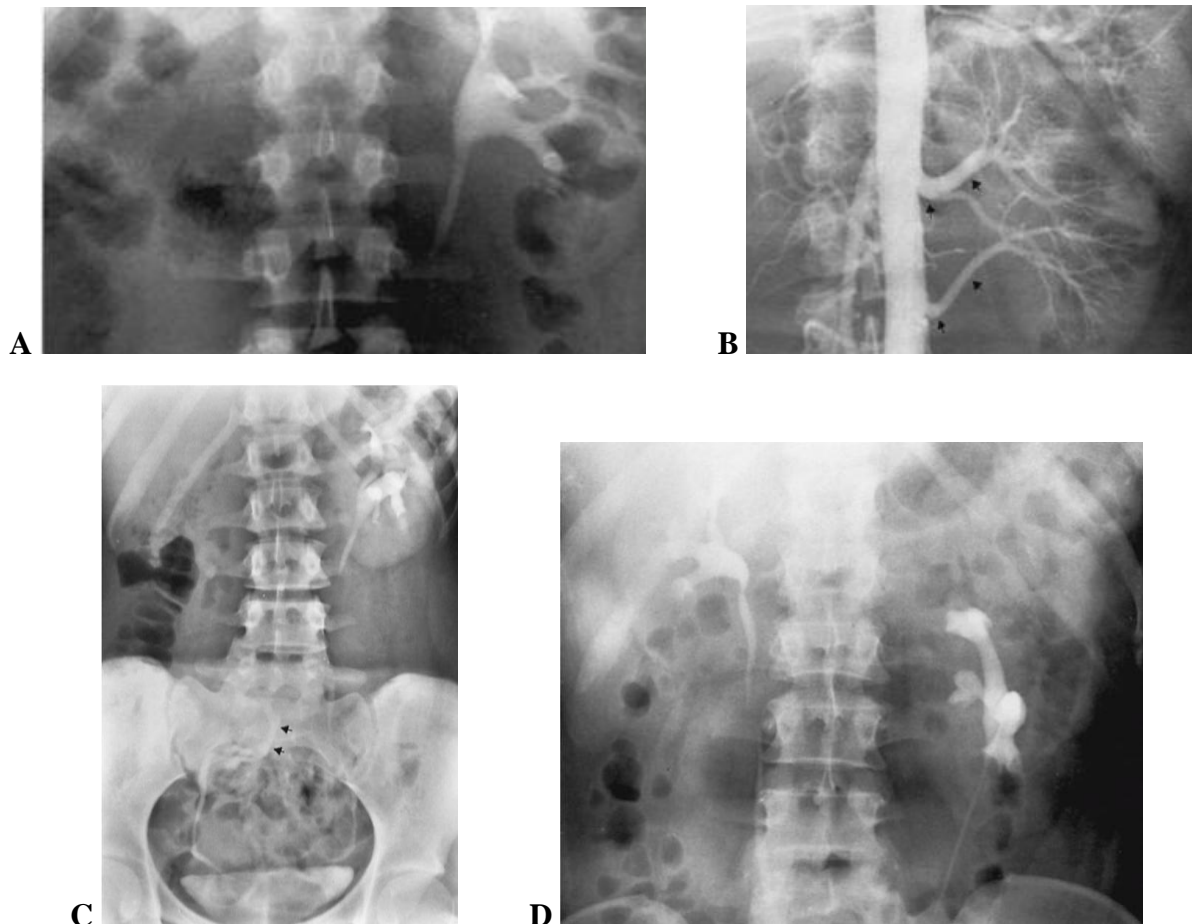


Figure 5.19 — Solitary kidney. (A) Excretory urogram demonstrates a normal left kidney with no evidence of right renal tissue. (B) Aortogram shows two renal arteries to the left kidney (arrows) and no evidence of a right renal artery, thus confirming the diagnosis of unilateral renal agenesis.

(C) Pelvic kidney. The arrows point to the collecting system.

(D) Malrotation of the left kidney. Note the apparent lateral displacement of the upper ureter and the elongation of the pelvis

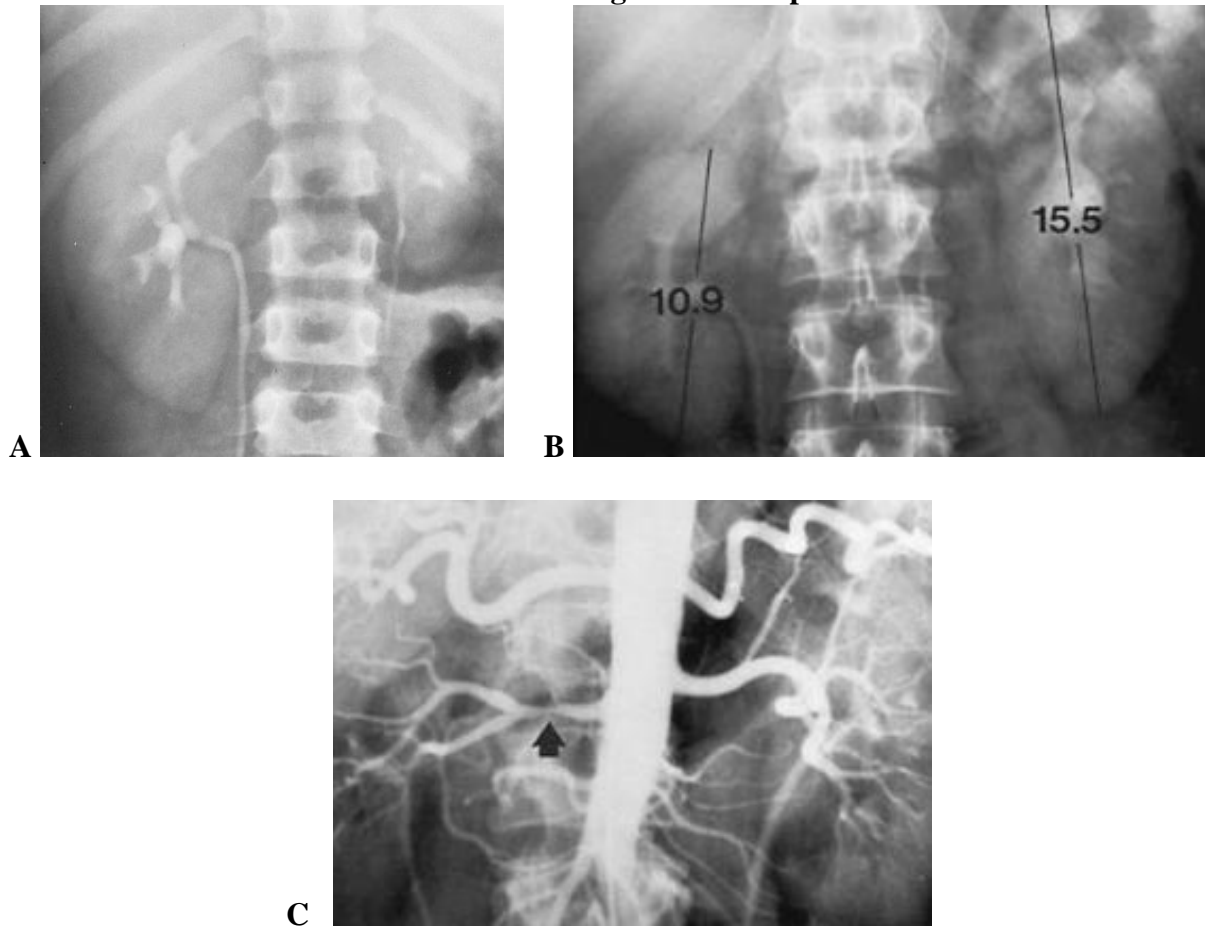


Figure 5.20 — (A) Congenital hypoplasia.

The small left kidney, a miniature replica of a normal kidney, has good function and a normal relation between the amount of parenchyma and the size of the collecting system.

Note the compensatory hypertrophy of the right kidney.

Renal ischemia associated with hypertension.

Diminished size of the right kidney (B) due to renal artery stenosis (C) (arrow)

Nephroptosis

Excessive caudal movement of a mobile kidney (especially the right) when the patient goes from supine to erect position. There may be associated changes in the ureter (angulation at the ureteropelvic junction, loops, kinks, and tortuosity). If a ptotic kidney becomes fixed in its dropped state, permanent ureteral kinking causes impaired drainage, increased hydronephrosis, and a greater chance of infection.

Calculus

Round or oval, frequently mobile filling defect. Often multiple and bilateral. A large calculus may form a cast of the pelvocalyceal system (staghorn calculus). If the obstruction is acute, the increased intrapelvic pressure may permit little or no glomerular filtration and produce the radiographic appearance of a delayed but prolonged nephrogram and the lack of calyceal filling on the affected side. More than 80 % of renal calculi are radiopaque and detectable on plain abdominal radio-

graphs. Completely lucent calculi are composed of uric acid or urates, xanthine, or matrix concentrations. Cystine calculi are mildly opaque (figure 5.21–5.23).

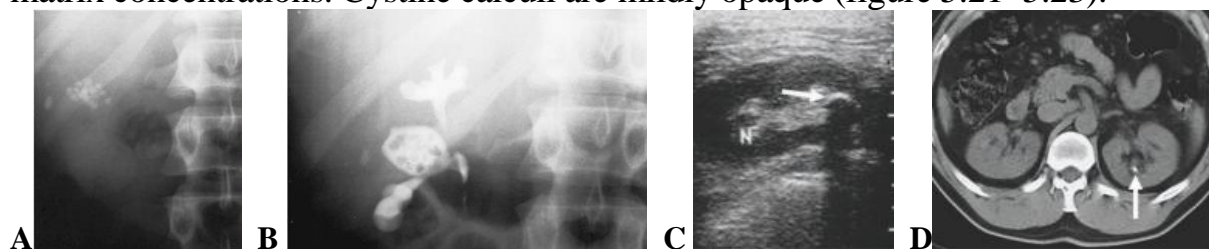


Figure 5.21 — Cystine stones. (A) Plain film shows multiple radiopaque calculi. (B) Excretory urogram demonstrates the stones as lucent filling defects in the opacified renal pelvis. (C) On US renal calculi are strongly echogenic structures (arrow) with posterior shadowing. (D) On CT they are very dense and are demonstrated in the renal pelvis (b, arrow)

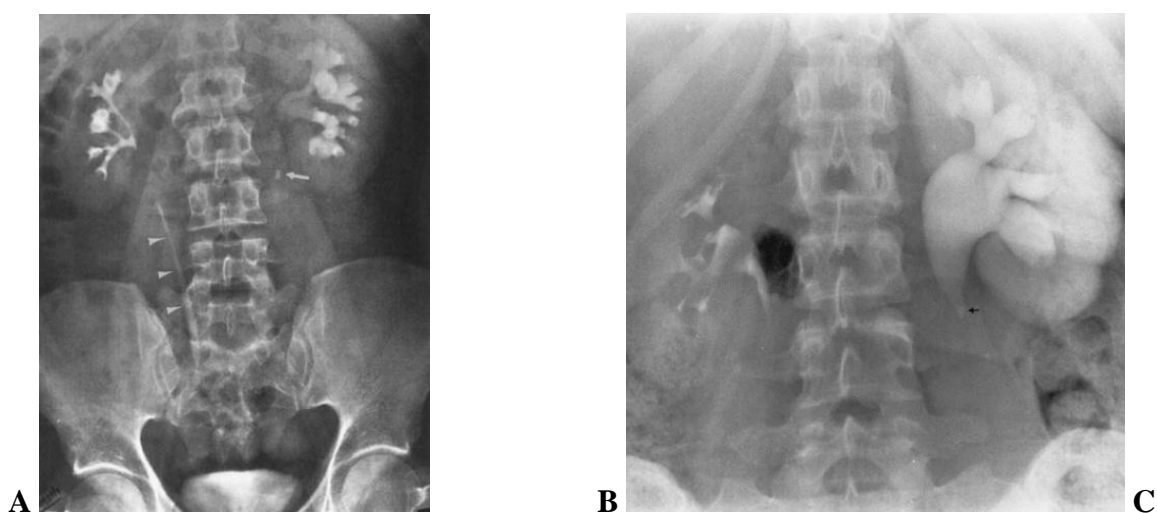


Figure 5.22 — (A) An anteroposterior film from an intravenous urogram was taken at 10 minutes in a patient with a proximal left ureteral calculus (arrow) and associated left collecting system dilatation. The right collecting system is normal, and the right ureter (arrowheads) and bladder are visualized. (B) Obstructing ureteral calculus. Excretory urogram demonstrates a prolonged nephrogram and marked dilatation of the collecting system and pelvis proximal to the obstructing stone (arrow).

(C) Coronal CECT shows prompt concentration & excretion of urine from the left kidney. While the right kidney has a delayed nephrogram and dilated calices, due to an obstructing ureteral stone (black arrow)

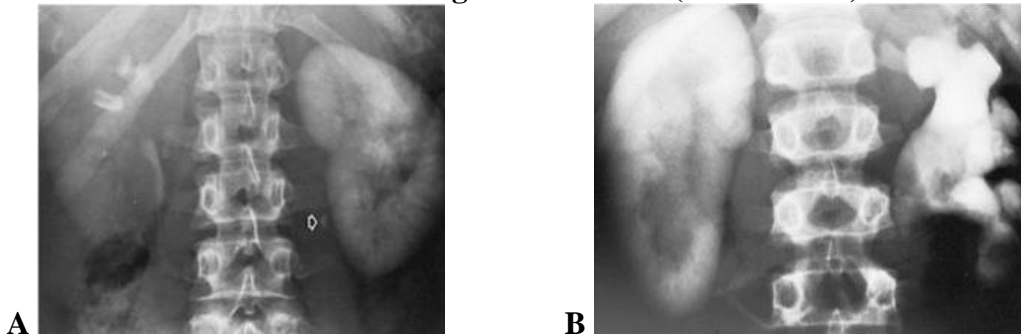


Figure 5.23 — Acute urinary tract obstruction. (A) Excretory urogram demonstrates a prolonged nephrogram on the left with fine cortical striations (alternating radiolucent and radiopaque lines) and no calyceal filling. An arrow points to the obstructing stone in the proximal left ureter.

(B) In another patient, there is a prolonged and intensified obstructive nephrogram of the right kidney. On the left, there is marked dilatation of the pelvocalyceal system but no persistent nephrogram, reflecting an intermittent chronic obstruction on this side

Acute pyelonephritis

Unilateral global enlargement of the kidney with decreased and delayed contrast material excretion and mild dilatation of the collecting system. There is often focal polar swelling and calyceal compression (figure 5.24).

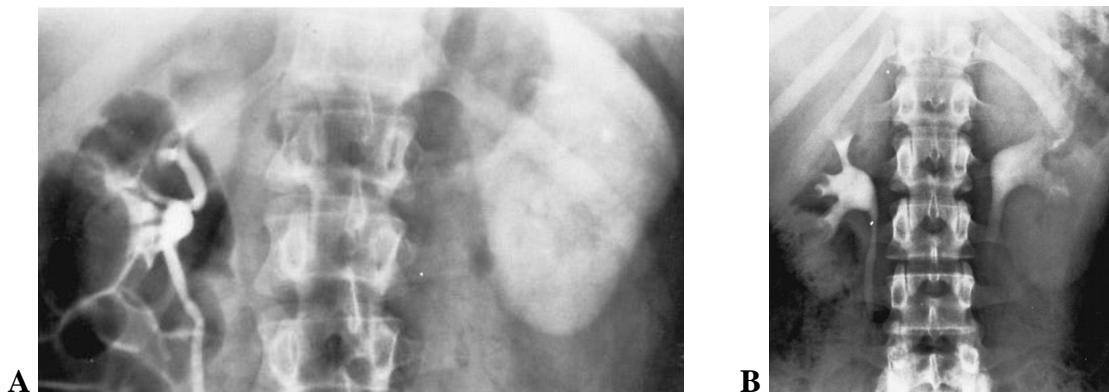


Figure 5.24 — (A) Acute bacterial nephritis. Persistent dense nephrogram on the left with minimal opacification of the collecting system.

(B) Acute pyelonephritis. Generalized enlargement of the left kidney with decreased density of contrast material in the collecting system.

(C) Acute pyelonephritis. Postcontrast scan shows characteristic low-density striations (arrows) in the left kidney

Compensatory hypertrophy

Unilateral smooth, large kidney that is normal in all respects except for its size and the thickness of the renal parenchyma. The pelvocalyceal system and ureter may appear distended (high urinary flow rate). Response to congenital absence, surgical removal, or disease of the contralateral kidney.

Chronic pyelonephritis

Clubbed, dilated calyces are caused by retraction of papillae and most frequently involve the poles. Depressed cortical scars typically develop over involved calyces.

Renal cyst

This common benign entity is found in approximately 30 % of all elderly patients. It often occurs bilaterally and can be associated with hepatic cysts. Simple renal cysts have a thin, smooth margin, have no internal echo on US, and are of water density on CT (less than 20 Hounsfield Units). They are predominantly found in the renal cortex, but can also protrude into the renal hilum, in which case they have to be distinguished from a dilated renal pelvis (figure 5.25–5.27).

Parapelvic renal cysts located in the renal sinus fat can also create the impression of hydronephrosis but are easily discernible from the actual renal pelvis on the excretory phase of a contrast-enhanced CT scan.

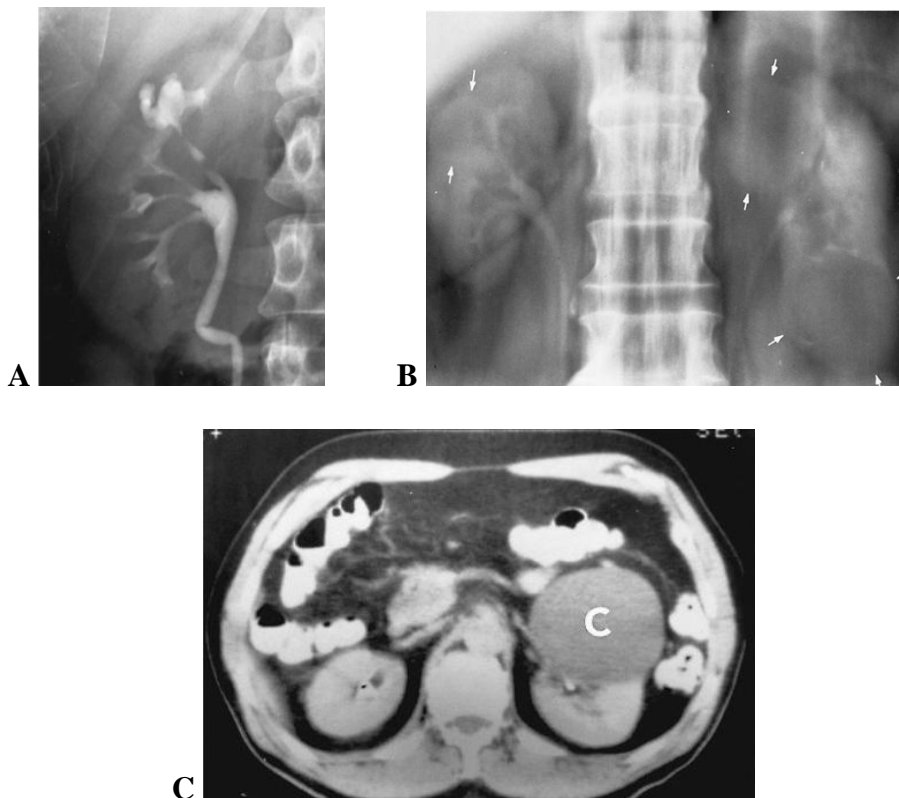


Figure 5.25 — (A) Chronic atrophic pyelonephritis. Focal reduction in parenchymal thickness involving the upper pole of the right kidney.

(B) Renal cysts. Nephrotomogram demonstrates bilateral renal cysts (arrows).

(C) Benign renal cyst. Nonenhancing left renal mass (c) with a sharply marginated border and a thin wall

Simple renal cyst

Focal contour expansion of the kidney outline on the nephrogram. The cortical margin appears as a very thin, smooth radiopaque rim about the bulging lucent cyst (beak sign). A thickened wall suggests bleeding into a cyst, cyst infection, or a malignant lesion. When a simple cyst is completely embedded in the kidney parenchyma, the thin rim and beak are absent, and the renal size and contour are normal. A renal cyst causes focal displacement of adjacent portions of the pelvocalyceal system, with the collecting structures remaining smooth and attenuated rather than shaggy and obliterated as with a malignant neoplasm.



Figure 5.26 — Segmental multicystic dysplastic kidney involving only the medial portion of the right kidney. (A) Excretory urogram shows a large multiloculated renal mass displacing the opacified collecting system (arrowhead) over the spine.

(B) Enhanced CT scan confirms the intrarenal multiloculated mass.

(C) Multicystic dysplastic kidney. Sagittal sonogram demonstrates the cystic kidney. Note the absence of communication between the cystic structures



Figure 5.27 — (A) Adult polycystic kidney disease. Excretory urogram shows marked multifocal enlargement of both kidneys, focal displacement of the collecting structures, and normal opacification.

(B) Chronic glomerulonephritis. Plain film tomogram shows bilateral small, smooth kidneys with diffuse fine calcification in the renal parenchyma.

(C) Renal hamartoma. Arteriography shows the mass to be hypervascular

Acute glomerulonephritides

Bilateral large kidneys (may be of normal size) with global parenchymal thickening and smooth contours. The nephrogram is homogeneously faint or

normal. The pelvocalyceal system is normal, though opacification is often faint (ultrasound is the most efficacious test to show that the calyces are not dilated and thus not obstructed). If the disease progresses to a chronic stage (especially in the poststreptococcal type), the kidneys become bilaterally small with smooth contours.

Renal hamartoma

A combined excretory urogram and inferior vena cavagram shows a large mass in the lower pole of the right kidney with displacement but no invasion of the pelvocalyceal system and inferior vena cava. Arteriography shows the mass to be hypervascular (the radiographic appearance is indistinguishable from that of renal cell carcinoma) (figure 5.27).

Renal cell carcinoma

Eighty percent of all solid renal tumors are renal cell carcinomas (figure 5.28–5.29).

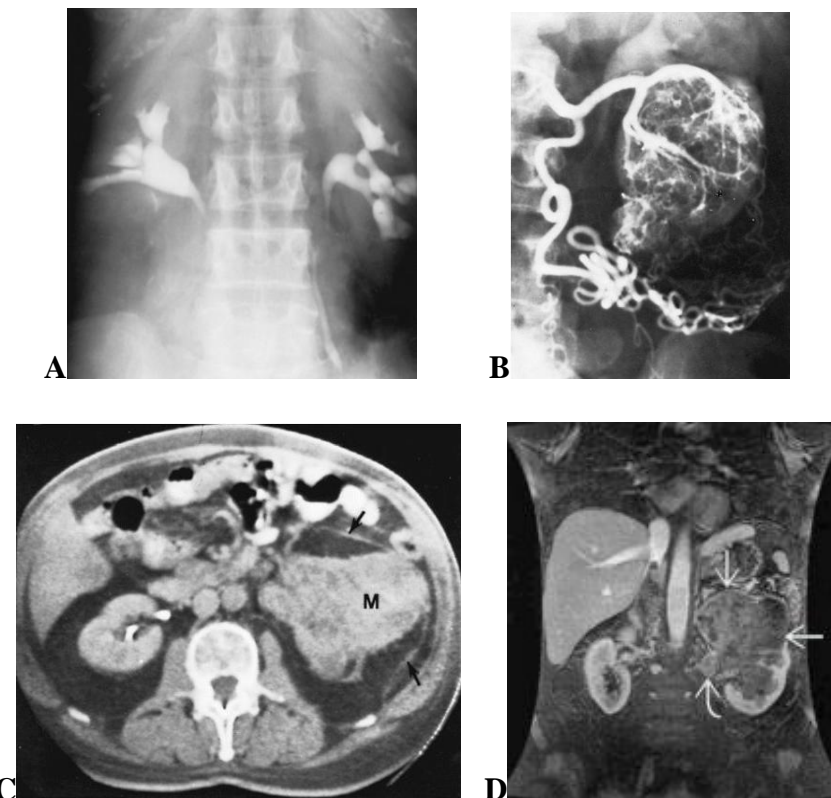


Figure 5.28 — (A) Renal cell carcinoma. Upward displacement of the right kidney and distortion of the collecting system by the large lower pole mass.

(B) In another patient, left renal arteriogram demonstrates a large hypervascular mass with striking enlargement of capsular vessels.

(C) Renal cell carcinoma. Large mass (M) of the left kidney with thickening of Gerota's fascia (arrows).

(D) Coronal T1 MR scan shows a large infiltrative and exophytic mass that invades the renal sinus (arrows), filling both the renal pelvis and the renal vein

They are predominantly found in the elderly. Any solid lesion in the kidney represents a malignant neoplasm until proven otherwise, unless there are definite benign features such as internal fat (figure 5.29). Suspicion of renal cell carci-

noma always warrants surgery, as tissue biopsy is contraindicated. Renal cell carcinoma is often very vascular and can contain areas of calcification and necrosis; occasionally it can be predominantly cystic. There is a tendency for vascular invasion by the tumor, growing into renal veins, and sometimes also extending into the inferior vena cava, even up to the right atrium.

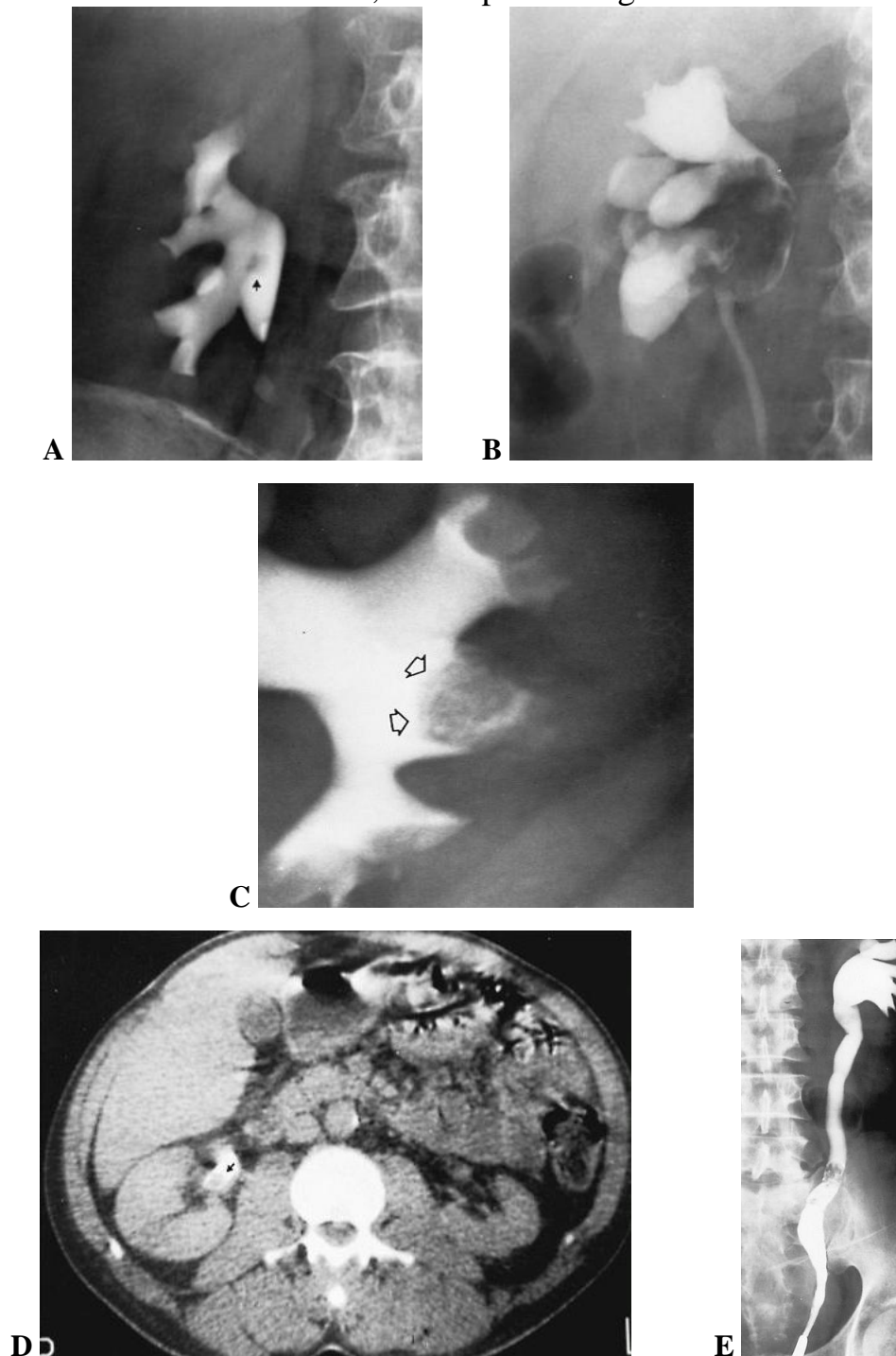


Figure 5.29 — Transitional cell carcinoma of the renal pelvis in different patients.

(A) A small filling defect (arrow) in the renal pelvis simulates a blood clot, stone, fungus ball, or sloughed papilla.

(B) A huge mass fills virtually all the renal pelvis.

(C) A small filling defect occupies an interpolar calyx (arrows). Although the defect might at first be mistaken for a large but otherwise normal papilla, the many small contrast stipples and the suggestively irregular border make its neoplastic nature evident.

(D) Transitional cell carcinoma. Filling defect (arrow) in the opacified renal pelvis.

(E) Transitional cell carcinoma of the midureter. Irregular stricture with proximal ureteral and pelvocalyceal dilatation

Cystitis (figure 5.30)

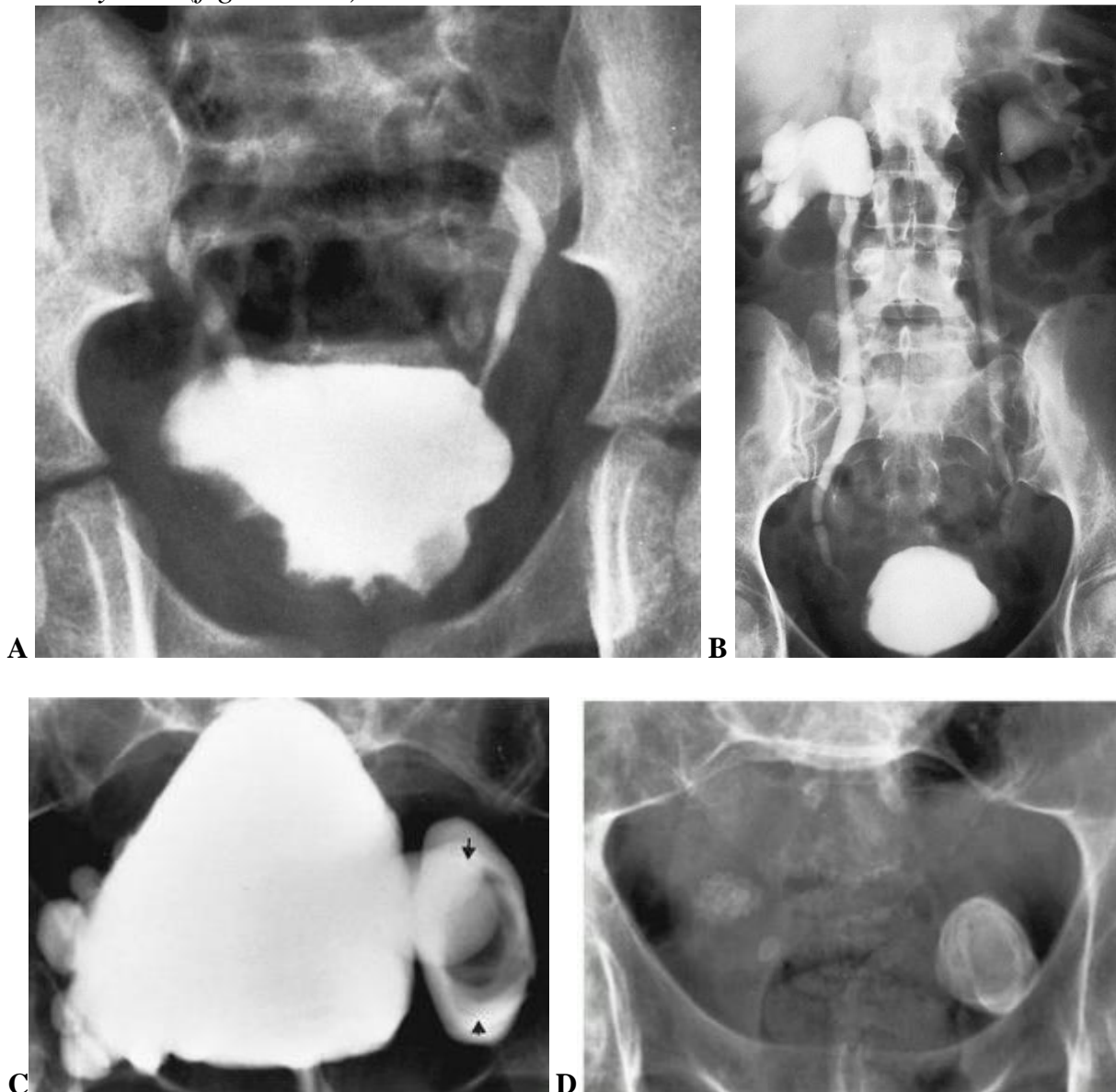


Figure 5.30 — (A) Cystitis. Irregular, lobulated filling defects (representing intense mucosal edema) at the base of the bladder.

(B) Radiation cystitis causing ureteral obstruction. After radiotherapy for cervical cancer, an excretory urogram shows the bladder wall to be thickened and bladder opacity to be reduced. Narrowing of the distal ureters causes bilateral hydronephrosis.

Bladder calculi. (C) Excretory urogram demonstrates a large stone (arrows) in a left-sided bladder diverticulum. (D) Plain radiograph of the pelvis shows the laminated stone and multiple smaller calculi that were obscured by contrast material

in the right-sided bladder diverticula on the contrast-filled view

Unilateral or bilateral obstruction of the distal ureters. In acute cystitis, there is compression of the intramural portion of the ureters by edema and inflammation. In chronic cystitis, the ureterovesical junction is obstructed by fibrosis or an inflammatory mass (figure 5.30).

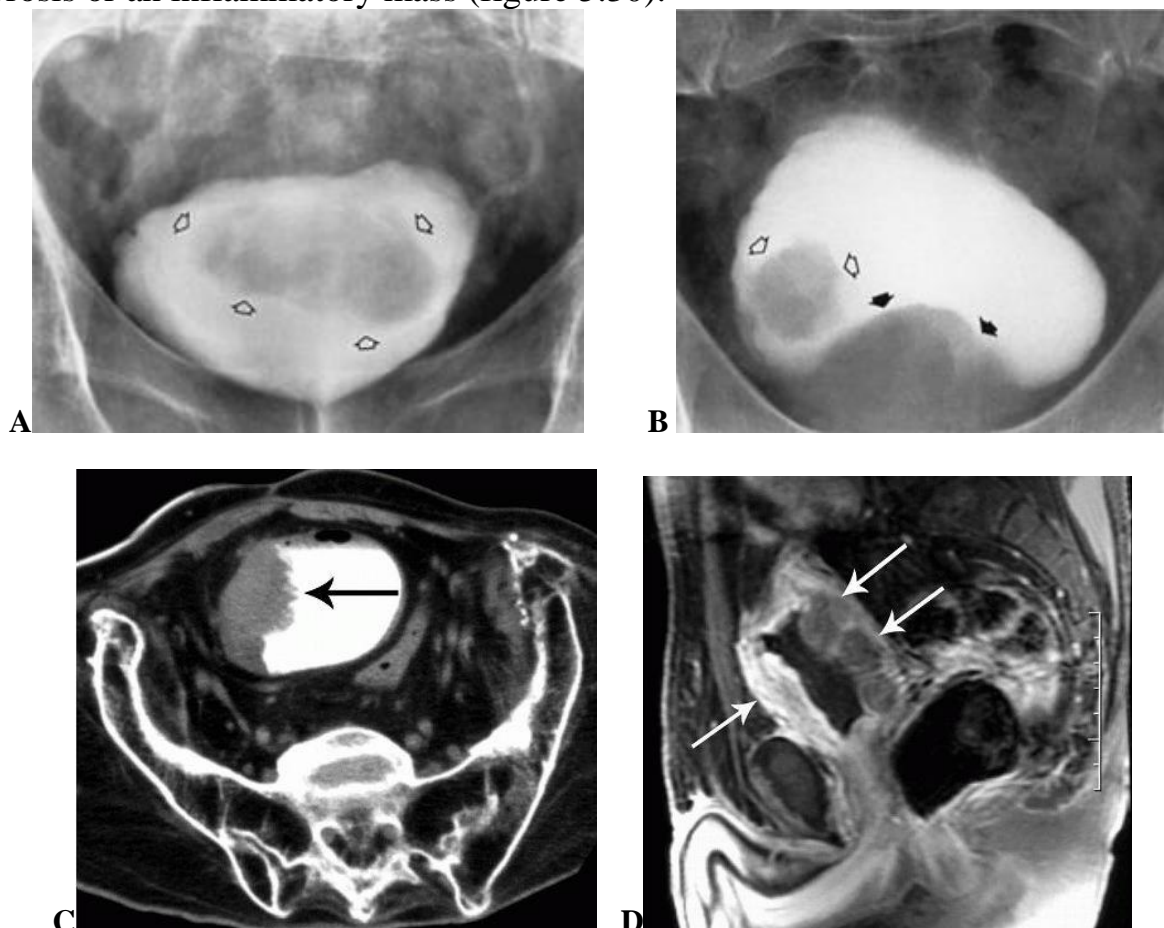


Figure 5.31 — Transitional cell carcinoma.

(A) Large, irregular filling defect (arrows) in the bladder.

(B) In another patient, the irregular tumor (open arrows) is associated with a large filling defect (closed arrows), representing benign prostatic hypertrophy, at the base of the bladder.

(C) Squamous cell carcinoma. CT cystogram shows an irregular mass involving the lateral wall of the bladder. Note the loss of trabecular structure in the bones and fatty infiltration of the muscles in this paraplegic patient.

(D) Squamous cell carcinoma. Sagittal enhanced and fat-suppressed T1-weighted MR image shows thickening of the anterior and posterior walls of the bladder (arrows), which represented chronic inflammatory changes with diffuse invasive malignancy.

Urodynamic studies provide accurate and objective information on the pathophysiology of the lower urinary tract in patients with symptoms suggesting dysfunction of the bladder and/or urethra. The basis of urodynamics is the recording of pressure within the bladder (the cystometrogram) or urethra (the urethral profile) and the flow of urine (during voiding (the flow rate)). The rela-

tionship between pressure and flow has been studied for 50 years but refinements in techniques and advances in technology, such as the addition of ultrasound and real-time imaging, have made urodynamics an accurate science. Urodynamic techniques included: cystodynamogram, intravenous urodynamogram, videocystometrography.

Urethra, imaging methods (figure 5.32)

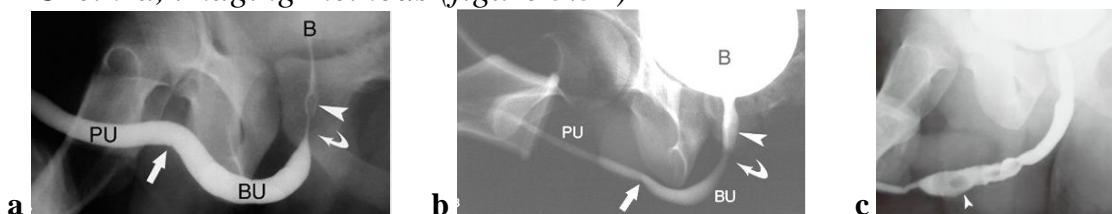


Figure 5.32 — Normal male urethra. (a) Retrograde urethrogram (RUG). (b) Voiding cystourethrogram (VCUG). The penile urethra (PU) extends from the urethral meatus to the suspensory ligament of the penis (straight arrows) at the penoscrotal junction. The bulbous urethra (BU) extends from the penoscrotal junction to the urogenital diaphragm (curved arrows), marked by the tip of the cone on the RUG and the slight narrowing of urethral caliber on the VCUG. The membranous urethra (curved arrows) is only 1 cm in length and is entirely within the muscle of the urogenital diaphragm. On a RUG, the membranous urethra extends between the tip of the cone and the verumontanum. The verumontanum (arrowheads) is a nodular structure that produces a filling defect on the urethrograms by bulging into the prostatic urethra. The prostatic urethra extends from the inferior aspect of the verumontanum to the base of the bladder (B). (c) The stones (arrowhead) lie in a segment of an anterior urethral stricture

The urethra is studied by retrograde and voiding urethrography. The retrograde urethrogram is a simple study of the anterior male urethra. Contrast medium is injected into the anterior urethra by means of a syringe or catheter that occludes the meatal orifice. Films are exposed in the right posterior oblique projection.

Voiding cystourethrography is performed by filling the bladder with contrast via a catheter. The catheter is removed, and films are obtained while the patient urinates into a basin on the fluoroscopy table.

Imaging methods of characteristic

The choices for imaging of the pelvicaliceal system and ureters have expanded. An excretory urogram (XU), also called an intravenous pyelogram (IVP), has been the traditional choice. This study is performed by obtaining a series of radiographs at various times and in various projections following IV administration of contrast agent. The images of the collecting system are routinely of high quality and remain the gold standard. However, detection of lesions in the renal parenchyma is limited. With the development of multidetector CT (MDCT) and continued improvement in MR, we now have available the CT-IVP and the MR-IVP, which combine optimal imaging of the renal parenchyma with satisfactory images of the collecting system and ureters. MR urography can be performed without the use of IV contrast utilizing T2 weighting to provide visualization of urine-filled structures. Poor renal function or high-grade obstruction limits the use of IV contrast agents because of poor concentration of contrast within the collecting system. When a percutaneous nephrostomy catheter has been placed in the collecting system, antegrade pyelography is an

additional choice. US is the imaging method of choice for screening for hydronephrosis but is limited in its ability to demonstrate small uroepithelial tumors. CT, routinely performed without IV or oral contrast agents, has supplanted plain radiographs and IVP in the diagnosis of renal stones in the kidneys and ureters.

Scintigraphy has provided a unique tool for the noninvasive evaluation of renal pathophysiology, and the past two decades have witnessed a rapid increase in the scope and number of radionuclide renal studies.

6. Radiology therapy

Introduction

Millions cancer patients receive radiation therapy each year, either alone or in conjunction with surgery, chemotherapy or other forms of cancer therapy. Other terms for radiation therapy include radiotherapy or irradiation. Radiation therapy is useful in cases where surgical removal of the cancer is not possible or when surgery might debilitate the patient (for example, when tumors that are located close to the spinal cord). Together with image guided treatment planning, radiation therapy is a powerful tool in the treatment of cancer, particularly when the cancer is detected at an early stage.

Radiation treatment (radiology therapy) principles and methods

Equipment, types used ionizing irradiations

Radiotherapy or radiation treatment is the use of x-rays, electrons or gamma rays to treat cancer. Radiation can cure or control cancer by inhibiting the cancer cells from dividing or reproducing. About fifty or sixty percent of patients with cancer will require radiation at sometime during their lifetime. Radiation is an effective form of treatment for patients.

Radiation therapy uses high-energy of ionizing radiation to stop cancer cells from dividing. During radiation therapy, ionizing radiation deposit energy in the area being treated, damaging the genetic material of cells and making it impossible for these cells to divide. Although radiation damages both cancer cells and normal cells, the normal cells are usually able to repair themselves and function properly.

A *rad* is the scientific unit of measure of radiation energy dose. A patient who receives radiation therapy as a treatment for cancer will receive several thousand *rads* over a very short period of time (weeks or months). For example, modern mammography systems used to take x-ray images of the breast use approximately 0,1 to 0,2 *rad* dose per x-ray.

Radiation therapy is commonly applied to the cancerous tumor because of its ability to control cell growth. Ionizing radiation works of exposed tissue leading to cellular death. Ionizing radiation passes through tissues and dislodges electrons from atoms. Ionization, in turn, can cause cell death or a genetic change. To spare normal tissues (such as skin or organs which radiation must pass through in order to treat the tumor), shaped radiation beams are aimed from several angles of exposure to intersect at the tumor, providing a much larger absorbed dose there than in the surrounding, healthy tissue.

Radiation therapy may be used to treat localized solid tumors, such as cancers of the skin, head and neck, brain, breast, prostate and cervix, can also be used to treat leukemia and lymphoma. The goal of radiation treatment can be:

- Radical (or curative) — radiation can be a very effective treatment for prostate cancer.

- Palliative, that is, to alleviate or reduce symptoms (a pain).

- Symptomatic — elimination symptoms (compression vein cava).

There are basically two types of radiation treatment:

1. External (distant) radiation therapy.

2. Brachytherapy, or radiation at a short distance (contact radiation therapy).

A patient may receive one or the other, or assotiated of both. The combined of an irradiation with operation or chemotherapy is possible. The complex therapy included operation-, chemo- and radiotreatment.

Types of radiation used to treat cancer

Ionizing radiation can be divided into 2 major types:

- photons (x-rays and gamma rays);

- particle radiation (electrons, protons, neutrons, alpha particles, and beta particles).

Some types of ionizing radiation have more energy than others. The higher the energy, the more deeply the radiation can penetrate into the tissues. The way a certain type of radiation behaves is important in planning radiation treatments. The radiation oncologist selects the type and energy of radiation that is most suitable for each patient's cancer.

The more common types of radiation used for cancer treatment:

- High-energy photons come from radioactive sources such as cobalt, cesium, or a machine called a linear accelerator.

- Electron beams produced by a linear accelerator are used for tumors close to a body surface since they penetrate less into deeper tissues.

- Protons are a newer form of treatment. Protons are parts of atoms that cause little damage to tissues they pass through but are very effective in killing cells at the end of their path. This means that proton beam radiation may be able to deliver more radiation to the cancer while reducing side effects of nearby normal tissues. Proton beam radiation therapy requires highly specialized equipment and is currently only available in a few medical centers.

- Neutrons are used for some cancers of the head, neck, and prostate. They can sometimes be effective when other forms of radiation therapy don't work.

The periods of radiation treatment included:

1. Preradiation (before treatment, treatment planning).

2. Treatment (sessions).

3. After treatment a period.

I. Treatment planning

The objective of treatment planning is to determine the configuration and parameters of beams that will lead to an optimum dose distribution. The parameters include the number and directions of proton beams. Computerised dose planning systems are used to construct an isodose distribution with beams of appropriate energy, size, weighting, gantry angle and wedge to give a homogeneous result over the target volume. In a complex procedure called dosimetry, computer programs are used to determine how much radiation the surrounding normal structures would be exposed to in order to deliver the prescribed dose to the cancer.

The doctor and dosimetrist will work together to determine the amount of radiation patient will receive and the best way to aim it at the cancer, based on the size of the tumor, how sensitive the tumor is to radiation, and the ability of the normal tissue in the area to tolerate the radiation.

Steps in radiation treatment planning:

Consultation: At the beginning, the patient will be seen by the radiation oncologist for a consultation. During the consultation, the radiation oncologist will perform a history and a physical examination. He will review all the pertinent data and all of the investigations that have been performed. He may also request other tests or consultations to be made.

Simulation: After the consultation, the radiation oncologist will formulate a treatment plan. Here, the patient comes to the radiation department and lies down on a table under a machine, called a simulator. Various immobilization devices may be necessary, such as a head rest or a face mask, in order to make sure the patient is positioned correctly and in the same way for each treatment. There will be various markings that will be made on the skin and various x-rays will be taken.

During simulation, the area of the patient's body to be treated is marked directly on the patient's skin with markers. Very tiny permanent marks, or tattoos are sometimes made to ensure that daily treatments are delivered accurately. These are also useful for future treatment planning sessions and treatment updates. CT scans may have to be taken in order that the computers can calculate and prescribe the dose distribution of the radiation.

The radiotherapy simulator is the mechanical analog of an isocentric therapy unit. It serves several functions, but its primary purpose is to help establish the optimal beam and setup parameters for a patient before the first treatment. These parameters may include the gantry angle, field size, target-to-skin distance and treatment couch position for each beam. The patient setup position, skin marks, and immobilization devices can also be determined during the treatment simulation.

Radiation physicists and dosimetrists use computer models to plan the treatment. This computerized treatment planning allows the treatment to be delivered more accurately, both in terms of the "beam shape" that is achieved with precise collimator settings and in terms of the angles and directions used to deliver the radiation to the cancer. By using the computer to help, the radiation oncologist can deliver the radiation precisely to cancer, delivering a minimal amount of radiation to healthy tissues.

The radiation treatment planning models usually use a three-dimensional (3D) re-creation of the patient's anatomy. Images of the patient are acquired from the CT or MR scanner and then sent by network or computer disk to the radiation treatment planning computer.

II. Radiology *treatment* (of treatment sessions are similar and follow this procedure):

1. Radiation treatments are divided over many sessions encompassing several weeks. Because of this, very tiny marks, or tattoos, are made on the patient's skin to ensure the accuracy of treatment.

2. For daily treatments, the patient is positioned by the therapist on the treatment table. Patient positioning is very important for treatment delivery accuracy. The patient may communicate at any time with the therapist.

3. The actual treatment delivery session can last anywhere from 5 to 15 minutes.

III. *After treatment a period.* The patient is observed for estimation of efficiency of radiology treatment, correction of side effects, symptomatic therapy (usually one week).

Dose

The amount of radiation used in photon radiation therapy is measured in *gray* (Gy), and varies depending on the type and stage of cancer being treated. For curative cases, the typical dose for a solid epithelial tumor ranges from 60 to 80 Gy, while lymphomas are treated with 20 to 40 Gy.

Fractionation

The total dose is fractionated (spread out over time) for several important reasons. Fractionation allows normal cells time to recover, while tumor cells are generally less efficient in repair between fractions. Fractionation also allows tumor cells that were in a relatively radio-resistant phase of the cell cycle during one treatment to cycle into a sensitive phase of the cycle before the next fraction is given. Similarly, tumor cells that were chronically or acutely hypoxic (and therefore more radioresistant) may reoxygenate between fractions, improving the tumor cell kill.

In Europe, the typical fractionation schedule for adults is 2 Gy per day, five days a week.

Effect on different types of cancer (radiosensitivity)

Different cancers respond differently to radiation therapy.

The response of a cancer to radiation is described by its radiosensitivity. Highly radiosensitive cancer cells are rapidly killed by modest doses of radiation. These include leukemias, most lymphomas and germ cell tumors. The majority of epithelial cancers are only moderately radiosensitive, and require a significantly higher dose of radiation (60–70 Gy) to achieve a radical cure. Some types of cancer are notably radioresistant, that is, much higher doses are required to produce a radical cure than may be safe in clinical practice. Renal cell cancer and melanoma are generally considered to be radioresistant.

It is important to distinguish the radiosensitivity of a particular tumor, which to some extent is a laboratory measure, from the radiation "curability" of a cancer in actual clinical practice. For example, leukemias are not generally curable with radiation therapy, because they are disseminated through the body. Lymphoma may be radically curable if it is localised to one area of the body. Similarly, many of the common, moderately radioresponsive tumors are routinely treated with curative doses of radiation therapy if they are at an early stage. For example: non-melanoma skin cancer, head and neck cancer, breast cancer, non-small cell lung cancer, cervical cancer, anal cancer, prostate cancer. Metastatic cancers are generally incurable with radiation therapy because it is not possible to treat the whole body.

Types of radiation therapy

Historically, the three main divisions of radiation therapy are external beam radiation therapy or brachytherapy or sealed source radiation therapy, and systemic radioisotope therapy or unsealed source radiotherapy. The differences relate to the position of the radiation source; external is outside the body, brachytherapy uses sealed radioactive sources placed precisely in the area under treatment, and systemic radionuclides are given by infusion or oral ingestion. Brachytherapy can use temporary or permanent placement of radioactive sources. The temporary sources are usually placed by a technique called afterloading. In afterloading a hollow tube or applicator is placed surgically in the organ to be treated, and the sources are loaded into the applicator after the applicator is implanted. This minimizes radiation exposure to health care personnel.

Particle therapy is a special case of external beam radiation therapy where the particles are protons or heavier ions.

Intraoperative radiation therapy is a special type of radiation therapy that is delivered immediately after surgical removal of the cancer. This method has been employed in breast cancer, brain tumors and rectal cancers.

External beam radiation therapy

External (beam) radiation is the most widely used type of radiation therapy. The radiation is focused from a source outside the body onto the area affected by the cancer. It is much like getting an x-ray, but for a longer time. This type of radiation is most often given by machines called linear accelerators. External beam radiation allows large areas of the body to be treated and allows treatment of more than one area such as the main tumor and nearby lymph nodes. External radiation is usually given in daily treatments over several weeks.

External beam sources

Linear accelerators are the common source of high energy X-ray beams producing megavoltage photons of between 4 and 20 million volt energy able to penetrate to the most deep-seated tumours in the largest of patients. Clinically, 4–8 MV beams are the most useful providing a balance between penetration and

adequate surface dose. The fundamental property of megavoltage beams to have skin sparing is both beneficial in terms of reducing skin reaction but also potentially hazardous in reducing dose to surface or superficial tumour (figure 6.1).

Modern high-energy linear accelerators offer a choice of *photon* and *electron high-energies*. The production of high-energy photons can be described briefly as follows. Electrons are emitted from the heated gun filament, and their energy is gradually increased as they move through the waveguide. The beam of electrons is focused and to hit a high atomic number target. The resultant X-ray beam is collimated. The beam is collimated using diaphragms and a set of multileaf collimator leaves.

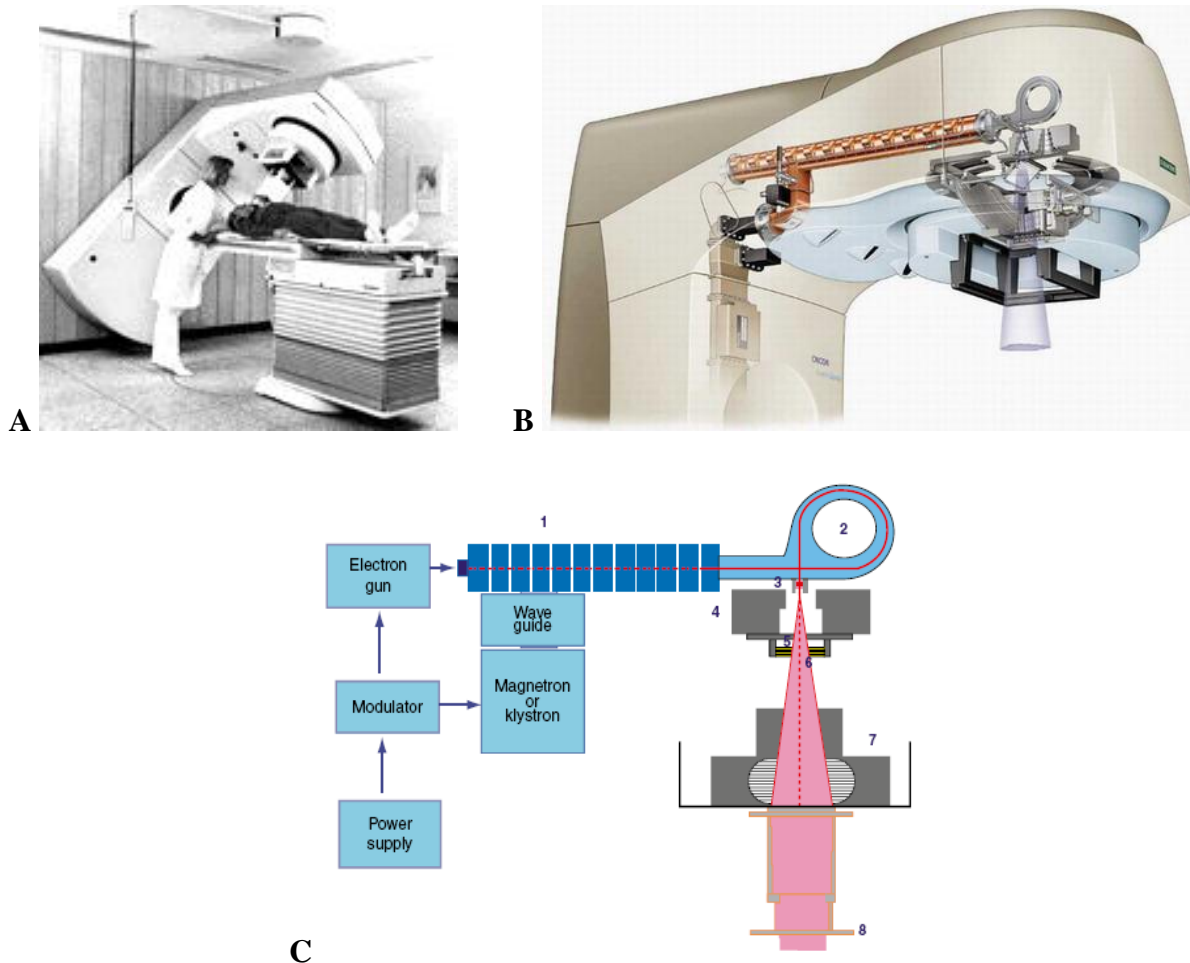


Figure 6.1 — (A) General illustration of a linear accelerator. (B) Treatment head of a linear accelerator. (C) Scheme of linear accelerator.

- (1) The production and the acceleration of electrons,
- (2) the 270° bending of electrons, (3) target and primary filter,
- (4) primary collimators, (5) main filter, (6) ionizing chamber,
- (7) multileaf collimator, (8) electron applicator

Electron beams used for treatment can be produced either by rapidly scanning the narrow beam of electrons across the desired area or more commonly the beam is broadened by the use of a scattering foil in place of the X-ray target. In

normal use, a series of openings in an electron 'applicator' are used to collimate the beam at or close to the patient's skin.

Cobalt machines were widely used in the past and in some centres still have their place. They require less maintenance comprising a cobalt source that releases gamma rays with energy equivalent 1 MV and a relatively simple mechanism exposing the source to provide the beam. The penetration of the beam, however, is relatively poor and because it arises from a source of finite size the penumbra of the beam is quite large. Such considerations have led most centres to relegate cobalt units to be replaced by modern linear accelerators or, where retained, for palliative treatments and out of hours work where their simplicity does have advantages (figure 6.2).

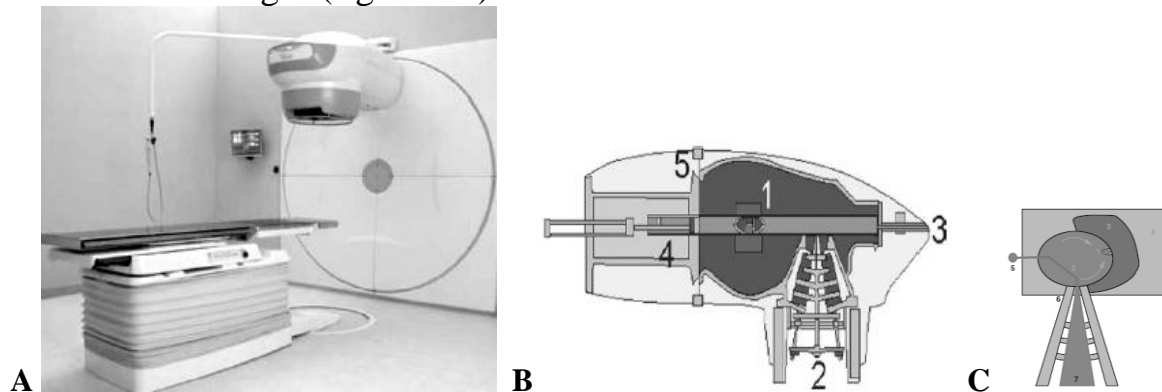


Figure 6.2 — (A) Modern Cobalt-60 therapy unit.

(B) Scheme treatment head of a cobalt-60 teletherapy unit.

The cobalt source (1) is situated in a drawer, and surrounded by lead. When the device is in the resting position, the source is protected by layers of enriched uranium.

The source is then pushed by a pneumatic system (4) to the treatment position.

The collimator system (2); manual system that can pull the source to the resting position in case of emergency (3); link between the head and the rotating part of the machine that is used to change the source when its activity is no longer sufficient for treatment (5).

(C) Scheme cobalt-60 head: 1, cobalt-60 source; 2, tungsten cylinder;

3, enriched uranium; 4, lead; 5, laser source; 6, collimator; 7, γ -rays

Particle therapy

There are, however, many other particles that can be used in therapy. Neutrons have been evaluated over many years and their clinical utility remains limited and they cannot be regarded as part of routine clinical practice. Protons in contrast have excited increasing interest in recent years. Their main advantage is that their energy deposition follows the Bragg peak with a high-intensity highly localized deposition of energy at a fixed depth. This has advantages in the treatment of certain sites; for example, retinal tumours and tumours of the brain stem where highly localized energy deposition avoiding surrounding structures is required. They have also been used in other sites, for example, prostatic carcinoma, as a means of enabling dose escalation within normal tissue tolerance.

In particle therapy (proton therapy being one example), energetic ionizing particles are directed at the target tumor. The dose increases while the particle penetrates the tissue, up to a maximum (the Bragg peak) that occurs near the end of the particle's range, and it then drops to (almost) zero. The advantage of this energy deposition profile is that less energy is deposited into the healthy tissue surrounding the target tissue.

Internal radiation therapy

Also known as *brachytherapy* (brak-e-THER-uh-pee), internal radiation is typically used when doctors need to deliver a high dose of radiation to a small area. Rather than coming from machines outside the body, the radiation source is placed inside the body. Most often, the radioactive material — encased in wires, seeds, capsules or tubes (catheters) — is placed inside the tumor.

Internal radiation implants containing radioactive material are usually placed during surgery or using a needle (interstitial radiotherapy). Brachytherapy may include placing implants inside a body cavity, such as the vagina (a technique called intracavitary radiation) or by putting radioactive material directly into body tissue (called interstitial radiotreatment). In both instances placement is usually done once, though it may be done up to several times, and is temporary, lasting from a few minutes to several days.

In brachytherapy, radiation sources are precisely placed directly at the site of the cancerous tumour. This means that the irradiation only affects a very localized area — exposure to radiation of healthy tissues further away from the sources is reduced. These characteristics of brachytherapy provide advantages over external beam radiation therapy — the tumour can be treated with very high doses of localized radiation, whilst reducing the probability of unnecessary damage to surrounding healthy tissues. A course of brachytherapy can often be completed in less time than other radiation therapy techniques. This can help reduce the chance of surviving cancer cells dividing and growing in the intervals between each radiation therapy dose.

As one example of the localized nature of breast brachytherapy, the device delivers the radiation dose through multiple catheters, each of which can be individually controlled. This approach decreases the exposure of healthy tissue and resulting side effects, compared both to external beam radiation therapy and older methods of breast brachytherapy. Severe pain or illness is not likely to occur during implant therapy.

Radionuclide therapy

Internal radiation can also be given systemically, meaning it travels throughout the body. Also called radiopharmaceutical therapy, systemic radiation uses radioactive material mixed in a solution. This type of radiation can be given intravenously through an IV, by mouth or it can be injected into a body cavity. For instance, if cancer has spread to bones, it might be inefficient to aim external radia-

tion at every small spot where cancer has spread. But by giving radiation through an IV, the radioactive material can travel through the blood to each cancer site.

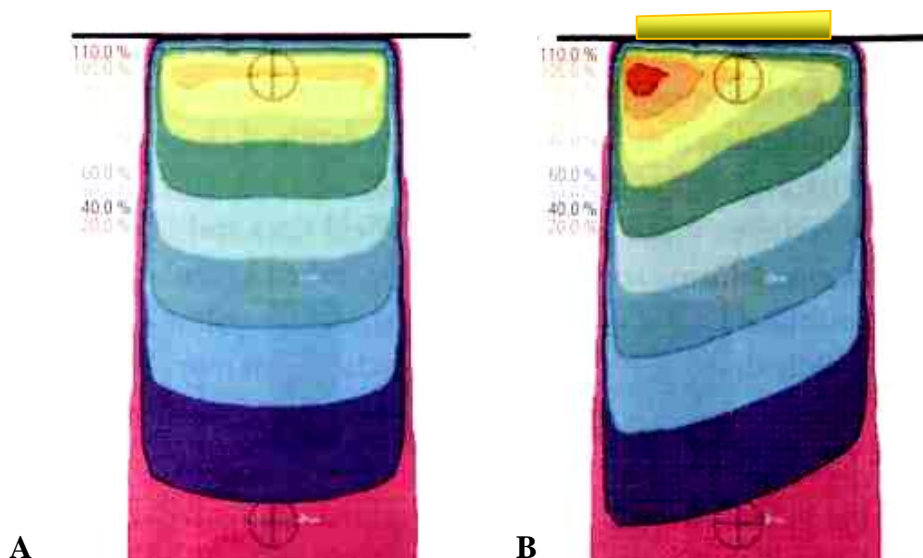
Systemic radionuclide therapy is a form of targeted therapy. Targeting can be due to the chemical properties of the nuclide such as radioiodine which is specifically absorbed by the thyroid gland a thousand fold better than other bodily organs. Examples are the infusion of oral iodine-131 to treat **thyroid cancer or thyrotoxicosis**.

A radioactive material is inserted directly into or next to a tumour and concentrates the dose there. The dose falls off very rapidly according to the inverse square law, and surrounding normal tissues receive substantially lower doses than the tumour. When 65 Gy are delivered at 0.5 cm from the source, the dose at 2 cm is only 4.0 Gy.

A major use of systemic radionuclide therapy is in the treatment of **bone metastasis** from cancer. The radionuclides travel selectively to areas of damaged bone, and spare normal undamaged bone. Isotopes commonly used in the treatment of bone metastasis are strontium-89 and samarium (^{153}Sm) lexidronam.

Dose distributions

An isodose curve connects points of equal dose in a single plane. The shape of the isodose curves is affected by the beam parameters such as field size and beam filter characteristics (figure 6.3–6.4).



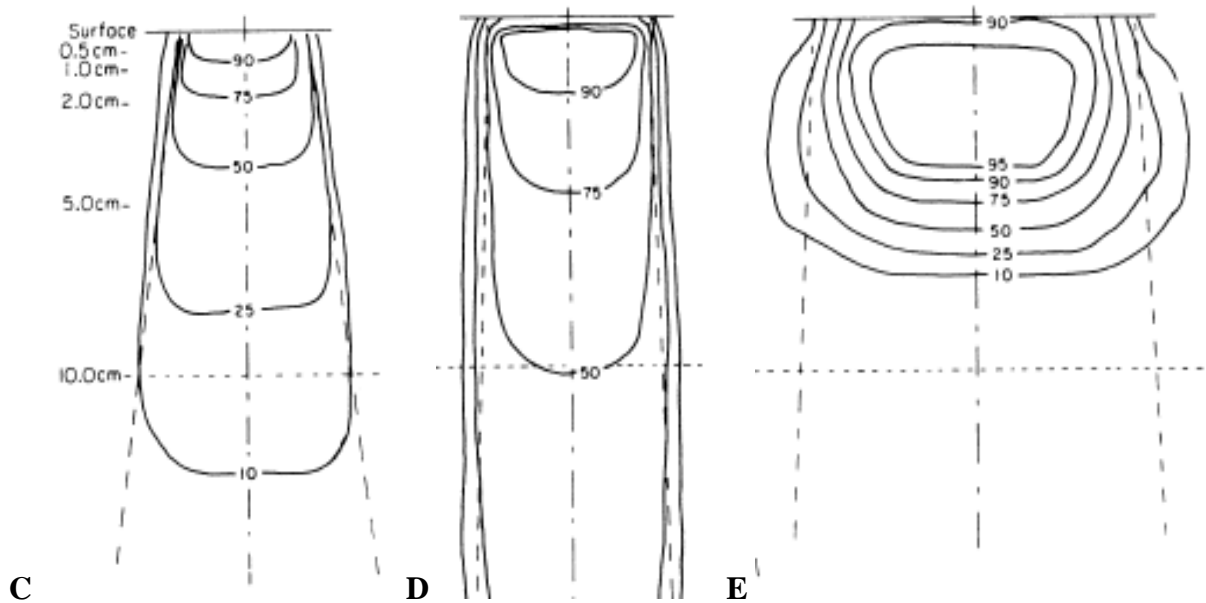


Figure 6.3 — Isodose distribution on a water phantom at 100 cm.
(A) Note the change in shape of the isodose lines as the depth is increased. At 3 cm deep, the 95 % isodose is deeper at the outside of the beam, in contrast to this at approximately 15 cm deep, the 50 % isodose is deepest at the centre of the beam.
(B) Shows a 25° wedge field (lead) also incident on a flat water phantom.
(C) Typical depth dose curves for photons of cesium-137, **(D)** cobalt-60 and **(E)** electrons 15 MeV (mega electron-volt)

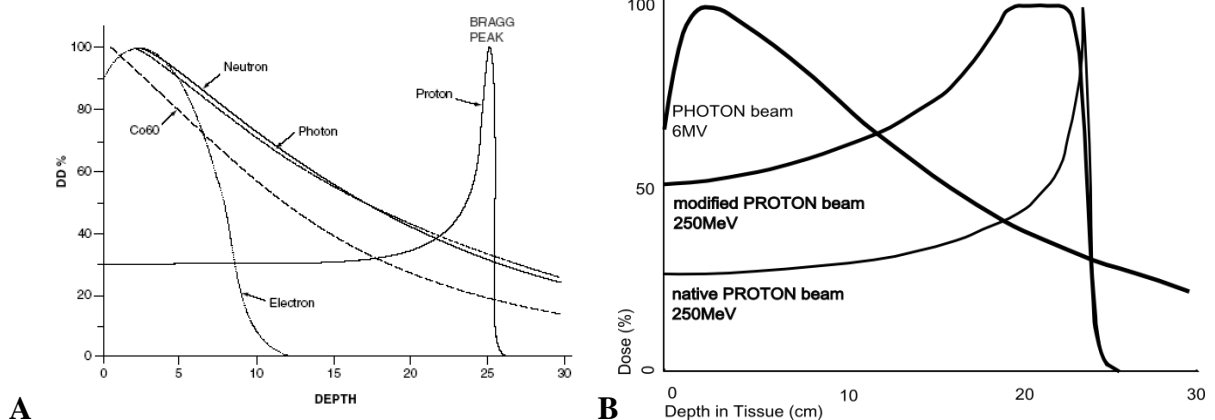


Figure 6.4 — (A, B) Dose distributions on a tissue (percent depth dose curves) of different beams ionizing irradiation

For megavoltage photons, the maximum dose does not occur at the surface but at a depth of a few millimetres (D_{max}). The depth at which the maximum dose occurs is dependent primarily on the beam energy. After D_{max} , a gradual decrease in the dose deposited occurs as the number of photons in the beam is reduced (figure 6.5).

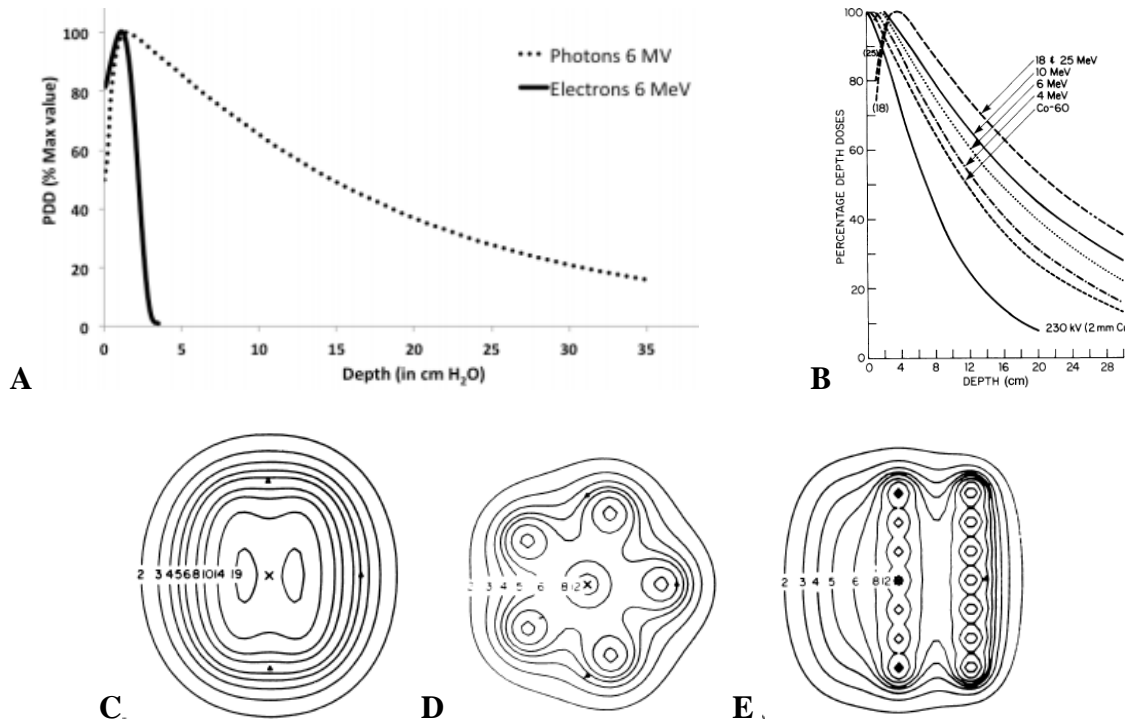


Figure 6.5 — (A) Percent depth doses as a function of depth tissue. In few cm the electron dose is absorbed while a greater depth is needed to absorb the photon dose. (B) Electrons (4-25 MeV) and photons (Co-60 and X-ray 230 kV) percent depth dose curves. (C, D, E) Examples of interstitial depth dose curves (dose distribution) for different quantity sources radiation (internal radiation implants)

In contrast to photons, electron beams begin to deposit energy immediately on entering the patient.

7. Radiology therapy of malignant tumours

Introduction

Radiation therapy may be used to treat localized solid tumors, such as cancers of the skin, head and neck, brain, breast, prostate and cervix, can also be used to treat leukemia and lymphoma.

Radiation therapy is commonly applied to the cancerous tumor because of its ability to control cell growth. Ionizing radiation works of exposed tissue leading to cellular death. To spare normal tissues (such as skin or organs which radiation must pass through in order to treat the tumor), shaped radiation beams are aimed from several angles of exposure to intersect at the tumor, providing a much larger absorbed dose there than in the surrounding, healthy tissue.

Clinical applications of electron beam therapy

Electron beams are particularly useful in the treatment of superficial and subcutaneous volumes of tissue, particularly if the treatment should be limited to a unilateral lesion requiring a low dose to the opposite side of the body. These cases include tumors of the parotid, ear, oral cavity, and oropharynx.

Electron beams may be the primary mode of therapy or combined with photon beams. There are major clinical applications, such as treating a radically dissected neck or areas in which there is a high risk of residual disease. Electron beam therapy also can be used to boost the dose to specific sites, such as the breast or to lymph nodes (figure 7.1).

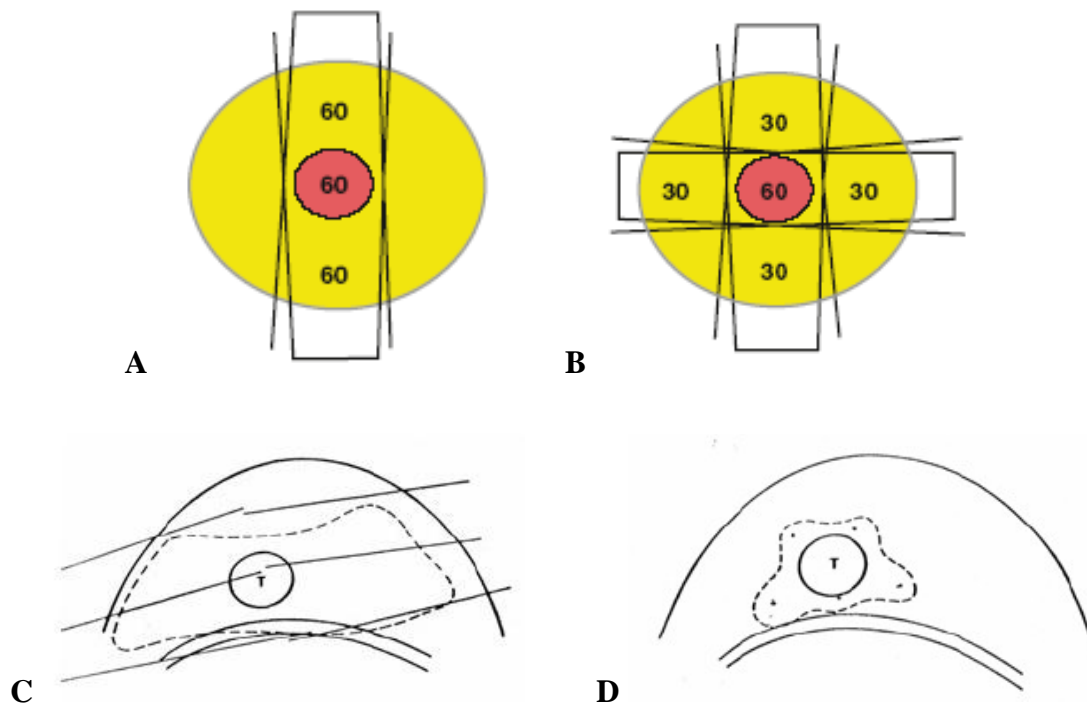


Figure 7.1 — (A, B) Multiple radiotherapy fields and change in isodose. Comparison of the 50% dose distribution between a distant (C, photons cobalt-60) and contact (D, interstitial) radiotherapy Techniques

Shielding electron beams clinically is easily done with high-density materials, such as lead. One centimeter of lead transmits only 5 % of an 18-MeV electron dose. Electrons produced at the 7-MeV level require only 2 mm of lead. Added distance alone offered by intervening tissues significantly decreases the dose to deeper structures. For treating lesions of the oral cavity, intraoral stents contain lead, and protection of adjacent tissues is achieved by increasing the distance with tissue-equivalent Lucite. Because of the easy blocking of the beam by dense materials, lead is used extensively for defining treatment fields and for actual field shaping. The fields may be defined by lead cutouts placed on a tray attached to the head of the accelerator. Special electron beam cones are commercially available. The area covered to the 80 % line of the 18-MeV electron beams is decreased by 0,5 cm at all margins of the field by shielding, requiring a proportionately larger field to ensure coverage of the entire lesion and a satisfactory surrounding margin. A differential in depth dose may be achieved by plastic energy moderators placed over a portion of the field.

Skin and lip tumors

Electron beam therapy is ideal for radiation therapy of all skin and lip cancers and is particularly useful in the treatment of lesions that present problems or are critically located (e. g., lesions involving the eyelid, nose, or ear). For small superficial basal cell carcinomas, a 1-cm margin surrounding the gross lesion is adequate. In large infiltrative lesions with diffuse induration associated with a surgical scar, 2- or 3-cm margins are required, with wide borders of uninvolved tissue. For squamous cell carcinoma, the field usually can be reduced at 50 Gy. Most lesions located on the eyelids, external nose, cheeks, or ears are not deeply invasive and are treated with electron beams at energies of 6 MeV to 9 MeV. If the lesion approaches 2 cm in thickness, 9-MeV to 12-MeV electron beams should be used. Protective devices should be designed to delineate the treatment field and to conform to the irregular shape of a lesion. A wax ledge placed around the opening in a lead mask may provide a seating for the treatment portal and enhance precision in directing the beam. To achieve almost complete protection, 3 mm of lead, which absorbs almost 98 % of 7-MeV electron beams, should be used. Lead is also used for protection of the deeper structures. In treatment of the cheek or the lip, lead in an intraoral stent made for the patient protects the gingiva and tongue. For treatment of the eyelid or near the eye, a lead shield is placed under the lid. Because the eye shields must be thin, they are suitable only for 7-MeV electron beams. Thicker external blocks may be necessary to protect the eye at higher electron energies.

Upper respiratory and digestive tracts (figure 7.2)

Electron beams alone may be used to treat carcinomas of the upper respiratory tract and digestive passages, frequently combined with external beam high-energy photons or with interstitial brachytherapy, as in the treatment of well-lateralized lesions of the oral cavity, oropharynx, hypopharynx, or supraglottic larynx.

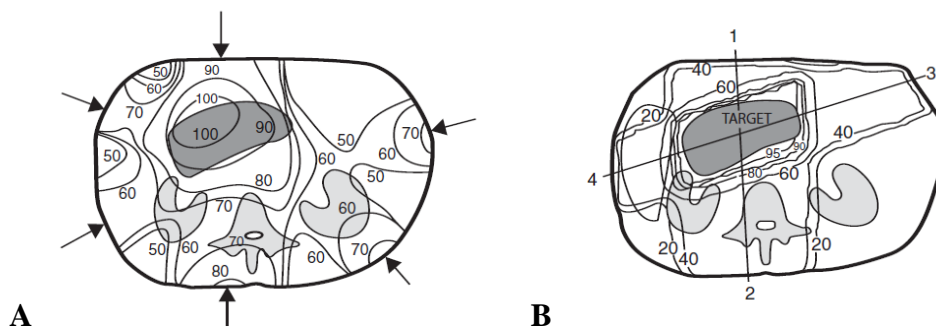


Figure 7.2 — Comparison of treatment plans axial isodoses for the distant radiotherapy of a case pancreas carcinoma using different photons beams (A) at 250 kV 6 fields and (B) 18MV X-rays 4 fields

Electron beam therapy for lesions of the oral cavity may be used with intraoral cones, which must provide coverage of the lesion with an adequate margin of normal mucous membrane on all sides. An intraoral stent may be necessary to maintain the position of the cone and to reproduce the placement of the cone at each

treatment session. The electron energy (6, 9, or 12 MeV) is chosen according to the characteristics of the tumor and the depth of extension of the tumor.

Breast cancer

Electron beam therapy has been of particular value in the treatment of breast cancer, both for administering an additional dose to the site of tumor excision in conservation treatment and for treating subclinical disease in patients who have had surgical removal of the primary breast lesion and axillary lymphatics. During radiation therapy, the supine patient has the arm abducted to 90 degrees and the forearm maintained in an upright position by a hanging bar, which the hand grasps. The head may be turned sharply to the contralateral side. The beam remains vertical. Various manipulations of the machine, collimator, and other factors may be needed to achieve proper placement of the treatment field. Radiation therapy also may be designed for the chest wall. Because the average chest wall thickness after radical mastectomy is the 2,0 cm, low-energy electron beams (6 to 9 MeV) may be appropriate. If the chest wall thickness is greater, electron beams of high energy (12 MeV) may be necessary. Computed tomography offers an excellent means of measuring the thickness of the chest wall and aids in the choice of the appropriate energy level to be used.

Salivary gland tumors

Treatment for salivary gland tumors generally uses electrons (80 % of dose) in combination with photons (20 % of dose). The application of electron beam therapy alone or with photon beams is most effective after the bulk of the tumor has been removed. The area to be irradiated includes the entire parotid bed and the full extent of the surgical scar. However, special consideration should be given to potential seventh cranial nerve involvement in all patients with adenocystic carcinomas. The temporal bone must be irradiated. The entire ipsilateral neck may be irradiated in treating the parotid gland area if the primary tumor is a high-grade malignancy, if the tumor is found in connective tissues, if there is extensive invasion of perineural lymphatics, or if there are positive nodes in the operative specimen.

Neoplasms of other sites

Certain lymphomas that present as subcutaneous masses or dermal lesions can be treated by electron beam therapy. In many soft tissue sarcomas, electron beam therapy can be used as total treatment or as an adjunct to photon beam treatment, with preservation of function and diminution in the number of late side effects of the treatment. Primary or recurrent carcinomas of the vulva, distal vagina, urethra, suburethral area, or other areas that recur after surgical removal and carcinomas of the cervix that recur in the vagina may be treated with electron beams (6, 9, or 12 MeV), incorporating an appropriate bolus. Intraoperative electron beam used as a boost followed by photon beam treatment represents an innovative regimen, particularly in treating gastric cancer, retroperitoneal sarcomas, head and neck cancers, and genitourinary and gynecologic cancers.

For curative cases, the typical dose for a solid epithelial tumor ranges from 60 to 80 Gy, while lymphomas are treated with 30 Gy. Preventative (adjuvant) doses are typically around 50 Gy in 2 Gy fractions (for breast, head, and neck cancers).

Brachytherapy

Skin cancer

Radiation therapy is an important management option in selected patients, offering an advantage in treating large lesions with deep tissue infiltration. Treatment margins may be as wide as necessary for facial tumors, obviating the need for extensive surgical reconstruction. Radiation may be preferred for elderly, debilitated, or medically inoperable patients as anesthesia is not necessary, and when cosmesis is not a factor, fractionation can minimize the number of treatments.

Skin cancers with perineural invasion are particularly difficult to control, and salvage after surgical recurrence is unlikely. Treatment fields encompass the nerve at risk to the base of skull with postoperative radiation to 60 Gy to the tumor bed, 50 Gy to the proximal involved nerve with negative surgical margins, and 70 Gy for microscopic or gross positive margins.

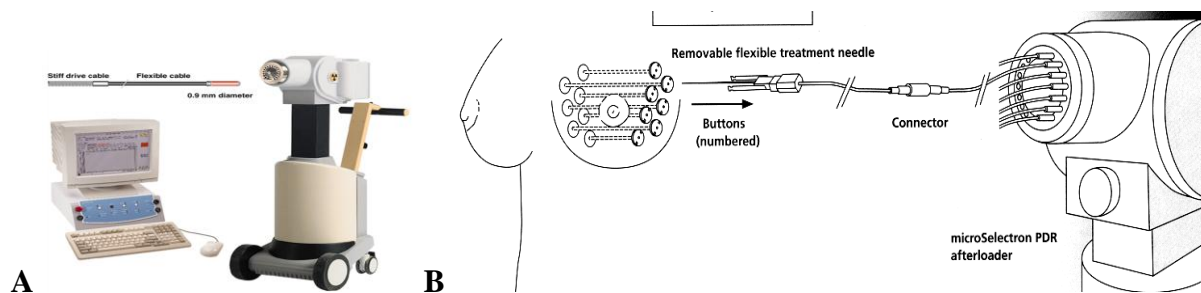


Figure 7.3 — (A) The device of contact radiotherapy “MICROSELETRON» and (B) scheme using it for breast brachytherapy

Customized surface molds employing afterloading ^{192}Ir or high-dose-rate brachytherapy sources (figure 7.3) are useful when protracted daily treatment fractionation is inconvenient or for treatment of lesions on the shin or dorsum of the hand, where conventional radiation therapy is poorly tolerated. Low-dose-rate interstitial brachytherapy can treat periorificial tumors of embryonic fusion regions of the face. Excellent disease control and cosmesis are reported with doses of 50 Gy at dose-rates 2 Gy/hr with low risk of late complications.

Esophageal cancer

In addition to external beam radiation therapy, intracavitary therapy can be used with curative or palliative intent. The advantage of brachytherapy centers on exploitation of the inverse square law and quick dose falloff, thus sparing surrounding tissues from radiation while providing focal dose escalation. The radioactive source of choice is usually iridium-192 (^{192}Ir). High-dose-rate (HDR) techniques can deliver 100 to 400 Gy per hour, allowing treatment to be given in 5 to 10 minutes.

With brachytherapy, an afterloading catheter is introduced through the nose into the esophagus to the primary tumor site under fluoroscopic guidance. After localization films are taken and dosimetry generated, the catheter is then attached to a remote afterloader through a guide cable and the ^{192}Ir source inserted through remote control. Dose can be shaped and modified through the use of dwell times.

For patients treated with curative intent (unifocal thoracic tumors <10 cm, no distant metastases, no airway involvement or cervical esophageal location), the American Brachytherapy Society recommends a brachytherapy dose of 10 Gy in 2 weekly fractions of 5 Gy each or 20 Gy in a single course at 1 Gy per hour. The recommended active length is the visible mucosal tumor with a 1- to 2-cm proximal and distal margins. Ideally, brachytherapy is started 2 to 3 weeks following completion of concurrent external irradiation/chemotherapy to allow mucositis resolution.

Prostate cancer

Brachytherapy for early-stage disease: preplanned transperineal implantation. With the advent of transperineal CT and ultrasound-guided permanent prostatic implantation, the accuracy of isotope source placement has dramatically improved compared with older retropubic methods.

A computerized plan is generated from the transverse ultrasound images, producing isodose distributions and the ideal location of seeds within the gland to deliver the prescription dose to the prostate. Several days to weeks later, the implantation procedure is performed. Needles are then placed under ultrasonographic guidance through a perineal template according to the coordinates determined by the preplan. Radioactive seeds are individually deposited in the needle with the aid of an applicator or with preloaded seeds on a semirigid strand containing the preplanned number of seeds.

At present, the commonly used dose for interstitial implantation is 140 Gy, prescribed to the isodose surface that completely encompasses the prostate as contoured from imaging studies.

Soft tissue sarcomas

Brachytherapy may be used as the sole radiation therapy mode of treatment, using doses of 50 Gy. For unresectable sarcomas, doses above 70 Gy are used, limiting the high-dose volume to the tumor plus a minimal margin.

Interstitial brachytherapy can be used to deliver all or part of the radiation dose. After surgical excision of the tumor, hollow plastic afterloading catheters are inserted using sharp metal trocars in a single plane at approximately 1-cm intervals within the tumor bed (figure 7.4). Surgical clips placed at the margin of the tumor bed permit the target volume to be delineated for planning purposes, and the catheters are secured in place.

Catheters are loaded with wired ^{192}Ir seeds no sooner than the sixth post-operative day to reduce the risk of wound complications. After completion of the treatment, sources are removed and catheters are cut at one end for removal by pulling through the skin.

For radioimplants, a dose of 45 Gy has been shown to be adequate adjuvant treatment when used alone for high-grade lesions. Brachytherapy treatments are usually given twice daily at 5 Gy per fraction to 50 Gy.

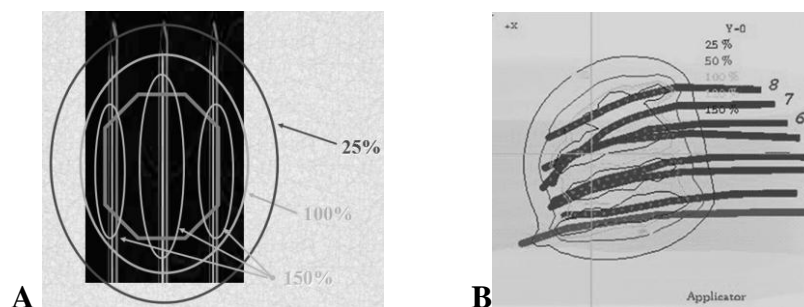


Figure 7.4 — (A) Examples dose distribution from radionuclide interstitial needles and (B) three-dimensional computer-generated image of catheters with a radionuclide inside of the tumor

Treatment of thyroid cancer

The thyroid gland absorbs nearly all of the iodine in the blood. Because of this, radioactive iodine (also known as radioiodine or iodine-131) can be used to destroy the thyroid gland and thyroid cancer with limited effects on the rest of the body. This treatment is often used after thyroid cancer surgery to destroy any thyroid cells that may have been left behind, or to treat some types of thyroid cancer that have spread to lymph nodes and other parts of the body. An international trial has been performed for ablation of cancer cells thyroid tissue using 3.7 GBq (100 mCi) of ^{131}I .

Iodine-131 therapy may be combined with external radiation therapy. The dose to metastases from ^{131}I may be calculated using single-photon emission computed tomography (SPECT) imaging.

In patients with unresectable or inoperable primary tumors, ^{131}I does not seem to affect the rate of tumor regression appreciably or to prolong survival. A combination of ^{131}I and external radiation therapy seems to offer the best results.

Side effects of radiation therapy

Radiation therapy is in itself painless. Many low-dose palliative treatments (for example, radiation therapy to bony metastases) cause minimal or no side effects, although short-term pain flare up can be experienced in the days following treatment due to oedema compressing nerves in the treated area. Higher doses (after radiology treatment of malignancy) can cause varying side effects during treatment (acute side effects), in the months or years following treatment (long-term side effects), or after re-treatment (cumulative side effects). The nature, severity, and longevity of side effects depends on the organs that receive the radiation, the treatment itself (type of radiation, dose, fractionation, concurrent chemotherapy), and the patient.

Most side effects are predictable and expected. Side effects from radiation are usually limited to the area of the patient's body that is under treatment. One of the aims of modern radiation therapy is to reduce side effects to a minimum, and to help the patient to understand and to deal with those side effects which are unavoidable.

The extent and the exact type of side effects are determined by the location of the tumor and the location of the radiation being delivered. The side effects of radiation therapy depend on the treatment dose and the part of the body that is being treated. The most common side effects may be loss of hair in the area being treated, tiredness, skin reactions (such as rash or redness) in the treated area, loss of appetite, and nausea. Radiation therapy may also cause a decrease in the number of white blood cells (cells that help protect the body against infection).

The main side effects reported are fatigue and skin irritation, like a mild to moderate sun burn. The fatigue often sets in during the middle of a course of treatment and can last for weeks after treatment ends. The irritated skin will heal, but may not be as elastic as it was before.

For instance, patients who are undergoing breast irradiation will typically experience a redness, dryness or itchiness of the breasts that usually begins two to three weeks after the treatment is commenced. It will then continue, but will eventually leave several weeks after the radiation treatment course is completed.

Another example of a side effect is diarrhea, nausea or vomiting. This is sometimes experienced by patients undergoing radiation treatment to their abdomens or bowels. In most cases, these side effects, which are called acute, take place during the radiation treatment course and will continue for a few weeks after the course is completed.

In almost all cases, these side effects will go away and patients will be fine. In rare instances, some patients will experience long-term side effects or complications, because the radiation causes damage to an internal organ adjacent to or near the tumor site.

Normal tissue reactions

Normal tissues vary in their response to radiation. As with tumors, normal tissues that are dividing more rapidly may be affected and cause some of the side effects of radiation treatment. Since radiation is a local treatment, side effects are usually confined to the area being treated.

The early reactions are seen during the first days or weeks after irradiation (for example diarrhea or acute mucositis) and may continue for several weeks after treatments are completed. They are temporary because the cell deficit is compensated for by the repopulation of stem cells, and subsequently of differentiated cells. Late reactions due to damage to the late-reacting tissues, for instance blood vessel damage, fibrosis, telangiectasia, etc, may be seen after months.

Common side effects of radiation therapy

- Hair loss to the area being treated.
- Fatigue.
- Skin reactions in the treated area.
- Loss of appetite.
- Nausea.

Acute side effects

Fatigue is a general effect of radiation but the exact cause is unknown. The tumor may cause the immune system to make substances that lead to fatigue. Fatigue may also be caused by anemia (low red blood cell count), poor nutrition, pain, medicines such as steroids or chemotherapy, depression, and stress. There is no single treatment for fatigue, but if possible, the cause of the fatigue is addressed. For example, if the fatigue is in part caused by anemia, some patients will benefit from blood transfusions or from medicines to stimulate the body to make more red blood cells.

Epithelial surfaces may sustain damage from radiation therapy. Depending on the area being treated, this may include the skin, oral mucosa, pharyngeal, bowel mucosa and ureter. The rates of onset of damage and recovery from it depend upon the turnover rate of epithelial cells. Typically the skin starts to become pink and sore several weeks into treatment. The reaction may become more severe during the treatment and for up to about one week following the end of radiation therapy, and the skin may break down. Although this moist desquamation is uncomfortable, recovery is usually quick. Skin reactions tend to be worse in areas where there are natural folds in the skin, such as underneath the female breast, behind the ear, and in the groin.

Skin

Modern radiation therapy may cause less damage to the skin than in earlier types of therapy because most of the radiation dose is delivered below the surface of the skin. During the first 2 weeks of treatment, a faint and short lasting redness may occur. Dryness and peeling of the skin, called dry desquamation, may occur in 3 to 4 weeks. The skin over the treatment area may become darker. This is because of the effect radiation has on the cells in the skin that produce pigment.

The skin may also become dry and itchy. Moisturizing the skin with aloe vera, lanolin, or vitamin E may help. After a month of treatment, some people receiving radiation may experience some extreme peeling and weeping (moist) areas. Let your medical care team know if this occurs. Later effects of radiation may include thinning of the skin. The skin may feel hard, especially if surgery

has also been done in the same area. Some people may have trouble with wound healing in the area that was treated.

Lung

When radiation treatments include the chest area, the lungs can be affected. One early change is a decrease in the levels of surfactant, the substance that helps keep the air passages open. This keeps the lungs from fully expanding, which may cause shortness of breath or cough. These symptoms are sometimes treated with steroids.

A possible late effect of radiation on the lungs is fibrosis (stiffening or scarring), which reduces the ability of the lungs to inflate and take in air. If a large area of the lungs is irradiated, these changes can cause shortness of breath and less tolerance for physical exercise.

Digestive tract

Radiation to the thorax and abdomen may result in swelling and inflammation of the esophagus, stomach or intestines, causing nausea, vomiting, or diarrhea. The lower bowel may be treated directly with radiation (treatment of rectal or anal cancer) or be exposed by radiation therapy to other pelvic structures (prostate, bladder, female genital tract). Typical symptoms are soreness, diarrhea, and nausea. Antacids, sometimes combined with a numbing medicine such as lidocaine, may be helpful in relieving pain from inflammation of the esophagus. Nausea and vomiting can also be treated with medicines. If it is severe, some patients may need intravenous fluids to avoid or treat dehydration. Diarrhea can be treated with medicines and by avoiding spicy.

Swelling (edema or oedema) — As part of the general inflammation that occurs, swelling of soft tissues may cause problems during radiation therapy. Surgical intervention may be considered prior to treatment with radiation. If surgery is deemed unnecessary or inappropriate, the patient may receive steroids during radiation therapy to reduce swelling.

Late side effects

Late side effects occur months to years after treatment and are generally limited to the area that has been treated. They are often due to damage of blood vessels and connective tissue cells.

Fibrosis — Tissues which have been irradiated tend to become less elastic over time due to a diffuse scarring process.

Epilation (hair loss) may occur on any hair bearing skin with doses above 1 Gy. It only occurs within the radiation field/s. Hair loss may be permanent with a single dose of 10 Gy, but if the dose is fractionated permanent hair loss may not occur until dose exceeds 45 Gy.

Dryness — The salivary glands and tear glands have a radiation tolerance of about 30 Gy in 2 Gy fractions, a dose which is exceeded by most radical head and neck cancer treatments. Dry mouth (xerostomia) and dry eyes (xerophthalmia) can become irritating long-term problems.

8. Radiology therapy of benign disease

Introduction

Radiation therapy attacks reproducing cancer cells, but it can also affect reproducing cells of normal tissues. The damage to normal cells is what causes side effects. Each time radiation therapy is given it involves a balance between destroying the cancer cells and sparing the normal cells.

Radiation therapy has several applications in non-malignant conditions, such as the treatment of trigeminal neuralgia, severe thyroid eye disease, and prevention of keloid scar growth. The use of radiation therapy in non-malignant conditions is limited partly by worries about the risk of radiation-induced cancers. Radiation can sometimes play a role in the development of cancer, particularly if people are exposed to it at an early age. We are all aware of the increased frequency of cancers, especially leukemias, among Japanese survivors of World War II. Patients should bear in mind that radiation, as delivered in a radiation department, is a very careful, precise and well monitored treatment which very rarely leads to the development of cancer.

Radiation treatment of benign disease

The use of radiation in the treatment of benign diseases has a long history. Soon after the discovery of x-rays by Roentgen in 1895, the therapeutic potential of radiation was recognized. In the first half of the 20th century, radiation therapy was used empirically for a host of conditions, both benign and malignant. In many situations in which no effective therapeutic alternatives existed, radiation therapy may have been one of the few treatment options available. Even with recognition of the risks of late skin injury, carcinogenesis, leukemogenesis, and genetic damage from all ionizing radiation, radiation therapy also continues to be accepted treatment for benign diseases that do not respond to other methods of therapy.

In many cases, the use of radiation therapy for benign disorders may be able to spare the patient morbidity associated with the progression of the disease, or additional medical or surgical therapy.

The need for informed consent exists everywhere in radiation oncology, and certainly in the use of radiation therapy for benign diseases. Patients should be informed of the rationale, potential side effects, and treatment alternatives to radiation treatment before it is delivered.

Radiation carcinogenesis, although always a concern when ionizing radiation is used, appears to be a greater risk for pediatric patients and young adults than for older adults, and must be weighed in relation to the consequences of progressive disease and the side effects associated with alternative therapies. Special caution should be used before radiation is delivered to pediatric patients and young adults for benign conditions. These young patients may be at in-

creased risk of second malignancy induction and late atrophy, especially if the area to be treated is in proximity to the breasts or thyroid, tissues that may be sensitive to carcinogenesis. As in all aspects of radiation therapy, care should be taken to use beams of appropriate energy and to shield adjacent normal structures.

Technical considerations

1. Before institution of therapy, the quality of irradiation, total dose, overall time, underlying organs at risk, and shielding factors should be considered.

2. Meticulous radiation protection techniques, including cones and lead shields, should be used in all instances.

3. The depth of penetration of the ionizing radiation beam should be chosen in accordance with the depth of the pathologic process.

As in all radiation therapy, the choice of beam energy depends on the depth of the target volume, and every effort is made to spare normal underlying tissue in superficial lesions. Absorption data for ionizing radiation therapy are readily obtained from standard depth-dose tables.

Internal lead shields placed in oral or nasal cavities tend to increase the dose to overlying tissue for both x-ray and electron-beam treatments. This increase is caused by backscattered electrons and may be minimized by encasing the shields in plastic.

Exophthalmos

Signs and symptoms of Graves' ophthalmopathy include bilateral exophthalmos, extraocular muscle dysfunction, diplopia, blurred vision, eyelid and periorbital edema, chemosis, lid lag and retraction, and compressive optic neuropathy. The pathogenesis is believed to be an autoimmune disease in which activated T-lymphocytes invade the orbit and stimulate glycosaminoglycan production in fibroblasts, resulting in tissue edema, lymphocytic infiltration, and marked enlargement of the extraocular muscles. Because lymphocytes and fibroblasts are sensitive to radiation, retrobulbar irradiation is a logical method of treatment. Systemic high-dose steroids are customarily used, but they must be given for long periods and have many side effects. Surgical orbital decompression is used when there is rapidly progressive optic neuropathy or severe proptosis.

Megavoltage external-beam irradiation using precise planning with high-resolution computed tomography (CT) scans and complete patient immobilization is recommended for optimization of dose distribution and to avoid unwanted irradiation of sensitive structures (e. g., lens, pituitary gland).

Small opposed bilateral fields are used to encompass both retrobulbar volumes with customized blocks to shield periorbital structures. Either a split-beam technique or a 5-degree posterior angulation should be used to avoid the

lens. The total dose is 20 Gy to the midplane, given in 10 fractions over 2 weeks. Photons of 5-MV are used in most cases.

Keloids

Some persons have a tendency to react to skin trauma with excessive production of fibrous tissue that extends beyond the wound, becomes hyalinized, and does not regress spontaneously. These keloids become unsightly masses, and they frequently cause itching and pain. They may occur in susceptible individuals after infection, burns, or (most commonly) surgical wounds.

Although suture tension and stitch infection in the wound may be contributing factors, the recurrence rate after excision is very high even in their absence, and surgical treatment alone is not recommended.

Radiation therapy is usually started within 24 hours after excision, using 120-kV x-rays or low-energy electrons. The radiation field is custom-shaped with lead, with a 0,5-cm margin around the suture lines. The ear lobes, when treated, are taped away from the face, and a direct anterior or posterior field is used with a small cone. If the lobe is more than 1-cm thick and the wound extends around it, a higher-energy beam is needed. The total dose is 10 to 15 Gy in two to five fractions in 1 to 2 weeks.

Treatment of established keloids by irradiation alone is not as successful but may be attempted if surgery is not indicated (e. g., in an elderly patient with a large symptomatic lesion or in presternal and shoulder keloids that commonly recur even after combined treatment.

Cutaneous lesions

Treatment of cavernous hemangiomas of the skin in infants by repeated doses of radium in surface applicators was commonplace many years ago. A trial of oral steroids is now the preferred treatment for skin hemangiomas requiring intervention, such as rapidly growing facial lesions causing disfigurement, and radiation therapy is reserved for lesions that threaten function or life and have failed alternative therapies.

For minor superficial hemangiomas, contact radiation therapy is most suitable. The skin dose is 5 to 10 Gy per treatment. For thicker lesions, orthovoltage irradiation is recommended, with doses of 1 to 4 Gy per treatment.

Bursitis and tendinitis

Bursitis and tendinitis most commonly affect the shoulders. These disorders are caused by degenerative and inflammatory changes in the supraspinatus and infraspinatus tendons that lead to calcium deposition, inflammation of the surface of the subdeltoid bursa, and even rupture and discharge of calcific material into the bursa. Calcification may occur without symptoms, or there may be pain, tenderness, and limitation of motion in acute, subacute, or chronic forms. It

is probably true, however, that irradiation is equally effective and is sometimes successful when invasive local treatments are not.

Limited fields encompass the joint only, using either opposed or occasionally a single anterior field. A daily dose of 1,5 to 2 Gy is given on 3 to 5 successive days for a total of 6 to 10 Gy. One or two additional treatments may be added after 1 or 2 weeks in chronic cases, in which results are much less satisfactory.

Rheumatoid arthritis

The patients selected had severe rheumatoid arthritis with active synovitis and significant disability treated unsuccessfully with nonsteroidal antiinflammatory agents, gold, and penicillamine. All patients would have been suitable candidates for cytotoxic therapy with agents such as azathioprine or cyclophosphamide, which, although effective in controlling advanced disease, may be accompanied by significant side effects.

In the Stanford trial, the regimen consisted of mantle field treatment with 20 Gy in 10 fractions of 2 Gy in 2 weeks. Patients were evaluated before and after therapy with respect to joint tenderness and joint swelling, duration of morning stiffness, and a global composite score. Complications of treatment included mild systemic effects, such as nausea and fatigue, and local effects, including dysphagia, xerostomia, and esophagitis.

Conclusions

Radiation therapy continues to be used in the treatment of various benign disorders because the profile of efficacy and morbidity compares well with the available treatment alternatives. There is a well-established role for radiotherapy in the management of benign neoplasms when surgical therapy is medically contraindicated or would carry undue morbidity. In addition, there are situations in which anatomically limited proliferations of lymphoid, epithelial, or mesenchymal tissue can cause significant morbidity that can be avoided or mitigated with local radiation treatment rather than systemic medical therapy or repeated surgical procedures.

9. Radiobiology of tumour

Biological effects of ionizing radiation

Cell damage

Current thinking suggests that there are two mechanisms for damage:

Direct action: is damage to the DNA material in the cell nucleus. The structure of DNA is a double helix which forms the "backbone" of the structure across which are a series of base pairs composed of adenine-thymine or cytosine-guanine. Damage to DNA may take the form of strand breaks either in the sugar-phosphate backbone or one or more of the base pairs (figure 9.1).

Indirect action: is caused by the radiolysis of water, the most common molecular constituent of tissue. Ionisation of the water molecule liberates an electron and produces hydrogen (H) and hydroxyl (OH) free radicals. These are highly reactive and will readily recombine, some to reform the water molecule, H_2O , and others to form more toxic compounds such as hydrogen peroxide, H_2O_2 . The effect of toxins produced in this manner may lead to cellular damage.

Damage to cells is not irreparable. However those cells which do not repair will either cease to function or will continue to function in a modified way. Cells which are modified may also be non-viable in the long term but some may be modified in such a manner that they undergo a neoplastic transformation characterized by unlimited proliferation (i.e. malignant tissue).

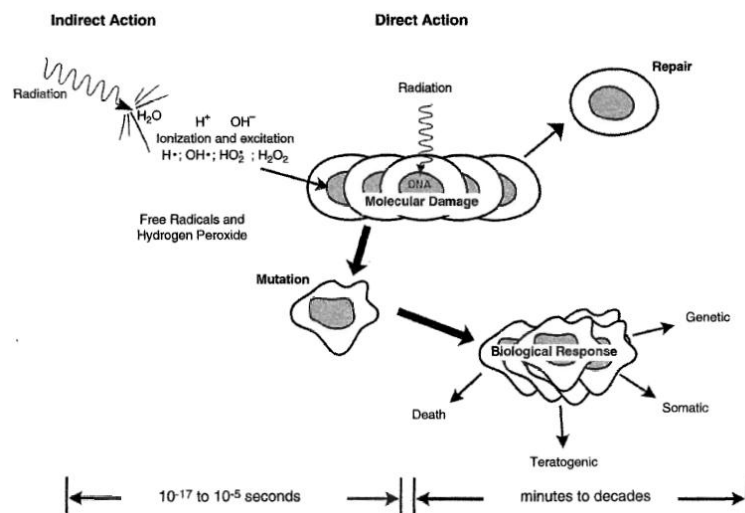


Figure 9.1 — Interaction of ionizing radiation with tissue

Radiobiological mechanisms

The biological damage inflicted by irradiation of human cells with ionizing radiation can be divided into 3 consecutive steps:

— A very short initial physical phase (about 10^{-18} s), during which photons interact with orbital electrons, raising them to higher energy levels inside the atoms (excitation), or ejecting some of them from the atoms (ionization). This is the energy deposition phase.

— A chemical phase, again very short (about 10^{-3} s), during which ionized and excited atoms interact, leading either directly or indirectly through the formation of free radicals to the breakage of chemical bonds. Free radicals are highly reactive and can induce chemical changes in biologically important molecules like DNA. Single-strand or double-strand break in DNA appears to be the basic damage leading to biological effects.

— A biological phase, much longer (seconds to years), during which the cells react to the inflicted chemical damage. Specific repair enzymes can successfully repair the vast majority of lesions in DNA. A few lesions however may not be repaired, and may therefore lead to cell death. Cell death is not immediate and usually occurs during the next cell division (apoptosis is a minor process in most human cells). However, death due to a lethal lesion may be delayed for a limited number of mitotic divisions (up to 5 or 6). Because the stem cells are the only cells which divide in normal tissues, the earliest effect observed is a deficit in stem cells. Later, the loss of stem cells will lead to a deficit in differentiated cells, causing the observed clinical reactions.

Radiation therapy works by damaging the DNA of cancerous cells. This DNA damage is caused by one of two types of energy, photon or charged particle. This damage is either direct or indirect ionization of the atoms which make up the DNA chain. Indirect ionization happens as a result of the ionization of water, forming free radicals, notably hydroxyl radicals, which then damage the DNA. It prove to be the most significant technique to cause cell death.

Cancer cells are generally undifferentiated and stem cell-like; they reproduce more than most healthy differentiated cells, and have a diminished ability to repair sub-lethal damage.

One of the major limitations of photon radiation therapy is that the cells of solid tumors become deficient in oxygen. Solid tumors can outgrow their blood supply, causing a low-oxygen state known as hypoxia. Oxygen is a potent radiosensitizer, increasing the effectiveness of a given dose of radiation by forming DNA-damaging free radicals. Tumor cells in a hypoxic environment may be as much as 2 to 3 times more resistant to radiation damage than those in a normal oxygen environment. Much research has been devoted to overcoming hypoxia including the use of high pressure oxygen tanks, blood substitutes that carry increased oxygen, hypoxic cell radiosensitizer drugs such as misoni-daole and metronidazole, and hypoxic cytotoxins (tissue poisons), such as tira-pazamine.

Radiation units

Measuring ionizing radiation

The ionizing effects of radiation are measured by units of exposure:

– The coulomb per kilogram (C/kg) is the SI unit of ionizing radiation exposure, and measures the amount of radiation required to create 1 coulomb of charge of each polarity in 1 kilogram of matter.

– The roentgen (R) is an older traditional unit that is almost out of use, which represented the amount of radiation required to liberate 1 esu of charge of each polarity in 1 cubic centimeter of dry air (table 9.1).

Table 9.1. — Basic radiation units.

Quantity	Conventional	SI Unit	Conversions
Exposure	Roentgen (R)	Coulomb/kg of air (C/kg)	1 C/kg = 3876 R
			1 R = 258 µCi/kg
Dose	Rad	Gray (Gy)	1 Gy = 100 rad
Dose equivalent	Rem	Sievert (Sv)	1 Sv = 100 rem
Activity	Curie (Ci)	Becquerel (Bq)	1 mCi = 37 MBq

However, the amount of damage done to matter (especially living tissue) by ionizing radiation is more closely related to the amount of energy deposited rather than the charge. This is called the absorbed dose.

– The gray (Gy), with units J/kg, is the SI unit of absorbed dose, which represents the amount of radiation required to deposit 1 joule of energy in 1 kilogram of any kind of matter.

–The rad (radioactivity absorbed dose), is the corresponding traditional unit, which is 0.01 J deposited per kg.

Equal doses of different types or energies of radiation cause different amounts of damage to living tissue. For example, 1 Gy of alpha radiation causes about 20 times as much damage as 1 Gy of X-rays. Therefore, the equivalent dose was defined to give an approximate measure of the biological effect of radiation. It is calculated by multiplying the absorbed dose by a weighting factor WR, which is different for each type of radiation (see above table). This weighting factor is also called the Q (quality factor), or RBE (relative biological effectiveness of the radiation) (table 9.2).

– The sievert (Sv) is the SI unit of equivalent dose. Although it has the same units as the gray, J/kg, it measures something different. It is the dose of a given type of radiation in Gy that has the same biological effect on a human as 1 Gy of x-rays or gamma radiation.

Smaller quantities are expressed in 'millisievert' (one thousandth) or 'microsievert' (one millionth) of a sievert.

Table 9.2. — Weighting factors for calculation of equivalent dose.

Type of radiation	Weighting factor
Photons i.e. X-rays and gamma rays	1
Electrons	1
Neutrons	5–20 depending on energy
Protons	5
Alpha particles	20

Equivalent dose = weighting factor × absorbed dose.

The effect of radiation on a given organism depends on the dose absorbed into the tissues, but also on the type of radiation and the sensitivity of the tissues or organs irradiated. The effect on the tissue will be different, however, depending on whether the particle is energetic or not. Photons generate other effects in the tissues than neutrons or alpha radiation. The absorbed dose is therefore corrected by a weighting factor which allows for the equivalent dose to be obtained. Thus X-, γ - or β -radiation are similar in their effects and do not need to be corrected (weighting factor equal to 1), while neutrons are assigned a weighting factor between 5 and 20 depending on their level of energy. The highest coefficient is applied to neutrons as their energy is between 100 and 2,000 keV, and reduces again after that. This is explained by the fact that very high energy neutrons pass through tissue so rapidly that they do less damage than if they passed at a lower energy level. Extremely ionizing α -radiation is in turn assigned a weighting factor of 20.

Apart from the normal measures of mass and volume, the amount of radioactive material is given in becquerel (Bq), a measure which enables us to compare the typical radioactivity of some natural and other materials (table 9.3). A becquerel is one atomic decay per second.

Table 9.3. — Examples of activity radionuclides.

1 adult human (100 Bq/kg)	7000 Bq
1 kg of coffee	1000 Bq
Radionuclide for medical diagnosis	70 million Bq
Radionuclide source for medical therapy	100 000 000 million Bq
1 kg uranium	25 million Bq
1 kg low level radioactive waste	1 million Bq
1 kg of granite	1000 Bq

Radiation hazard

The hazards of ionizing radiation were recognized soon after the discovery of the x-ray by Roentgen in 1895. A famous example is that of Antoine-Henri Becquerel, the professor of eventual two-time Nobel laureate Marie Curie, one of the discoverers (along with her husband, Pierre) of radium. In 1902, Marie Curie had painstakingly extracted a tenth of a gram of the new metal from large quantities of pitchblend, in which it was contained at a concentration of one part per million. The professor was so proud of his pupil's discovery that he carried a vial containing the first sample of radium ever produced in his vest pocket. Soon he noticed that he had developed a severe burn on the skin of his abdomen underneath the vial. The causative role of the radium in the production of the burn was verified when other researchers intentionally taped pieces of the new metal to their skin, producing similar burns. Experiments on animals by the Curies and others led to the development of therapeutic uses of radium emissions, known at the time as Curie therapy. That

the same invisible rays used to diagnose diseases such as cancer could also both cause and cure the disease astonished early x-ray researchers.

Radiation hazards occur as a result of damage to cells caused by radiation. This damage takes many forms:

- Cell death.
- Mitotic inhibition (temporary/permanent).
- Chromosome damage/genetic damage leading to mutations.
- Actively dividing cells are particularly sensitive (i. e. bone marrow, lymph glands, gonads).

The nature and degree of cell damage vary according to:

- Radiation dose.
- Dose rate.
- Irradiated volume.
- Type of radiation.

Radiation risks

Soon after the discovery of X-rays and radioactivity, it became evident that radiation could cause somatic damage to tissues (e.g. erythema), but it was not for some years that the long-term and genetic effects began to be appreciated.

Current knowledge of the risks of ionizing radiation is based on a wide range of epidemiological evidence from plant, animal and cell biology. The most significant body of information comes from the on-going study of those who survived the atom bombs dropped on Hiroshima and Nagasaki in 1945.

The damaging effects of radiation can be divided into two categories: deterministic effects and stochastic effects.

Stochastic effects

- Probability of effects not severity, regarded as a function of dose.
- No dose threshold below which an effect will not theoretically occur.
- Due to modified cell, e. g. somatic cell leading to cancers; reproduction cell leading to hereditary effect.

In stochastic effects, the probability of an effect occurring increases with dose up to a maximum, above which the curve flattens off. At low doses (< 100–200 mGy) effects cannot be easily measured because of the high incidence of cancer in the population and for practical purposes it is assumed that there is no ‘safe’ dose. It is this lack of evidence of a threshold dose that has resulted in the principle of keeping radiation doses as low as reasonably practicable (ALARP). There has, however, been some recent evidence to suggest that there may be some protective effect of radiation at very low doses, but this is a matter of current controversy.

Based heavily on studies of Japanese survivors of atomic bomb attacks, ICRP-calculated probability coefficients for stochastic effects in the general population are as follows:

- Fatal cancer: 5.0.

- Non-fatal cancer: 1.0.
- Severe hereditary effects: 1.3.

For example, if 100 people are exposed to 1 Sv of radiation, five will theoretically develop a fatal cancer. A dose of 5-6 Sv over a short time period leads to acute radiation sickness and death.

Deterministic effects

- Severity of effects varies with dose.
- Dose threshold may exist below which the effect will not occur.
- Due to cell death, deterministic effects occur when cell loss is sufficient to impair organ function (e.g. radiation burns, cataracts and decreased fertility).

Deterministic effects occur at high dose levels, such as those given in radiotherapy treatments and are due to radiation-induced cell death. These effects are characterized by having a threshold dose below which the effect is not observed. The severity of the effect increases with dose and dose rate. This may result in the death of the individual, depending on the organs exposed and the dose received. Cataract formation and skin damage are examples of deterministic effects. Normally, in diagnostic procedures, doses are well below the threshold where deterministic effects are observed, but the increasing use of interventional techniques has made exceeding a threshold dose for skin damage a possibility that cannot be ignored.

Doses lower than about 1 Gy generally cause no noticeable acute effects other than slight cellular changes (e.g. measurable chromosome aberrations). There is, however, the small possibility that a cell with noncritically damaged DNA can continue to reproduce and, with the effect of other agents, result in an increased probability of induced cancer or leukaemia. The timing of the appearance of radiation-induced cancers varies, with a mean incidence for leukaemia at about 7 years postirradiation, about 5 years for thyroid and bone cancers and 20 or more years for most other cancers. The time lag in the induction of cancers means that younger subjects are at greater risk. If damage is to the germ cells, genetic effects may occur in future offspring. To date, no hereditary effects have been demonstrated convincingly in humans; however, based on animal experiments, it is concluded that hereditary effects are a possibility. These long-term, low-dose stochastic effects are of a random statistical nature and the probability of occurrence (but not the severity of the effect) is related to dose.

Exposure from medical procedures

For medical radiation, the chest X-ray delivers 0,1–0,2 mSv to the chest wall and the gallbladder series approximately 0,25 mSv. The average nuclear medicine procedure delivers 3 mSv to the whole body. When these values are compared with those of natural sources of radiation, particularly cosmic rays, which deliver an average of 3,6 mSv/year in the United States and are higher in certain areas, the real magnitude of the low level of radiation can be appreciated (table 9.4). These levels of exposure from diagnostic medical procedures have no detectable biological effects.

Table 9.4. — Absorbed radiation dose from common natural and medical sources.

Source	Radiation dose (mSv)
<i>Diagnostic X-ray procedures</i>	
Chest X-ray	0.1
Intravenous pyelogram	2.5
Mammography (one film)	4
Gallbladder series	5.5
Panoramic dental X-ray	9
Barium enema series	80
X-ray CT of the head	60
<i>Diagnostic nuclear medicine procedures</i>	
^{99m} Tc-MAA lung perfusion study	1
^{99m} Tc-MDP bone scan (20 mCi)	3.5
<i>Natural sources</i>	
Two-hour flight	0.05
Drinking water	0.05
Natural gas at home (mainly radon)	0.1
Radionuclide in human body	0.4
Cosmic radiation (at sea level)	0.35
(at 2000 m)	5

Based on our current knowledge, no level of exposure to radiation can be described as absolutely safe and no level is uniformly dangerous. Fear of radiation must not be permitted to undermine the great value of radiation in clinical practice. However, safe handling of all levels of radiation is important to prevent or minimize possible biological effects.

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