A history of radiology of the abdomen is complex because it involves multiple imaging modalities and several organ systems. This chapter is arbitrarily divided into four sections for a more manageable historical review. The first section discusses the development of radiology of the gastrointestinal tract. Early radiographers were fascinated by the new ray's ability to reveal anatomy and physiology of the stomach within living beings, and this was the initial area of investigation. In the second section the difficulty of examining the normal and abnormal gallbladder and biliary system is related. Ultimately, success in this endeavor was achieved with the advent of halogenated contrast agents and advanced imaging technology. In the third section imaging of the solid organs of the abdomen, including liver, spleen, and pancreas, is seen to be closely tied to the development of modalities such as nuclear medicine, ultrasound, computed tomography (CT), and magnetic resonance (MR) imaging. The fourth section is a brief historical review of intra-abdominal interventional radiology. Each era in the history of abdominal imaging reflects the work of countless men and women who have contributed to the field.¹

THE GASTROINTESTINAL TRACT

Immediately after Röntgen's discovery of X rays, the chief problems in successfully imaging the abdomen were the absence of inherent contrast within this region and the lack of equipment capable of penetrating structures deep in the body. Nevertheless, abdominal radiographs occasionally demonstrated an air-filled stomach, suggesting that at least in some instances the hollow visci could be visualized.² In fact, percussion of the stomach after inflation with air had been carried out for many years, and this procedure was suggested as a means to better demonstrate the stomach by radiography.³ German researcher Carl Wegele suggested that a metal wire be inserted through an orally placed gastric tube to provide a guide to the positions of both the esophagus and the stomach. An outline of the stomach indicating its size and position in the abdomen could also be determined in this fashion.⁴ This technique apparently was never widely applied, but at least one early investigator published pictures demonstrating its use (Fig. 8.1).⁵

The pioneers of radiology recognized clearly that with some sort of contrast even their underpowered
equipment might be capable of demonstrating intra-abdominal anatomy. With the publication in January 1896 of a radiograph depicting contrast-filled vessels in a cadaver's hand, Eduard Hascheck and Otto Lindenthal, both working in Vienna, showed the potential for radiopaque agents in other parts of the living body.\(^5\)

In March 1896 Wolf Becher published a paper in Berlin that laid down the theoretical concepts and presented a practical example of the use of contrast in demonstrating the gastrointestinal tract.\(^7\) He injected liquor plumbi subacetici into a guinea pig's stomach to image this structure radiographically. The stomach and part of the small bowel were visualized (Fig. 8.2). However, he recognized that this particular substance was toxic and suggested that a substance capable of absorbing X rays, yet not harmful to humans, be sought to pursue radiographic investigation of the human gastrointestinal tract. Modifying Becher's model, John Hemmeter of the University of Maryland proposed that instilling lead acetate into a rubber bag the patient had swallowed previously might provide information regarding position and size of the stomach by radiographic means.\(^8\)

These techniques failed to see widespread use, presumably because of the difficulty, discomfort, and unreliability met with in

Fig. 8.1 Carl Wegele first suggested the use of a metal wire as contrast medium to determine the position, size, and shape of the stomach (1896). Dr. E. Lindemann of Hamburg performed the experiment and produced this radiograph following a twenty-two-minute exposure of the patient in a reclining position. (Reprinted from Bruwer, Classic Descriptions in Roentgenology, with permission from Charles C. Thomas, Pub.)

Fig. 8.2 Wolf Becher's 1896 publication of a positive contrast gastrointestinal study of a guinea pig's stomach and small bowel led to a search for nontoxic substances for use in humans. He had sacrificed the animal and directly injected a lead solution into the stomach and intestine before using a thirty-five-minute exposure to produce this picture. In his article he apologized for the loss of contrast secondary to photographic reproduction. (Reprinted from Bruwer, Classic Descriptions in Roentgenology, with permission from Charles C. Thomas, Pub.)
and then radiographed the abdomen to discover that the "whole gastric area became visible as a faint shadow."10 Charles Lester Leonard of Philadelphia also used a bismuth formulation administered orally to radiograph the stomach and published these results in 1897.11 In France Jean-Charles Roux and Victor Balthazard observed fluoroscopic motion of the stomach by having patients swallow food or liquids mixed with bismuth subnitrate.12

While these and many other investigators contributed significantly to the early radiographic knowledge of the gastrointestinal tract, Walter Bradford Cannon (Fig. 8.4), through diligence and innovation, did the most to establish the true clinical value of contrast studies. As first year medical students at Harvard University, Cannon and Albert Moser were guided by their professor of physiology, Henry Bowditch, in a research project using X-rays to study swallowing. They fluoroscopically observed the mechanics of swallowing in animal experiments with dogs, roosters, frogs, and geese. Pearl buttons were first tried as contrast material, but ultimately bismuth compounds and bismuth mixed with food and liquids were used. In addition to observing deglutition and past-through, their clinical use. In 1897, however, George Pfahler of Philadelphia (Fig. 8.3) observed while radiographing a patient's abdomen that "the radiographic plate showed bismuth in the stomach which had been taken therapeutically."13 Bismuth was a remedy commonly used to treat presumed gastric ulcers during this period, and although Pfahler did not recognize the potential of this agent as a contrast medium, others soon did. In Buffalo A. L. Benedict gave bismuth powder in capsule form.
sage of these substances through the esophagus, they observed gastric peristalsis early in 1897 (Fig. 8.5). These investigations with animals led to the publication of several important reports on technique and produced observations documenting the basic physiology of the gastrointestinal tract.\textsuperscript{13,14} Cannon's recognition of the change in gastric peristalsis secondary to emotional states eventually led him to his lifelong research on the effects of rage, hunger, and other stress on the body, and the role of the sympathetic nervous system and adrenal gland in these responses.\textsuperscript{15}

Further investigations by Cannon and Moser in mammals led eventually to the study of a seven-year-old girl in whom they noted that "the thickness of the thorax, the distance of the esophagus from the surface, and the relation to dense tissues, render the observation of a swallowed mass difficult, especially when the mass is in rather rapid motion."\textsuperscript{16} Within a year Cannon, in collaboration with Francis H. Williams, conducted a study of gastric motility in two patients, an effort later labeled "the beginning of clinical gastrointestinal radiology."\textsuperscript{17}

Francis Williams (Fig. 8.6), a true pioneer in assessing the clinical value of X rays, investigated a broad array of clinical problems and abnormalities at both the Massachusetts Institute of Technology and Boston City Hospital. His book, \textit{The Roentgen Rays in Medicine and Surgery}, published in 1901, was the first detailed text showing the value of the new technology.\textsuperscript{18} Although much of the book was devoted to pulmonary diseases, a portion of it applied specifically to the gastrointestinal tract. Williams, like others, faced the problem of lack of contrast between intra-abdominal structures and remarked that radiographic study of "the abdominal cavity (had) not progressed so far because of natural difficulties."\textsuperscript{19} To solve the problem he suggested the use of contrast agents, including air and bismuth, as well as recalling the Lindemann technique of wire insertion. He also proposed the use of Scellitiz powder (a common patent medicine antacid) to produce gas in the stomach.\textsuperscript{20} His work with Cannon using bismuth subnitrate in two children, as well as his work with a third child, is recorded along with his conclusions that both the outline and motion of the stomach during the physiologic changes of respiration and digestion could be obtained (Fig. 8.7). Children may have been favored as sub-
Fig. 8.8 Hermann Rieder (1858–1932) was a German physician who popularized rapid radiographic acquisition as the means to record the contrast-filled gastrointestinal tract. Guido Holzknecht of Vienna disagreed with Rieder and proposed that a better examination of the gastrointestinal tract would be made by fluoroscopy. This conflict ultimately led to a debate as to whether direct (radiographic) or indirect (fluoroscopic) findings were more indicative of gastrointestinal pathology. (Courtesy of the Center for the American History of Radiology, Reston, Va.)

Radiographic apparatus. Williams went on to suggest that “the constant presence of a darkened area in the stomach, for example, may suggest the thickening of its walls due to a malignant disease; some displacements or adhesions may be recognized, as well as hourglass contractions, or an unusual delay of the digestive process.”21 Together, Cannon and Williams popularized in the United States the clinical use of X rays for gastrointestinal disorders.

In Europe the German physician Hermann Rieder (Fig. 8.8) was even more influential as a champion of X-ray examination of the gastrointestinal tract. His detailed report in 1904 of the use of bismuth as a contrast agent for this purpose soon brought him fame as the originator of the “Rieder meal,” a mixture of contrast and cereal designed to be palatable when ingested. He also became a proponent of the use of radiographic pictures or radiographs instead of fluoroscopic tracings as a means of recording his observations of the contrast-filled digestive system (Fig. 8.9).22 This alternative method of data collection quickly became accepted internationally and sparked prolonged and heated debate in radiology circles. The chief opposition spokesman was Guido Holzknecht of Vienna who, in 1905, with L. Brauner wrote that “the action of massage on the stomach, displacement of the organ during respiration, etc., can be better studied by fluoroscopic examination,” adding, “fluoroscopy, which Rieder wrongly neglected, has opened up to us a whole world of diagnostic possibilities…”23

This dichotomy of thinking was clearly if not firmly established in the United States, and proponents for one or the other of the recording techniques had their say in journals, at meetings, and in fledgling radiolo-
gy departments. Henry Hulst of Grand Rapids, Michigan (Fig. 8.10), who at the
annual meeting of the American Roentgen Ray Society (ARRS) in 1905
had praised Rieder’s radiographic technique, by 1906 stated that “fluoro-
scopy...deserves a place in the examination of the stomach.” He went
on to say that “what we want is not merely Roentgenography or Roentgenoscopy,
but Roentgenology.”24,25 Hulst revealed an acerbic nature in his president’s
address at the 1906 ARRS meeting in discussing gastroptosis, a controversial diag-
nosis at the time: “You may imagine my astonishment the other day when a colleague insisted...that the prone position is the best and only correct one for
determining the position of the normal and abnormal stomach, because...‘origin-
ally man went on all fours’...[haven’t we changed all that]...now...we are no
longer...amœba reaching after pabulum with pseudopods but [are] enlightened
bipeds blessed with a stomach suited to our high state.”26 Such highly evolved
viscera provoked ongoing controversy on the best imaging methods.

Supporting Rieder’s radiographic technique was Mhran Kassabian (Fig.
8.10), who said, “I do not employ the fluoroscope, as it is dangerous alike for
the operator and patient, and because the taking of a skiphograph is only a ques-
tion of seconds.”27 By the ninth annual meeting of the ARRS in 1908, Hulst had
become a strong advocate of the Holzknecht fluoroscopic school and commented:

Dr. Leonard [who had presented a paper favoring radiographic study of
the viscera] and I do not seem to be
able to agree...now he is trying to
catch physiologic waves in the stom-
ach...The way to study peristalsis is
with the fluoroscope...Rieder was the
first to study extensively the human
stomach with the bismuth meal and
Roentgenography, and he does it well.
Then Holzknecht took up...fluoroscopy
and he does that well; but
[doesn’t do] Roentgenography as well
as Rieder; yet it cannot be denied that
Holzknecht has done more for Roentgenology of the stomach than
all of us combined.”28

The argument continued as to
which was the better recording method,
“direct” (radiographic filming) or “indirect” (fluoroscopic observation). In
1915 Aria! George and Ralph Leonard
published an elegant book intended as
an atlas of gastrointestinal pathology
demonstrated radiographically.29 In
their opening paragraph they indicated that two schools of roentgenologic investigation had developed, a Continental school and an American school. They discussed many early investigators such as Rieder (misspelled Reider) and Holzknecht, and suggested that because of inefficient radiographic film apparatus, expense, and large numbers of patients, fluoroscopy and a patient's symptoms played a more frequent role in formulating diagnoses. Thus, they claimed, a great deal of importance was placed on movement: peristalsis, hyperperistalsis, emptying time of the stomach, spasm, and residual gastric content. And while some attention was given to tenderness to palpation and to clinical history, this focus of fluoroscopy was not adequate for diagnosing duodenal abnormalities.

George and Leonard described the Rieder meal as consisting of 40 grams of bismuth subcarbonate and 300 cubic centimeters of cooked cereal and stated that its coarseness prevented filling of the duodenum. Consequently, they began to use milk and buttermilk mixed with bismuth and, ultimately, with barium for their examinations. Other media they tried included water, potato pap, malted milk, soup, and cereals. They proposed a standard meal so that results from different researchers could be accurately compared.

The routine examination for 1915 was as follows: The patient would present without having had breakfast, although a cup of coffee and toast two hours before the exam permitted. Several radiographic plates were made of the gallbladder region and entire abdomen to rule out renal calculi and gallstones and to assess gas distribution. The contrast meal was then administered orally in two large glasses. Following the first dose the roentgenoscope (i.e., fluoroscope) was used to see the esophagus and the manner in which the stomach filled. After that, the second dose was swallowed and the first radiographic plate was exposed. Intensifying screens and powerful apparatus for gastrointestinal work were used. Radiographic plates were also exposed after the meal at six hours and twenty-four hours with a light lunch permitted between the first and sixth-hour plates. Many positions were used, but most images were done in prone position. With this standard but arduous approach George and Leonard obtained excellent radiographs, many of which appeared in their book.

Both the direct and indirect approaches attracted outstanding American roentgenologists, two of whom were Lewis Gregory Cole of New York City and Russell D. Carman of the Mayo Clinic. Cole (Fig. S.11) was an advocate of the Rieder or radiographic technique of gastrointestinal tract investigation. His precise evaluation of GI tract radiographs elevated him to prominence as an advocate of the direct method of diagnosis. He commonly used as many as fifty to sixty radiographic exposures for his gastric studies (Fig. S.12) and was known for his expert diagnoses. In 1913 he and a surgical colleague, George E. Brewer, began a friendly competition to test the accuracy of X-ray studies of the stomach compared with subsequent surgical results. Cole's radiographic reports were sealed and read to operating room personnel just prior to surgery. With the first patient Cole radiographically diagnosed a duodenal ulcer, and indeed this was
trointestinal tract radiology throughout the world. Elucida-
tion and demonstration of findings, such as the hourglass
stomach and ulcer niche, were major contributions of the
author. Carman’s most celebrated diagnosis, however, was made
many years later. On returning from a European trip he suf-
f ered gastric pains and found himself before a fluoroscopic
screen on 8 October 1925. The fluoroscopist told Carman that
he had spasm and some films would be taken. Carman
returned to his office with his films and, holding them to a
window, diagnosed inoperable gastric carcinoma. Having just
finished a rough draft on a paper of this topic, he pointed
out the telltale findings to his assembled staff. Carman died of his disease
eight months later.35

The debate over direct or indirect techniques for radiographic evaluation
of the gastrointestinal tract ultimately was settled by taking the best from both
methods. In Germany F. Reiche in 1909 observed that the bismuth-filled stom-
ach of a patient was still filled several hours later and took twenty hours to
empty completely. He also noted a pro-

confirmed in surgery. A similar result
was noted in the second case. The third
patient was diagnosed as having unre-
sectable gastric carcinoma, and at
surgey this, too, was observed. The trial
went on for twenty-seven cases, of which
Cole correctly diagnosed twenty-four.
Brewer was thoroughly convinced of the
value of the radiological investigation
and reported his view at the American
Surgical Association meeting in 1914.
Not long after, this endorsement was
published: “The time seems near at
hand when chronic surgical lesions of
the stomach should not be operated
upon without previous roentgenologica
examination, if it is possible to obtain
one.”31 The extraordinary accuracy
Cole displayed was one of the reasons
for the early development of standard
referrals from clinicians to radiologists.

Carman (Fig. 8.13) began his radi-
ology career in St. Louis in 1902, but
joined the Mayo Clinic in Minnesota in
1913. Over the next four years he per-
formed tens of thousands of gastroin-
testinal tract examinations advocating
Holzknecht’s fluoroscopic technique.
This experience led to the publication
of his classic book *The Roentgen Diagnosis
of Diseases of the Alimentary Canal* in
1917.32 Wide distribution of this text
permitted a shared experience in gas-

Fig. 8.12 This radiograph of a
gastric ulcer would have been
imaged on several of the fifty to
sixty radiographs routinely
obtained by Cole during a gas-
trointestinal tract examination. He
was well known for his meticu-
losous attention to detail, and this
was reflected in his astounding
diagnostic accuracy. (Reprinted
from Bruwer, Classic Descriptions
in Roentgenology, with permis-
sion from Charles C. Thomas, Pub.)

Fig. 8.13 Russell Carman (1875–
1926) became one of the best
known American radiologists fol-
lowing his tenure at the Mayo
Clinic where, in a four-year period,
he performed more than fifty-thou-
sand gastrointestinal tract examina-
tions. Carmen was an advocate of
fluoroscopic technique. (Courtesy
of the Center for the American
History of Radiology, Reston, Va.)
jection of contrast near the lesser curvature of the stomach in this patient, who at autopsy was found to have an ulcer at this site. Reiche thus proposed both indirect (peristaltic abnormality) and direct (contrast projection) findings for the identification of gastric ulcers.34,35

Another radiology pioneer, Martin Haudek of Austria, an advocate of the Holzknecht fluoroscopic technique, also began to see the value of combining methods. A surgeon confronted him, saying, “Haudek, you have been wrong on two counts. You saw an hourglass stomach [an indirect finding of gastric ulcer] and there was none, [and] you missed an ulcer which certainly was there.”56 Haudek reevaluated the radiographs and discovered a projection of contrast at the ulcer site. He subsequently collected a large number of cases with the same finding and published his results describing the ulcer niche in 1910.37,38 Thus, ironically, one of the classic radiographic findings of ulcer disease was recorded by an ardent proponent of the fluoroscopic school of diagnosis.

In the two decades following the discovery of X-rays, advances in technology and contrast media led to increasingly better examinations. The Snook interrupterless transformer, developed in 1907 by Homer Snook of Philadelphia, permitted “serial roentgenography” by 1909. This latter technique, proposed by Cole, used short X-ray exposures to make up to twelve radiographic plates in one phase of the respiratory cycle.39,40 In 1908 Cole introduced the tilt table and used it extensively in his examination of the gastrointestinal tract.41

The development of the hot-cathode X-ray tube by William Coolidge of the General Electric Research Laboratory in Schenectady in 1913 was invaluable in furthering not only gastrointestinal tract radiology but radiology in general. This new tube, a reliable and powerful source of X-rays, permitted specific radiologic techniques for different body regions as well as more consistent and comparable results.42 In combination with growing clinical experience, these technological advances ultimately ended the debate between fluoroscopists and radiographers. The British pioneer of alimentary tract radiology, Alfred Barclay, wrote: “...it is interesting to note the gradual evolution of the two schools of the early days of gastrointestinal work. We have seen how both schools have slowly converged, till at the present time the technique...[for gastrointestinal studies throughout the world is] a combination of screen and plate methods.”43

The use of bismuth in its various formulations for upper gastrointestinal tract examination began to be questioned as reports of toxicity were noted. In 1908 at the annual ARRS meeting, Sinclair Tousey of New York reported a fatal case of bismuth poisoning, presumably caused by the conversion of bismuth subnitrate into bismuth subnitrite.44 This conversion to a toxic substance had been reported a year earlier by A. Bohme in Germany.45 In fact, Joseph Sailer of Philadelphia had reported untoward effects of bismuth subnitrate as early as 1906.46 Investigators such as the German Carl Kaestle recommended the use of bismuth subcarbonate instead of bismuth subnitrite.47

Others began a search for a better contrast agent, and by about 1910 some radiologists had settled on barium sulfate as a suitable substitute. James Case of Battle Creek, Michigan, wrote:

A number of European roentgen workers have introduced the use of barium sulfate, not only for bowel injection but also as a substitute for bismuth in the “ordinary Rieder chest meal”. [Gottwald] Schwartz of Vienna has given the barium by mouth for over a year without any untoward effects. [Alban] Kochler, of Wiesbaden, has used the barium sulfate without any untoward results; and was able to report only two cases in which the barium has proved harmful. In each of these cases a soluble salt of barium was used in place of the insoluble barium sulfate by physicians not accustomed to routine X-ray examinations...Barium is many times cheaper than bismuth, which makes its use certainly desirable.”48
Walter Cannon, who is mainly associated with examining esophageal and gastric motility, also deserves credit for the use of barium in examining the gastrointestinal tract. In 1896 he reported "barium and bismuth were selected from among the heavy salts and barium sulfate and bismuth subnitrate were chosen as salts which, because practically insoluble, would serve our purposes. Since bismuth subnitrate was a pharmacopoeial preparation we determined first to use that."

Cannon also showed the usefulness of barium and, in 1904, several years before its introduction in Europe, reported on its use in the American Journal of Physiology.

World War I caused a reduced supply of bismuth in the United States and may have contributed to the conversion of American radiologists to barium. Credit for popularizing the use of barium, however, goes to Carl Bachem (Fig. 8.14) and Hans Günther of Bonn, Germany, who, in their landmark article of 1910, addressed the toxicity and expense of bismuth. They described animal experiments with barium and reported on their study with patients using barium in small doses administered orally. Ultimately, they administered up to 150 grains of barium in the form of a chocolate drink that proved easy to ingest, nontoxic, and inexpensive, thus meeting all of the requirements for a successful contrast medium.

Double-contrast studies of the stomach were described as early as 1911 in a paper by Gyula von Elisch of Hungary. He introduced into the stomach a tube through which he gave small amounts of bismuth as a positive contrast agent. He then injected air, allowing the bismuth to coat the mucosal lining of the stomach (Fig. 8.15). He initially did this to overcome objections that bismuth by bulk alone would change the physiology of the stomach. He concluded his paper by stating that the hook shape of the stomach was a characteristic appearance and that the bismuth meal did not alter the shape of the stomach or cause the picture to be distorted. He also believed that his method was capable of providing finer detail in cases of tumor and stenosis and would thus be useful in the diagnosis of these diseases.

Years later, in 1937, Robert Arons and Sidney Mesirow at Michael Reese Hospital in Chicago demonstrated gastric mucosal detail using barium and Seidlitz powder as a gas-producing agent. In the 1960s and 1970s Japanese researchers such as Hikoo Shirakabe refined and popularized this type of examination. Igor Laufner was instrumental in promoting
Fig. 8.16 George Haenische (1874–1952) of Germany first suggested that contrast enemas be performed under fluoroscopic guidance, was one of the first to describe the findings of colon carcinoma and ultimately led the movement away from oral administration of contrast to study the large bowel. (Courtesy of the Center for the American History of Radiology.)

double-contrast studies of the upper gastrointestinal tract in the United States.\textsuperscript{55}

While most early gastrointestinal radiographers were preoccupied with the stomach, improvement in equipment soon permitted examination of both small and large intestines. In 1901 Francis Williams had written with characteristic caution that the large bowel should not be examined with contrast because “the risk of putting into the large intestine such a weight...might be dangerous to its integrity.”\textsuperscript{56} However, Rieder must have had some success with this technique, because he wrote that “the topographical relationship of the large intestine can be studied more exactly by means of enemas containing bismuth-liquid mixtures.”\textsuperscript{57} In the same year that Rieder wrote of his success, Schüle also published results of large bowel contrast studies.\textsuperscript{58}

At the ARRS meeting in 1910 George Haenische of Germany (Fig. 8.16) described the findings of colon carcinoma as seen by contrast enema, stating that “when you watch it (bismuth) go in with a fluoroscope and you see it stop and then you see it go on again in a thin finger-like process and widen out, something is wrong.”\textsuperscript{59} He was also the first to suggest that the contrast enema be introduced under fluoroscopic guidance before radiographic plates were made.\textsuperscript{60} In a much later article Haenische concentrated on diagnoses of benign and malignant obstructions of the bowel, and argued that trying to use oral administration of contrast to study the small and large bowel was inadequate and that only the contrast enema was suitable.\textsuperscript{61}

In 1923 A.W. Fischer of Frankfurt described a double-contrast large bowel study in which he first filled the intestine with barium sulfate and subsequently insufflated with air. Using a fluoroscopic screen, he turned the patient several times around the long axis of the body and then radiographed the large bowel. He concluded in his last paragraph that “the combination method which I have just described constitutes, in my opinion, an important addition....It may be of special value in improving our ability to make early diagnosis of carcinoma of the large intestine.”\textsuperscript{62}

Examinations of the duodenum were difficult but could be performed well by experienced radiologists such as Cole and Carman (Fig. 8.17). Small bowel examination remained problematic because of peristalsis and overlapping loops of bowel. Nevertheless, Gottwald Schwartz of Vienna and James T. Case of Michigan each published findings of small bowel abnormalities in those early years.\textsuperscript{63,64} Enteroclysis was initially described (but not identified as
such) by Gilberto Pesguera in Mt. McGregor, New York, in 1929. He wrote that “A duodenal tube is swallowed by the patient...[A] mixture of barium, acacia and water is then permitted to flow slowly...The entire small bowel can be studied in less than one-half hour.” He cited A. Abrams and G. O. Jarvis as well as Jacob Buckstein as others who had also used duodenal tubes to study the gallbladder and duodenum (Fig. 8.18).65

The term enteroclysis was first used in 1939 by Jacob Gershon-Cohen and Harry Shay of Philadelphia, who discussed the use of double contrast to check findings in single-contrast examinations. They said, “It is hoped that this technique will come to have a far wider application and will prove useful in the diagnosis of...[various conditions] of the small intestine.”66 The technique was revived many years later in 1982 by J. L. Sellink and Roscoe Miller and is commonly performed today.67

THE GALLBLADDER AND BILIARY SYSTEM

A limited role for radiography in the detection of gallstones was established not long after X rays were discovered. The Lancet of 1 February 1896 reported that “professor Neusser [of Vienna]...obtained photographs showing gallstones in situ...taken by means of what professor Roentgen has called the X rays.”68,69 By 1897 French investigators Gilbert, Fournier, and Paul Oudin demonstrated the radiographic differences between cholesterol and pigmented gallstones.70 Others were able to successfully demonstrate gallstones by radiography but not in the abdomen prior to surgery.71 In 1898 A. Buxbaum in Karlsbad was finally able to radiograph gallstones in a human.72 The success of imaging gallstones was mixed, however. Carl Beck of New York was successful in only two of nineteen cases, and Francis Williams, while publishing an example of multifaceted stones in his classic text, wrote that in vivo detection of gallstones would be difficult (Fig. 8.19).73,74

Poor radiographic technique was responsible for some of the problems in gallstone detection, but inexperience added to the difficulty, as evidenced by Cole’s ability to retrospectively detect gallstones where they had been over-
looked on earlier images. As experience grew, new radiographic signs of gallbladder disease were discovered, leading in some cases to significant success in radiographic detection of gallbladder pathology. J. W. Churchman described milk of calcium bile in 1917. Ariel George and Ralph Leonard, in their book *The Pathological Gallbladder* (1922), further added to knowledge of gallbladder radiology by describing signs such as laminated stones, ring densities in stones, and “negative” stones, as well as noting distortion of the stomach or duodenum as probable indirect evidence of gallbladder pathology (Fig. 8.20). They were successful in excluding or diagnosing gallbladder disease in 114 of 128 patients on whom surgery was performed.

The advent of cholecystography led to a second and advanced phase in the diagnosis of gallbladder disease. The initial observation by John Abel and Leonard Rowntree of Johns Hopkins University in 1909 that a derivative of phenolphthalein was “excreted in the conjugated form in the bile” (and that this agent and other derivatives had low toxicity when administered in dogs) stimulated a search for an acceptable cholecystographic contrast medium for humans. In 1921 Peyton Rous and Philip McMaster of the Rockefeller Institute made an important observation that the gallbladder, by absorbing water, could concentrate bile eight to ten times. This discovery, along with the demonstration by Earl Osborne in 1923 that the urinary tract could be imaged radiographically after the intravenous injection of sodium iodid, established the necessary background for the emergence of cholecystography.

Not long thereafter, Warren Cole (not related to L. G. Cole), a second-year medical student at the Washington School of Medicine in St. Louis, at the suggestion of Evarts Graham, chair of surgery, began work on a project designed to image the gallbladder following intravenous injection of halo-genated phenolphthaleins. These experiments initially used rabbits and dogs as subjects and were unsuccessful, as the gallbladders were not demonstrated and some animals suffered toxicity. But in late 1923 Cole asked Graham to look at a dense gallbladder outline on one of the films of an experimental animal (Fig. 8.21). They both thought that at that time, Cole recounted, that they “had found the traditional pot of gold at the end of the rainbow.” However, for several days afterwards, they could not reproduce the gallbladder images in dogs using the same bromide compound. In discussion
with the dogs’ handlers Cole discovered that the morning meals had not been omitted. He then conducted his experiments again, after having the dogs fast. In a high proportion of cases the gallbladder was successfully imaged, and human experimentation with calcium tetrabromophenolthalein as the first imaging agent was begun. The work of Cole and Graham heralded the beginning of successful cholecystography.\(^2\) In his Carman lecture delivered at the forty-sixth annual meeting of the Radiological Society of North America of 1960, Warren Cole related that not long after their successful discovery, he and Graham met Rowntree, expressed their appreciation for his prior invaluable work, and asked why he and his group had not carried their experiments further. Rowntree responded that he had been perhaps “too close to the forest to see the trees.”\(^3\)

In further work Cole and Graham discovered other iodinated compounds which produced less vomiting in their patients.\(^4\) They also suggested that “it would be desirable to have a (gallbladder imaging) substance that could be given by mouth.”\(^5\) Subsequently, Merrill Sosman at Massachusetts General Hospital made an important discovery. He observed the reappearance of a gallbladder shadow in a patient in whom he had done an intravenous cholecystogram three days earlier. He theorized that some of the contrast material from the initial study had entered the gastrointestinal tract from the gallbladder and had been absorbed from the small bowel and recycled into the biliary system.\(^6\) After dog trials, oral administration of an iodinated phenolphtalein in humans led in 1925 to successful oral cholecystography by Lester Whitaker at the Peter Bent Brigham Hospital in Boston and simultaneously by Thomas Menees in Grand Rapids, Michigan (Fig. 8.22).\(^7\) As with the earlier discovery of X rays, the announcement of intravenous and oral cholecystography was not hailed universally. Cole related that during a presentation of his work on intravenous cholecystography “a member of the audience arose in discussion to denounce cholecystography as being worthless, adding that anyone giving the medium by vein ‘should be put in jail’.”\(^8\)

In 1915 Carman inadvertently performed the first cholangiogram when barium entered the intrahepatic biliary

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\(^2\) Fig. 8.21 Warren Cole as a medical student began work which ultimately led to human experimentation with calcium tetrabromophenolthalein as the first gallbladder imaging agent. In collaboration with Graham, he established the possibility of intravenous cholecystography. This image of a dog gallbladder was obtained twenty-four hours after IV injection of 1.5 gram of tetrabromophenolthalein. (Reprinted from Bruwer, Classic Descriptions in Roentgenology, with permission from Charles C. Thomas, Pub.)

\(^3\) Fig. 8.22 The oral cholecystogram became the primary modality for gallbladder imaging following successful human trials initiated by Whitaker and Menees. This example by Whitaker was shown following a talk by Menees at the Radiological Society of North America meeting in 1925. It demonstrates a normal gallbladder sixteen hours after administration of contrast and a contracted gallbladder one hour and forty minutes after a meal consisting of egg yolks and cream. (Reprinted from Bruwer, Classic Descriptions in Roentgenology, with permission from Charles C. Thomas, Pub.)
system through a perforated duodenum during an upper gastrointestinal tract study. In 1922 Charles Tenney and S. H. Patterson of Toledo, Ohio, intentionally injected bismuth into a biliary fistula and demonstrated the biliary ducts. They cited a related case performed in 1921 by Fort Worth, Texas, investigators Frank Beale and Samuel Jagoda. Others had similar success using barium and Lipiodol. Gaston Cotte of Lyon in 1925 may have been the first to suggest injecting contrast material through a T-tube and the possibility of intraoperative biliary tract radiography. In 1931 Pablo Mirizzi and Carlos Losada in Argentina furthered Cotte's original idea and published their work on operative cholangiography. P. Huard and Do-Xuan-Hop of Indochina in 1937 first reported percutaneous needle injection of contrast material into the intrahepatic biliary system.

LIVER, SPLEEN, AND PANCREAS

Soon after the discovery of X rays, plain radiographic imaging of the solid organs of the abdomen was suggested by William Morton of New York, who demonstrated the outline of the liver in an infant. Francis Williams recognized that the liver, spleen, and occasionally the pancreas could be seen when outlined by gas in the stomach, small bowel, and colon. In fact, Williams and others introduced air into the hollow visci in order to outline these structures. This indirect imaging was also performed with the technique of diagnostic pneumoperitoneum (air injected into the peritoneal cavity to provide contrast for the intra-abdominal viscera and organs). In 1913 and 1914 Eugen Weber of Kiev and Alexander Lorey of Germany further explored the use of diagnostic pneumoperitoneum for this purpose.

Direct contrast imaging of the solid intra-abdominal organs was first accomplished in the spleen. Mitsutomo Oka in Japan was investigating the toxicity of colloidal thorium dioxide in rats when he observed splenic opacification (Fig. 8.23). This agent had been used in various experiments in the early 1900s and was extensively applied in cerebral angiography. The accidental observation of splenic opacification with thorium dioxide led to its use in imaging both liver and spleen, because it provided excellent contrast and had no obvious side effects. By 1947 the first human to suffer cancer attributed to the use of thorium was reported. Other reports of cancer of the liver, bile duct, spleen, and bone marrow ultimately led researchers to stop using thorium for imaging.

Radioisotope imaging of intra-abdominal structures was portended by the distribution of phosphorus in various organs including the liver, as noted by George de Hevesey and D. Chiewitz in Copenhagen. Successful imaging of the thyroid with iodine-131 and the development of the scintillation scan-
ner served to advance the possibility of imaging liver, spleen, and pancreas with appropriate radioisotope combinations. Iodine-labeled rose Bengal and radioactive gold were established as radionuclide imaging agents for the liver in the 1950s. \[107,108\] Technetium Tc 99m-labeled sulfur colloid and the development of the Anger camera further advanced the use of radioisotope studies of the liver and spleen. \[109\]

Another technique for direct imaging of the intra-abdominal solid organs was angiography. Although Hascheck and Lindenthal, within a month of the discovery of X rays, had produced an angiogram of the hand in a cadaver-specimen, the search for a safe contrast agent for \textit{in vivo} use extended over many years. An overlooked effort by Carlos Heuser of Argentina had produced a successful arm venogram in 1919 using intravenous potassium iodide injections. \[110\] It was not until after the use of iodinated contrast materials for intravenous pyelography by Osborne and Rowntree in 1921 that the potential use of this substance for angiography was recognized. In 1923 J. Berberich and S. Hirsch of Frankfurt, and in 1924 Barney Brooks, Department of Surgery of Washington University in St. Louis, using different halogenated contrast agents, successfully performed peripheral angiography. \[111,112\] Pioneers in the development of portal venography included Jean-Athanase Sicard and Jacques Forestier of Paris, who directly injected Lipiodol into the portal veins at laparotomy, and Alan Whipple of Columbia-Presbyterian Medical Center, who in 1945 first performed intra-operative portal venography. \[113,114\] Subsequent developments included hepatic vein angiography and contrast angiography performed through catheters placed in the celiac and common hepatic arteries. \[115,116\] With the introduction in 1953 of the Seldinger technique for percutaneous catheter placement in angiography, examinations of the liver, spleen, and pancreas became common. \[117\]

**INNOVATIVE METHODS IN ABDOMINAL IMAGING**

Douglas Howry of the University of Colorado first described ultrasonography for the delineation of soft tissue structures in 1952, and he expanded on this topic in several articles over the next few years (Fig. 8.24). \[118,119\] John Wild and John Reid, working at the Naval Air Station at Wold-Chamberlain Field in Minneapolis, and Ian Donald of Glasgow also helped establish ultrasound as a viable diagnostic technique. \[120,121\] The use of ultrasound for intra-abdominal pathology had its trials with A-mode ultrasound in the late 1960s, but was significantly advanced by an article published by Joseph Holmes and Howry in Denver in 1963. \[122\] In 1970 Atis Freimanis and W. M. Asher at Ohio State University published results including “echographic signs” of normal and abnormal states in more than six hundred abdominal

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Fig. 8.24 Douglas Howry was one of the first investigators to realize the value of ultrasonography in delineating soft tissue structures. His work ultimately led to the sonographic breakthrough in defining solid organs of the abdomen. This study of foreign objects in a liver block performed in 1952 helped to establish the possibility of using ultrasound for intra-abdominal solid organ diagnosis. (Courtesy of the historical collections of the American Institute for Ultrasound in Medicine)
ultrasound examinations, thus popularizing the use of clinical ultrasound for this purpose. Other ultrasonographers instrumental in the early development of this technique were Roy Filby, Uve Hublitz, George Leopold, and Bruce Doust, all of the United States.\textsuperscript{124,126,126,127}

One of the most striking advances in imaging the abdomen was the development of CT. Several contributors to this development in the fields of mathematics and engineering have been recognized, but it was clearly Godfrey Hounsfield working in Middlesex, England, who deserves credit for bringing this technique into wide clinical use. In the late 1960s he began to investigate "the possibility that a computer might be able to reconstruct a picture from sets of very accurate measurements taken through the body at a multitude of different angles."\textsuperscript{128} The first results of his work were presented at the 1972 Congress of the British Institute of Radiology and were published in 1973.\textsuperscript{129,130} Shortly thereafter, R. S. Ledley and a group at Georgetown University reported their initial experience with whole-body scanning.\textsuperscript{131} Other early investigators of abdominal pathology were Ralph Alfdi, Dieter Schellinger, Patrick Sheedy, Robert Stanley, and Mel Korobkin.\textsuperscript{132,133,134,135,136}

MR imaging has been the outgrowth of nuclear MR as described by Felix Bloch of Stanford University and Edward Purcell of Harvard University in 1946.\textsuperscript{137,138} Raymond Damadian described the use of MR to differentiate normal from neoplastic tissue in the early 1970s, but Paul Lauterbur is credited with pioneering the use of MR for imaging.\textsuperscript{139} He produced his first MR image, two water-filled capillary tubes, in 1973.\textsuperscript{140} Images of live animals were published in 1974.\textsuperscript{141} In 1977 Damadian performed the first whole body MR scan.\textsuperscript{142} Since that time thousands of articles and books demonstrating the use of MR imaging of the abdomen have been published.

The term interventional radiology was coined by Alexander Margulis of the University of California at San Francisco in 1967 to describe the "growing body of manipulative procedures performed by a physician skillful in radiologic techniques and experienced in clinical problems."\textsuperscript{143} The range of procedures capable of being performed in both the hollow visci and solid organs of the abdomen has been astounding. The advancement is related to both technical innovations and the dedication, insight, and skill of many radiologists. In the early 1970s H. H. Holm of Denmark and others used ultrasound guidance to perform a variety of percutaneous punctures.\textsuperscript{144} This led to subsequent large series of abdominal abscess drainages, such as those reported by Edward Smith in 1974.\textsuperscript{145} The use of CT for biopsy localization and abscess drainage was described by John Haaga of the Cleveland Clinic in the late 1970s.\textsuperscript{146,147} Percutaneous techniques continued to enjoy wide acceptance in the late 1970s and through the early 1980s.\textsuperscript{148,149} Ultimately achieving status as a mainstay in most radiology practices.\textsuperscript{148,149}

Within the biliary system, percutaneous removal of biliary calculi was accomplished by Joachim Burhenne in San Francisco and reported in 1973.\textsuperscript{150} According to Burhenne, nonvascular interventional radiology of the abdomen actually began in 1921, when Hans Burkhardt and Walter Müller of Germany laid the groundwork by performing percutaneous injections of a radiographically opaque substance into the gallbladders of cadavers in order to visualize gallstones and bile ducts.\textsuperscript{151,152} Burhenne cites the percutaneous transhepatic external bile drainage technique of Jorge Remolar of Argentina as an early example and model for subsequent interventional application, and credits Juri Kaufe of Lund, Sweden, as one of the first to perform percutaneous biliary drainage by catheter prior to surgery.\textsuperscript{153,154} Katsutaka Mori of Kumamoto, Japan, and Ernest Ring of the University of Pennsylvania were instrumental in establishing internal biliary drainage into the gastrointestinal tract, and William Molnar at Ohio State University, through percutaneous transhepatic catheter insertion, revealed an
Interventional method to relieve jaundice,\(^{155,156,157}\). Percutaneous insertions of permanent biliary prostheses were performed first by Raul Pereiras at the University of Miami for relief of malignant obstructive jaundice in 1978.\(^{158}\)

Interventional procedures in the hollow visci of the abdomen also have gained popularity. Both percutaneous placement of feeding tubes and balloon dilatation of esophageal and gastrointestinal tract strictures have been topics of numerous articles over the last decade. Among the pioneers in these techniques are Gordon McLean, John Wills, Chia-Sing Ho, and Richard London.\(^{159,160,161,162,163}\)

**SUMMARY**

In its first hundred years radiology of the abdomen has improved with each technological and biochemical advancement. Contrast enhancement of the gastrointestinal tract revealed not only anatomy but also showed the promise of physiological assessment as well. Originally used for morphologic demonstration, the newer technological imaging modalities such as nuclear medicine, ultrasound, CT, and MR imaging have more recently found utility in the functional evaluation of solid organs. Innovative techniques such as single photon emission computed tomography, positron emission tomography, Doppler ultrasound, and MR angiography are but a few of the more recent techniques finding application in the diagnosis of intra-abdominal diseases. Current and undoubtedly future work applying this technology to cellular anatomic and physiological imaging may ultimately lead to an improved understanding of diseases such as cancer. Refined treatment options and improved methods of disease prevention may then be attained.

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**REFERENCES:**

1. My grandfather, Samuel Goodman, wrote the following poem for me when I graduated from elementary school. While he meant this as a lesson for me, a lesson I have sometimes taken to heart, he was certainly reflective on the efforts of those pioneers mentioned in this chapter.

   The heights by great men reached and kept
   were not attained by sudden flight
   but they, while other companions slept,
   were boiling upward in the night.


15 Bruwer, p. 1810.
19 Ibid., p. 538.
20 Ibid., p. 539.
21 Ibid., p. 372.
25 Bruwer, p. 1783.
26 Hulst, p. 1-16.
30 Brecher and Brecher, p. 126.
33 Brecher and Brecher, pp. 134-135.
48 Brecher and Brecher, pp. 124-125.
49 Ibid.
50 Ibid.


98 Brecher and Brecher, p. 62.


100 Buckstein, p. 605.


104 Buckstein, p. 604.


106 Brecher and Brecher, p. 383.


110 Brecher and Brecher, p. 230.


