At the outset of the Röntgen era, X-ray imaging of the chest was a crude experimental technology of uncertain clinical utility. By the end of the twentieth century it had become a sophisticated art and science essential to modern medicine. To document this extraordinary evolution, we have attempted to distill and describe the most seminal of the many discoveries and inventions that appeared during the century. The discussion is divided into four parts: (1) the pioneering period, 1896-1915; (2) the period from World War I through World War II, 1916-1945; (3) the post-World War II period, 1946-1965; and (4) the modern period, 1965-1995.

Most of the basic technical and diagnostic precepts of clinical chest fluoroscopy were fully established during the first twelve months after Röntgen's discovery. During the second period marked improvement was made in the technology of halide film emulsions, intensifying screens, and X-ray generation, leading to the replacement of fluoroscopy by radiography as the dominant mode of clinical chest imaging. Other new techniques in the period included bronchography, body section imaging, percutaneous chest biopsy, and pulmonary angiography.

During the third period chest diagnosis advanced, and technology was further refined. Film-screen radiography greatly improved as a result of high-kilovoltage technique, phototiming, scatter-absorbing grids, and automatic film processing.

The fourth period has seen the development of radically new radiological techniques: interventional manipulations, positron emission tomography (PET), ultrasonography, computed tomography (CT), magnetic resonance (MR) imaging, and digital radiography, as well as new imaging correlates for wholly new categories of pulmonary diseases based on the acquired immune deficiency syndrome (AIDS), drug-induced chest disease, and the adult respiratory distress syndrome (ARDS). Radiologists, nonradiologists, physicians, physicists, and engineers together were responsible for these advances.

**The Pioneering Period (1896–1915)**

Numerous fundamental discoveries and inventions in chest imaging originated in the first two decades of the X-ray era. Pioneers invented many new
Three conditions set the stage for rapid and widespread use of chest imaging in 1896. First, long-distance telegraphy provided almost immediate news of Röntgen's discovery throughout the industrialized world. Within a month of the discovery, editorials appeared in leading medical journals in Europe and America suggesting the potential medical utility of X rays. Second, a large number of physicists and engineers in Europe and North America had practical experience studying the emanations of Hittorf, Crookes, and Lenard tubes from which X rays could be generated. Finally, there was a strong medical imperative to pursue X-ray imaging as a new method for identifying the early stages of life-threatening respiratory infections. As a result, the pioneering stages of X-ray imaging of the chest tended to develop in parallel in countries throughout the industrialized world.

The leadership of chest radiology rested with the trio of Francis H. Williams of Boston, Guido Holzknecht of Vienna, and Antoine Béclère of Paris (Figs. 7.1a, b, and c). Each of these pioneers greatly influenced the development of the new field and was responsible for numerous devices necessary for clinical chest imaging, catalogued imaging findings of health and disease, validated observations against the existing standard of physical diagnosis, and established principles for clinical chest imaging. To the modern radiologist, these developments are an intriguing combination of technical crudity, detailed observation, and analytical elegance.
published discoveries on chest diagnosis. Although it is not certain that any of these great pioneers would have identified themselves as radiologists at that time, they were certainly the first great chest radiologists.

Within five years of Röntgen’s discovery, at least six major texts dealing with X-ray diagnosis of chest disease had been published. In 1899 Bécère wrote two small texts devoted solely to X-ray imaging of chest disease. In 1901 Williams produced a comprehensive text, half of which was devoted to the chest, with 658 pages and 391 figures. The book was immensely popular, selling out the first printing within three months. Two great German-language texts dealing with chest diagnosis also appeared in 1901, one by Holzknecht and the other by H. Ziemssen and H. Reider. Other significant texts dealing with chest radiology were published later during the pioneer period.

In this early period chest radiology was taught and learned as a part of general diagnosis and radiotherapy. Prospective radiologists were either self-taught or trained by experienced preceptors. Institutional departments of radiology were in their infancy at this time. One of the first teaching hospital departments of radiology in America was founded by Williams in 1896, when the trustees of the Boston City Hospital provided him with an X-ray examining room. Like other pioneers, Williams almost immediately began teaching X-ray imaging to medical students. He was a mentor to then medical student and later noted physiologist Walter B. Cannon, who used fluoroscopy to carry out his monumental studies on gastric digestion.

Technical Advances in Thoracic Imaging: Fluoroscopy

Because the early technology of X-ray generation was both rudimentary and unpredictable, the pioneers found fluoroscopy to be the most practical method available for X-ray imaging of the chest. Fluoroscopy had several advantages over radiography during this period. It was simpler, more immediate, less expensive, more dependable, and more readily available. The additional fluoroscopic capacity for demonstration of dynamic events led to many diagnostic breakthroughs and functional insights and helped to reinforce the authenticity of many early clinical discoveries. The one hundred volumes of fluoroscopic drawings accumulated by Francis Williams by the autumn of 1896 graphically illustrate just how rapidly the technique had become an everyday diagnostic tool. Antoine Bécère and other pioneers, whose diagnoses depended on the faint glow of the fluoroscopic screen, promptly recognized the importance of understanding the physiology of vision at low light levels.

Correlations with physical diagnosis

One of the first tasks of the early pioneers was to correlate chest fluoroscopy and physical diagnosis. By the end of 1896 the pioneers found that fluoroscopy appropriately mirrored the findings of physical diagnosis in pneumonia, and when they noted a discrepancy, it appeared that fluoroscopy was superior. Many French pioneers, including Bécère, C. Bouchard, and J.A. Bergonié, validated the fluoroscopic findings of pneumonia against percussion and auscultation. Bouchard found that as the percussed height of pleural fluid decreased, its fluoroscopic opacity diminished from above downwards. He also concluded that a residual apical lung opacity after clearing of tuberculous effusion was most likely a persistent tubercular focus. In Vienna J. Wasserman proved by autopsy findings that fluoroscopy could identify cavitary tuberculosis when physical diagnosis could not.

One of the most interesting pioneer inventions of 1896 was Francis Williams’s “see-hear device” which facilitated correlative studies of auscultation and fluoroscopy. It combined the elements of a stethoscope and fluoroscope in a vulcanite box placed over the fluoroscopic screen. Williams found that fluoroscopy was more dependable than
auscultation and percussion in the detection of consolidation, pleural effusion, and mediastinal displacement. He reported that in massive pleural effusion, percussion tended to underestimate mediastinal shift.23

The motion of the diaphragm was poorly understood before the Röntgen era. In the spring of 1896 W. J. Morton of New York and Francis Williams made independent fluoroscopic observations of the moving ribs, diaphragm, and beating heart. Williams found that the distance between the lowest and highest levels of the diaphragm was about 7 centimeters (cm.) during a vital capacity maneuver, 1.6 (cm.) during tidal breathing, and 2.1 (cm.) during a maximum exhalation from end-tidal expiration to residual volume (i.e., the expiratory reserve volume).24 Hugh Walsham, F. Gardiner, and many others found that, contrary to the prevalent view among physiologists that the diaphragm contracted latero-medially toward the central tendon during inspiration, the diaphragm descended and ascended during respiration.25,26

The fluoroscopic densitometer

Early roentgen workers quickly recognized that the lungs became much more luminous to the X-ray beam after a deep inspiration. Francis Williams developed a simple but elegant aluminum densitometer to quantitate changes in lung tissue density during respiration. Its two water-filled chambers could be placed in the field alongside the chest, and the level in a measurement chamber was adjusted to correspond to the degree of fluoroscopic blackening of the chest by sucking or blowing into connected tubing. Williams documented that the lungs varied in luminosity during breathing and that the increased luminance corresponded with inspiratory breath sounds. He found that a fully inflated excised lung of 7.2 (cm.) thickness had a tissue density equal to 6 millimeters of water (i.e., 8.3 percent of pure water).27 Williams's crude calculation of lung density compares remarkably well with values that can be derived from modern data for lung volume, pulmonary tissue volume, and pulmonary blood volume.

Orthodiaphraphy

For the pioneers orthodiaphraphy was an essential means of creating accurate fluoroscopic outlines of thoracic anatomy in the absence of dependable radiographic technique. It provided a "hard copy" for records and consultation. The technique was based on a highly-collimated, nondivergent X-ray beam that could be used to accurately position the contours of anatomic chest boundaries for tracing onto sheets of cloth or paper positioned over the fluoroscopic screen. Among the many early practitioners of orthodiaphraphy were Williams, F. Moritz of Germany, Holzknecht, and Bergonie.28

Stereoscopy

Within a few years of Röntgen's discovery, Elihu Thomson in the United States, James Mackenzie Davidson (Fig. 7.2) in Britain, and Bécère in France independently laid the groundwork for stereoscopy by applying known photographic principles to X-ray imaging.29 Two slightly different image perspectives were created for each eye to provide a depth dimension.30 Just after the turn of the century, Eugene W. Caldwell

Fig. 7.2 James Mackenzie Davidson (1856–1919).
(Courtesy of the Center for the American History of Radiology, Reston, Va.)
developed an ingenious dual-focus tube coupled to a fluoroscope with a rapidly rotating shutter to obtain stereoscopic images. During the pioneering period chest stereoscopy was used primarily to localize foreign bodies.

**Technical Advances in Thoracic Imaging: Radiography**

Although fluoroscopy truly dominated clinical chest imaging in the early period, the pioneers periodically used chest radiography to document clinical findings, especially in the mediastinum, where motion degradation of the image was less obvious. Indeed, a few pioneers, like Hugh Walshe of Britain, noted that calcified intrathoracic lymph nodes were occasionally detected with radiography when they were not apparent during fluoroscopy.31

For routine clinical examination of the lungs, radiographic lung detail was inadequate. Because of the low power output of X-ray machines, the limited tolerance of gas-filled X-ray tubes, and the insensitivity of halide emulsions, the exposures required for chest radiography were excessively long. The maximum output of the earliest hand-operated X-ray generator was no more than 1 million volt-seconds (about 1/500th of what is commonly employed for chest radiography today). At St. Thomas's Hospital in London a thirty-minute exposure was required to image the chest of a ten-year-old child.32 To obtain a posteroanterior view of the chest, the X-ray tube and collimator were placed beneath a radiolucent stretcher, and a light-tight film envelope was placed on the patient's anterior chest wall. Weights were sometimes attached to the glass plate resting on the thorax to reduce motion of the chest wall during X-ray exposure.33

Radiographic technique was much too cumbersome, time consuming, inconvenient, unreliable, and costly to warrant its routine use. Fragile wet glass plates of silver-collodion emulsion had to be prepared just before exposure and developed immediately after exposure. Even bromide paper emulsions, which permitted the most rapid processing time, required at least an hour before a dry chest image negative could be viewed. Double or triple loading of film emulsions was commonly used as a hedge against inadvertent over- or underexposure due to the variable thickness of halide emulsions. When a radiographic negative was finally obtained, it was generally viewed in a frame placed in front of a window or in front of an incandescent bulb with a light diffuser.34,35

Although most of the early milestones in chest diagnosis were based on fluoroscopic diagnosis, radiography also made contributions, especially to surgical imaging needs such as localization of foreign bodies. Among the earliest surgical pioneers to use chest radiography was John Macintyre (Fig. 7.3) of Glasgow, who located a coin stuck in the esophagus.36

**Intensifying screens**

The development of efficient calcium tungstate intensifying screens was an important step toward shorter exposures for chest radiography. Ziemssen and Reider of Germany gained extensive early clinical experience with high-quality “instantaneous” (i.e., less than one-second exposure time) chest radiographs.38 G. E. Pfahl of Philadelphia reportedly abandoned fluoroscopy for radiography in 1905, when most pioneers still found that the crude intensi-
fying screens degraded lung detail. It was not until after World War I that high-quality chest radiography became widely available.\(^\text{39}\) It is interesting that intensifying screens provoked an early controversy over the most appropriate kilovoltage for chest radiography. On the one side were fluoroscopists, like Francis Williams, who only occasionally used chest radiography and preferred low kilovoltage for increased contrast between lung and bone for nonscreen technique.\(^\text{40}\) On the other side were the enthusiasts of radiography, like Ziemssen and Reider, who preferred intensifying screens and high kilovoltage to shorten exposure time.\(^\text{41}\)

**Photofluorography**

Some pioneers, such as Hugh Walsham and Eugene Caldwell, thought that camera images could document more static information than the fluoroscopic observer could absorb instantaneously.\(^\text{42}\) In 1936 the impracticality of large glass plates led J. M. Bleyer in the United States and Macintyre in Glasgow to develop camera photography of the fluorescent screen as an alternative to radiography for documenting fluoroscopy of the chest.\(^\text{43,44}\) These pioneering experiments set the stage for future large-scale photofluorographic screening of tuberculosis.\(^\text{45}\)

**Diagnostic Breakthroughs in Thoracic Imaging**

Clinical radiology advanced along two broad fronts during the pioneering period. First, "surgical" imaging, which focused on the localization of foreign bodies, instruments, and calculi; and second, medical imaging, with a broader scope in identifying the characteristics of diseases, such as tuberculosis and congestive heart failure. Medical imaging provided the major impetus and foundation for the development of chest imaging during this period.

**Bronchial obstruction, lung abscess, and cancer**

In 1896 Bouchard identified the fluoroscopic signs of an obstructing bronchial adenoma in a young girl.\(^\text{46}\) Other pioneers, including Holzknecht, Williams, and Bécère, analyzed the radiologic appearance of bronchostenosis.\(^\text{47,48,49}\) They variously identified the effects of air trapping, including decreased ipsilateral diaphragmatic movement, increased contralateral ventilation, and contralateral mediastinal displacement.

Many pioneers identified the appearance of primary and secondary tumors in the lung. H. Leo of Germany found that physical diagnosis might not detect lung metastases when they were obvious with fluoroscopy.\(^\text{50}\) Williams identified regional metastatic hilar lymphadenopathy in patients with primary lung cancer and differentiated lung cancer from lung abscess.\(^\text{51}\)

**Cardiovascular disease**

M. Levy-Dorn of Germany was among the first to write that the heart becomes broader in transverse dimension after expiration.\(^\text{52}\) Williams identified the fluoroscopic correlates of congestive heart failure in 1896. He noted that clinically occult basilar lung opacification due to pulmonary edema in patients with mitral stenosis could be made to disappear after administration of digitalis.\(^\text{53}\) Fluoroscopy was also used to identify cardiovascular abnormalities, such as congenital heart disease, aortic aneurysm, arteriosclerosis, valvular heart disease, and enlargement of the cardiac chambers due to fluid overload.\(^\text{54}\)

**Diaphragmatic alterations**

Williams and Holzknecht extensively studied the position and motion of the diaphragm in health and disease.\(^\text{55,56}\) Williams noted decreased ipsilateral motion (and increased contralateral motion) of the diaphragm in pneumonia, pleural effusion, and adhesive pleuritis. Holzknecht studied the different motions of the diaphragm during sniffing, coughing, sneezing, and Valsalva's maneuver. With L. Hofbauer, Holzknecht identified the appearance of diaphragmatic rupture and abdominal herniation, and in 1907 described differences in the shape of the chest during diaphragmatic and costal breathing.\(^\text{57}\) R. Keinbock of Austria described
paradoxical motion of the paralyzed diaphragm in 1896.\textsuperscript{58,59}

**Emphysema**

The principal fluoroscopic characteristics of emphysema were carefully enumerated in the early days of the pioneering period. Williams noted:

The pulmonary area is more extensive and brighter than in health, and reaches not only lower down but higher up in the chest. The diaphragm is lower down in the thorax, and its excursion is restricted in the upper part of its usual movement. It sometimes happens that the diaphragm is so low down during full inspiration that it has a peculiar outline, this curve being made up of two curves on each side, instead of one, and following the organs directly under it. The cardiac outline...stands out with unusual clearness on the fluorescent screen....The heart...is lower down in the thorax...and its long axis is in a more vertical position.\textsuperscript{60}

Williams also recognized that in emphysema the vertical heart varied little in appearance during inspiration and expiration and, when viewed from the side, was at greater distance from the sternum in emphysema than in health.

**Mediastinal disease**

By means of cross-sectional and projectional drawings, both Holzknecht and Levy-Dorn analyzed the anatomic bases for radiologic images of mediastinal tumors.\textsuperscript{61} Holzknecht and others described distortions of the mediastinum caused by masses such as aortic aneurysms and thyroid goiters. Holzknecht intensively studied the posterior mediastinal compartment (i.e., the space posterior to the heart containing the trachea and esophagus), which was subsequently known as Holzknecht's space.\textsuperscript{62}

**Pleural disease**

Before the end of 1896 the pioneers had identified almost all of the fundamental alterations of the pleura (i.e., pleural effusion, adhesive pleuritis, simple and tension pneumothorax, and hydro pneumothorax).\textsuperscript{63,64} The fluoroscopic findings of pleural effusion were widely recognized by the pioneers.\textsuperscript{65} They noted that pleural fluid obscured or obliterated the diaphragmatic contour according to the amount of fluid present, and its outline was altered when the patient changed position. They attributed a higher lateral level of pleural effusion to a greater projected thickness along the lateral chest wall. They found that massive pleural effusion displaced the heart contralaterally and increased the excursion of the contralateral hemidiaphragm. In massive pleural effusion, they observed that the heart became displaced further to the contralateral side on expiration, reflecting greater selective ventilation of the normal lung. In adhesive pleuritis, they noted that diaphragmatic motion decreased on the ipsilateral side and increased on the contralateral side.

Williams and French pioneers Bécêtre, Bouchard, and T. Barthélémy enumerated the classic signs of simple pneumothorax, tension pneumothorax, and hydro pneumothorax.\textsuperscript{66,67} Williams described the fluoroscopic appearance of simple and tension pneumothorax as follows:

The affected side of the chest is unusually clear, and the light area in this region is larger than normal; the lung is retracted; the diaphragm is pushed low down in the chest and has little or no movement, and the organs on this side are displaced to the opposite side. The amount of displacement varies according to whether the air in the chest is or is not under greater than atmospheric pressure; if air is pumped into the thoracic cavity through a valve-like opening, and the pressure in that side of the thorax is thereby increased, the displacement of the organs may be very great.

Williams went on to describe the air-fluid interface of hydro pneumothorax in the sitting position as follows:

The general appearances on this side may be likened to a tumbler partially filled with black ink; when the patient moves backward or forward, the level of the fluid changes; if he is taken by the shoulders and gently shaken, the surface is disturbed, and the splashing of the fluid is clearly seen. When the fluid is at a certain level, especially if
the pneumohydrothorax is in the left side, the pulsations of the heart disturb its surface, and the waves caused by the partially submerged and beating heart can be observed. 69

Pneumonia

The pioneers found that fluoroscopy had the power to detect pneumonia even when there were no signs of it by auscultation or percussion. 69 Although the "visible bronchial tree" was formally described by Felix G. Fleischner in 1927, Williams apparently recognized it in 1896. Of a postmortem radiograph of the lung in a patient who died of pneumonia, Williams stated: "The lightest portion is healthy; the darkest parts have been more affected by the pneumonic process than those that are less dark. It is noteworthy that the smaller bronchi show as light lines in the dark portions of the lungs." 70 The various configurations of lobar opacification in pneumonia and their projected configurations were systematically analyzed by Holzknecht. 71

Of all medical afflications in the pioneering period, pulmonary tuberculosis was by far the greatest single cause of morbidity and mortality, and it exerted the greatest influence on the development of X-ray imaging of the chest. To many practitioners at the turn of the century, it was immediately evident that the X-ray offered an unprecedented potential means of early diagnosis of lower respiratory infection. As early as the meeting of the Association of American Physicians on 30 April 1896, Williams was able to report that fluoroscopy could successfully localize tuberculosis. 72 By 1 October he was able to summarize his findings of chest fluoroscopy in forty patients with tuberculosis. He found that fluoroscopy was valuable in determining the extent of disease. 73 Williams and many others in the United States and Europe reported on the successful use of fluoroscopy to detect tuberculosis even when physical diagnoses were unsuccessful. 74 In Britain clinicians were notably more circumspect in accepting X-ray imaging as a means of diagnosing tuberculosis during the early years of the specialty. 75

The fluoroscopic signs of tuberculosis became well known in 1896: darkening of the diseased lung apex, restriction in the excursion of the ipsilateral diaphragm, displacement of the heart and mediastinum to the ipsilateral side due to restricted expansion of the diseased lung, and increased diaphragmatic excursion on the normal side. 76 Although Williams and other pioneers agreed that the fluoroscope could detect occult disease, they cautioned that normal chest fluoroscopy did not exclude tuberculosis. 77

A GROWING FIELD, 1916–1946

In comparison with the explosive development of the first few years of the field, chest radiology underwent more gradual if no less substantial progress during the period from World War I through World War II. The technology, science, and art of chest diagnosis progressively matured, and the field of radiology began to emerge as a bona fide specialty of medicine. The most notable technical achievement of the period was the improvement of radiography to the extent that it began to challenge fluoroscopy as the routine primary mode of chest imaging.

Unlike the earlier period, which was dominated by individuals, the leadership of chest imaging was divided
Fig. 7.5 Henry K. Pancoast
(1875–1939).

Fig. 7.6 Ross Golden (1890–1975).

Fig. 7.7 LeRoy Sante (1900–1964).

Fig. 7.8 Aubrey O. Hampton
(1900–1955).

Fig. 7.9 George W. Holmes
(1875–1959).

Fig. 7.10 Laurence L. Robbins
(1911–1980).

(Figures 7.5–7.10 Courtesy of the Center for the American History of Radiology, Reston, Va.)
among a much larger group of outstanding general radiologists during these years. These included Felix G. Fleischner, Nils Westermark, Leo G. Rigler, Eugene P. Pendergrass (Fig. 7.4), Peter Kerley, Henry K. Pancoast (Fig. 7.5), Edward W. Twining, Ross Golden (Fig. 7.6), LeRoy Sante (Fig. 7.7), Aubrey O. Hampton (Fig. 7.8), George W. Holmes (Fig. 7.9), and Laurence L. Robbins (Fig. 7.10). Most of these leaders made major contributions to nonthoracic imaging and a few, most notably Fleischner and Rigler, continued as leaders in the post-World War II period.

In this period a large number of radiologists made significant contributions to an ever-increasing body of knowledge on chest imaging. Most of these radiologists did not restrict their interests to the chest and few, if any, would have identified themselves as chest radiologists.

A large number of texts dealing with chest disease appeared during this period. Notable among these was a German-language work by Herbert Assman in 1922, containing 300 pages devoted to chest diagnosis. Other substantial texts included an atlas on the stages of tuberculosis by Kennon Dunham in 1915 and a text on general radiologic instruction for students and young practitioners by George W. Holmes and H. E. Ruggles in 1919. Other authors who produced texts dealing with chest diagnosis were T. Groedel and F. Groedel (1914), R. Keinbock (1923), H. Wessler and L. Jaches (1925), F. G. Chandler and W. B. Wood (1928), W. Overend (1928), R. Lenk, W. Koch, and W. Wieck (1930), P. Kerley (1931), St. Engel and L. Schall (1933), L. R. Sante (1936), E. W. Twinning (1938), and A. Kohler (1939).

In keeping with the tradition of the pioneers, chest imaging continued to be taught as a component of general radiology by general radiologists. However, formal radiology training programs began to appear, and the leading teachers of the period were most often drawn from them. The first formal radiology residency in the United States began in 1916 at the Massachusetts General Hospital, where chest radiology was initially taught by George F. Holmes and later by Aubrey O. Hampton and Laurence L. Robbins.

Technical Advances in Thoracic Imaging

By the onset of World War I a series of improvements had already occurred in the technology of X-ray generation and image formation. The war created an immediate demand for more serviceable X-ray tubes, generators, and radiographic emulsions. The most pressing battlefield requirement during World War I was the facility to localize metallic foreign bodies with fluoroscopy and radiography. By World War II chest radiography had largely supplanted fluoroscopy in military medicine. For example, chest radiography was used in the war zone to evaluate Winston Churchill, who became ill following the Big Three Conference in Tehran. A radiograph of Churchill was obtained by the Massachusetts General Hospital X-ray unit of the United States 6th General Hospital in Marrakech, North Africa, using a portable field generator and a light-tight film processing tent.

Radiography

During this period more efficient hot cathode (i.e., Coolidge type) tubes and more powerful and dependable X-ray generators began to appear. Glass X-ray plates began to be replaced by a more practical cellulose acetate film base supporting more uniform and more sensitive halide emulsions. By 1918 double-coated X-ray film and purer, fine-grain calcium tungstate intensifying screens of high luminosity had greatly reduced exposure time. The introduction of rigid radiographic cassettes further improved image quality by maintaining tight contact between the intensifying screens and double-emulsion film. As a result of these improvements, George W. Holmes and other leading teachers of the period found that film radiography was a practical supplement to fluoroscopy for routine clinical imaging of the chest.
the following years fluoroscopy became gradually more restricted to the evaluation of problems related to motion of the heart, lungs, and diaphragm. Just before the end of World War II important experimental improvements were made with scatter-reducing grids and photo-timing devices.

**Bronchography**

During this period a large reservoir of patients suffering from post-pneumonic bronchiectasis provided a strong impetus for development of surgical intervention based on accurate localization of the affected lobes and segments. Early bronchographic experiments with iodoform and bismuth subcarbonate powder proved to be impractical. Jean-Athanase Sicard and Jacques Forestier introduced the first practical clinical contrast medium for bronchography, Lipiodol (11 percent iodized oil), in 1922.

**Angiography**

Interest in the pulmonary vasculature began at the turn of the century with speculation that the normal linear opacities in the perihilar regions of the chest were caused by pulmonary vasculature rather than bronchi. The initial attempt at experimental pulmonary angiography in 1910 consisted of fluoroscopic viewing of animals after intravenous injections of bismuth suspension. The possibility of pulmonary angiography in humans was promoted by Werner Forssmann's demonstration of percutaneous cannulation of the right cardiac chambers in 1929. Subsequent attempts at clinical pulmonary arteriography were carried out by L. Dunner and A. Calm in Berlin; C. Heuser in Buenos Aires; J.-A. Sicard and G. Forestier in Paris; A. Lindblom, E. Moniz, L. de Carvalho, and A. Lima in Lisbon; and A. Castellanos, R. Perieras, and A. Garcia in Havana. The introduction of timed serial radiographic exposures and concentrated iodinated contrast media just before World War II were important milestones in the development of clinical angiography of the lungs, hila, and mediastinum.

**Needle biopsy**

Percutaneous needle aspiration biopsy of pneumonia and cancer was carried out with relatively fine needles before World War I. By the 1930s an impressive clinical experience had been accumulated with fluoroscopically controlled percutaneous needle aspiration biopsy of lung tumors and pneumonia. Experiments with large-bore cutting needle biopsy and trephine air-drill biopsy for histologic diagnosis were marred by the occasional serious complication when applied to the lung parenchyma.

**Stereoscopy**

Stereoscopic techniques for radiography and photofluorography were perfected during this period in an attempt to overcome the confusing effects of bones and soft tissues superimposed on the lungs. Tube shift parallax fluoroscopy was also used to obtain threedimensional localization of intra-airway foreign bodies.

**Kymography**

Although radiographic cinematography had its origins in studies of the diaphragm during the pioneering period, it was not until the second period that timed exposures of alternating lead slits to demonstrate relative motion (i.e., kymography) became widely used for motion studies of the heart and great vessels. The technique provided unique information about incongruous movements between the diaphragm, rib cage, and mediastinal contents.

**Tomography**

From 1915 to 1931 numerous independent investigators (Karl Mayer, Andre Bocage, Alessandro Vallebona, Bernard Ziedes des Plantes, and others) experimented with projection tomography. The technique played an increasingly important role in clinical chest diagnosis during this period, especially in localizing studies of tuberculosis and lung cancer. One of the first practical chest tomographic...
units was developed by Jean Kieffer, a French-born American whose interest was stimulated by his own apical pulmonary tuberculosis that was obscured by overlying anatomy.115

Diagnostic Breakthroughs in Thoracic Imaging

The most important diagnostic breakthroughs of the second period were fundamental observations on pulmonary anatomy and diseases of the airways, interstitium, vasculature, and pleura.

Airways disease

The development of limited lung resection set the stage for surgical treatment of bronchiectasis and lung abscess.116,117 This opportunity for curative treatment fostered interest in systematic studies of airway anatomy and radiology.118,119 F. G. Fleischner studied the pathogenesis of bronchiectasis and identified a "reversible" form of bronchiectasis.120,121 Physiological studies in 1922 established that the bronchi elongate and widen during inspiration.122,123 Other investigators showed that although some giant lung cysts have open communication with the airways, others have valve-like obstructions.124

Atelectasis

Before World War II collateral air drift was identified as a key element in the conceptual basis of atelectasis.125 This work set the stage for more detailed radiological analyses of whole lung, lobar, segmental, and subsegmental atelectasis.126 L. L. Robbins and C. Hale formalized the characteristics of lobar and segmental atelectasis, as it was often expressed in centrally occluding bronchial tumors.127 F. G. Fleischner identified subsegmental atelectasis as long linear opacities that were perpendicular to the pleural surface. These became known as Fleischner’s lines.128 Fleischner also analyzed the roentgen anatomy of the right middle lobe and, with A. O. Hampton, clarified the differences between the radiographic appearance of right middle lobe atelectasis and interlobar pleural effusion.129,130 By further analyzing the roentgen characteristics of right middle lobe atelectasis, G. Kopstein laid the groundwork for the subsequent description of the “right middle lobe syndrome.”131,132

Bronchostenosis and carcinoma

Also in this period, lung cancer, chest metastases, and lymphomatous lesions became increasingly important public health concerns, leading to more systematic study of detection and differential diagnosis.133 George Holmes, Nils Westermark, Leo Rigler, and others described the radiographic appearance of bronchostenotic lesions.134,135,136 The classical appearance of a right hilar lung cancer associated with atelectasis of the right upper lobe was described in 1925 and became known as the S sign of Ross Golden.137 A. Cohen described obstructive emphysema distal to endobronchial cancer.138 In 1932 Henry Pancoast described the superior sulcus tumor bearing his name and characterized by ipsilateral pain, Horner’s syndrome, destruction of bone, and atrophy of hand muscles.139

Cardiovascular disease

In the years just before World War II Nils Westermark, Aubrey O. Hampton, Felix G. Fleischner, and Benjamin Castleman advanced the understanding of pulmonary embolism. Westermark described the oligemic appearance of the lung peripheral to occluding pulmonary emboli.140 Hampton and Castleman described the characteristic hump-like opacity of the peripheral pulmonary infarct.141 Fleischner, Hampton, and Castleman described the linear lung opacities associated with healed infarcts, atelectasis, and other pulmonary scars.142 C. Nessa and L. Rigler further analyzed the radiographic characteristics of pulmonary edema, and N. Westermark suggested that the Valsalva and Mueller maneuvers could be used to differentiate between pulmonary vascular engorgement and alveolar fluid.143,144
**Diaphragmatic abnormality**

The radiographic effects of diaphragmatic mass lesions, eventration, herniation, paralysis, and rupture attracted many authors’ attention.\(^{145}\)

Rostral shift of the dependent diaphragm and caudal displacement of the nondependent diaphragm were reported as responses to the effect of gravity in the lateral decubitus position.\(^{146}\) In 1927 K. Hitzenberger showed that the sniff maneuver produced transient paradoxical cephalic movement of weak or paralyzed diaphragmatic leaves.\(^{147}\)

**Interstitial lung disease**

In 1933 Peter Kerley described in the pulmonary septa the fine linear opacities that bear his name.\(^{148}\) It is now understood that septal lines are due to a thickening of the pulmonary septa rather than to distension of the lymphatics within the septa.

After World War I there was growing recognition in South Africa, the United States, and Europe of the importance of occupational lung disease, especially among stone workers and coal workers. This led to formal epidemiologic classification of the radiographic findings in pneumoconiosis.\(^{149,150,151}\) The work of Henry Pancoast and Eugene Fendergrass helped to elucidate the various radiographic stages of pneumoconiosis.\(^{152}\) The first of several versions of the International Labor Office classification system for radiographs in the pneumoconioses appeared in 1930.\(^{153}\) I. Rappaport’s 1936 concept of “shadow attenuation and summation” as a cause of small rounded opacities had a practical impact on the interpretation of radiographs in the pneumoconioses and other disseminated lung diseases.\(^{154}\) Other diffuse interstitial lung diseases began to attract attention as a result of the clinico-pathological studies of D. von Hansemann on lymphangitis reticularis in 1915 and of L. Hamman and A. R. Rich on rapidly progressive pulmonary fibrosis in 1935.\(^{155,156}\) At about this same time R. Lenk identified the radiographic characteristics of honeycomb lung, and E. Lucas and H. Pollack described the radiographic findings of lymphangitis carcinomatosis.\(^{157}\)

**Mediastinal disease**

Just before World War II E. W. Twining proposed a formal radiographic-anatomic scheme for segmenting the anterior mediastinum from the middle mediastinum containing the heart and great vessels.\(^{158}\) The new techniques of kymography, tomography, esophagography, and angiography were increasingly used to study mediastinal abnormalities. Kymography documented the pendulum movements of the mediastinum that occurred when differential pressures existed between the hemithoraces. These movements had previously been known to the pioneers from their fluoroscopic studies.\(^{159}\)

**Pleural disease**

In 1931 Leo Rigler originated the use of the lateral decubitus position for radiographic detection of small pleural effusions, effectively halving the minimum volume of detectable pleural effusion, from about 300 milliliters (ml) in the erect position to 100 to 150 ml in the decubitus position.\(^{160}\) R. Müller and S. Löffstadt further enhanced the sensitivity of lateral decubitus radiography by advocating the elevation of the hips, a maneuver that permitted detection of as little as 3 to 5 ml of fluid.\(^{161}\) W. Zawadowski’s analysis of extrapleural muscle, fat, and fascia as potential sources of the normal companion shadows of the ribs in 1936 had important implications for future studies of false-positive diagnoses of pleural plaques.\(^{162}\)

**Pneumonia**

Studies by the anatomist William Snow Miller greatly advanced understanding of acinar and septal anatomy, the basis for analysis of modern CT imaging of the lung.\(^{163}\) By overfilling the postmortem lung with Lipiodol, Edward Twining produced the radiographic equivalent of L. Aschoff’s acinar-nodule rosettes.\(^{164,165,166}\) This body of work set the stage for modern
correlative work on the radiographic anatomy of the acinus and pulmonary lobule. In 1927 F. G. Fleischner described the visible bronchial tree in pneumonia, a fundamental radiologic sign of consolidation that is still used today. LeRoy Sante studied the rate of resolution of lobar consolidative pneumonia in 1927, finding that clearing generally occurred in seven to ten days. Our earliest understanding of the roentgen characteristics of pneumocystis carinii pneumonia (PCP) began in the 1940s with recognition of ground-glass opacities in debilitated children suffering from plasma cell interstitial pneumonia. Many of these children were ultimately found to be suffering from PCP. Although the threat of tuberculosis waned during this period, radiography continued to be used to detect tuberculosis in high-risk groups and to evaluate collapse therapy (e.g., phrenic crush procedure, artificial pneumothorax, luerite ball insertion, and pneumoperitoneum). The discovery of streptomycin in 1944 provided the first true medical cure for the disease.

AFTER WORLD WAR II: 1946–1965

Technical Advances in Thoracic Imaging

World War II halted much scientific investigation, including medical research. Development in radiology was similarly curtailed, although a few highly significant achievements occurred during this period. Among these was the Picker Army field unit, which became standard equipment in all theaters of war. Widely used for the diagnosis of trauma, especially fractures, these units became the backbone of the diagnosis of chest disease.

In May 1942 Russell Morgan, then at the University of Chicago, reported the development of a new phototiming system. Morgan’s phototimer was initially designed for use with photofluorographic units, which were commonly used at that time as screening tools to detect tuberculosis; it soon became standard equipment throughout radiology.

J. W. Coltman of the Westinghouse Corporation announced the design of a practical image intensifying system in 1948, but it was not until 1953 that the first commercial intensifier was made available for clinical use. With this innovation fluoroscopy of all areas of the body including the thorax took a giant step forward, and television display of the image became possible. Meaningful recording of images in motion became a reality; practical cineradiography was introduced in 1954.

The 1950s were years of rapid technological development, although many of the advances could be considered equipment refinements rather than true technological breakthroughs. Shorter exposures became possible, largely as a result of the development of more powerful generators, and film processing became better controlled. These improvements were, of course, felt throughout diagnostic radiology, but chest radiographs, in particular, improved in quality with a concomitant decrease in patient exposure.

Tomography, which had been introduced by Ziedes des Plantes in 1931, was upgraded by the advent of pluridirectional tube movements. The polytome was developed by Massiot in France in 1951. During the succeeding years tomography was widely used for the diagnosis of chest disease: very thin sections and thicker “zonograms” were often employed for the evaluation of the mediastinum and the pulmonary nodule, among other indications, until the development of CT made conventional tomography obsolete. Some radiologists still advocate conventional tomography for study of the central airway.

Bronchography, first performed by Chevalier Jackson in 1918, received considerable impetus from the development of spot-film devices introduced by Scholz in 1951 and Leischman in 1953 and from the introduction of contrast agents such as Dionosil in the late 1950s. The procedure remained popular until its gradual replacement by CT in the late 1970s and early 1980s.

Clinical nuclear medicine came of age between 1955 and 1965 with the
introduction of radiopharmaceuticals, which permitted imaging of a variety of organs. Lung scanning using macroaggregated albumin was described independently by George Taplin and Henry Wagner in 1964.\textsuperscript{180,181} Pulmonary embolism was the first disease in which the value of lung scanning was demonstrated. Taplin suggested the use of technetium Tc 99m for lung scanning at a meeting honoring Felix Fleischner held in 1967 in Boston.\textsuperscript{182}

**Diagnostic Breakthroughs in Thoracic Imaging**

The discovery of significant new information is a daily occurrence in medicine. Similarly, there have been innumerable important developments in the field of thoracic radiology. To single out only a few as worthy is difficult, but in the following paragraphs we attempt to make such judgments. Personal bias and the arbitrary nature of the selections are freely admitted.

**Anatomic correlations with thoracic imaging**

It is axiomatic that no radiograph can be correctly interpreted without an understanding of the normal anatomic structures it delineates. In the years immediately following World War II a group of significant studies clarified roentgen anatomy of the chest.

Jackson and Huber in 1943 presented a landmark paper titled, "Correlated Applied Anatomy of the Bronchial Tree and Lungs with a System of Nomenclature."\textsuperscript{183} Their designation of the segmental bronchi remains the terminology most commonly used today.

In 1946 Thomas Lodge correlated the anatomy of the blood vessels of the lung with their appearances on the chest radiograph.\textsuperscript{184} In 1947 Brock published his book on the anatomy of the bronchial tree in which he described his studies using Wood's metal casts of the lungs.\textsuperscript{185} F. A. Boydén commented that Brock's contribution "represents a landmark in the development of this subject."\textsuperscript{186} In 1948 Gladnikoff wrote a classic monograph correlating mediastinal anatomy and radiography.\textsuperscript{187}

In 1951 Paul Marchand presented a landmark paper that, for reasons unclear, is not widely cited, but provided convincing anatomic evidence to allow understanding of the spread of disease through the mediastinum to the neck and to the lung.\textsuperscript{188} In this study, which used cadaver studies and radiographs, he established the communication between the pericardial space in the mediastinum as well as the communication of the mediastinal space with the sheaths around central bronchi and vessels. Edward Boydén further clarified the anatomy of the bronchial tree emphasizing anatomic variations, in his classic book entitled *Segmental Anatomy of the Lungs*.\textsuperscript{189} In this work he introduced the now popular Boydén nomenclature for designation of segmental bronchi. Two important papers by Lynne Reid, one written with George Simon, appeared in 1958 and further clarified subsegmental lung anatomy for the radiologist.\textsuperscript{190,191}

Thus, the 1950s were an important decade for clarification of radiographic anatomy, setting the stage for the more tightly focused observations to follow. Any discussion of roentgen-anatomic correlations must include Theodore Keats's classic *Atlas of Normal Roentgen Variants That Simulate Disease*.\textsuperscript{192} First published in 1973, it does not strictly fall within the time period being discussed, but Keats's collection of films began well before 1973 and produced a work that is constantly referred to by all radiologists, including those primarily interested in chest disease.

**Pathologic correlations with thoracic imaging**

For the first fifty years after Röntgen's discovery, specific correlations of thoracic abnormality as seen on radiographs with the underlying pathology were limited, at least in part because of the inadequacy of techniques for fixing lungs in the inflated state. Nevertheless, several important X-ray pathologic correlative studies appeared in the 1940s and 1950s. As early as 1945 Robbins and Hale presented a series of fundamental papers
concerned with detailed radiographic findings in pulmonary collapse.\(^{195}\) Oswald and Parkinson again discussed honeycomb lung in 1949, but it was not until the paper by Heppleston in 1956 that the underlying pathology was described.\(^{194,195}\)

Methods for fixing lungs in the inflated state improved during this period. Gough and Wentworth, as well as Cureton and Trapnell, described lung fixation techniques for use with radiographs, thus further refining the potential for X-ray anatomic and pathologic correlations.\(^{196,197}\) A flurry of key papers followed. In 1954 Herrnheiser and Hinson provided pathological material in an attempt to explain the butterfly or batwing appearance of pulmonary edema.\(^{198}\) In 1955 Gough provided correlations in pulmonary edema, pulmonary alveolar microthiaxis, uremic edema, and emphysema.\(^{199}\) During this period there was considerable activity concerned with the underlying pathology of Kerley line shadows. So-called B lines, described initially by Peter Kerley in 1933, and A and C lines, described by him in 1951, were studied intensively.\(^{200,201}\) In 1954 Fleischner and Reiner reviewed Gough sections of lungs from patients demonstrating thickened interlobular septa and concluded that these abnormal septa must be responsible for the production of B lines on roentgenograms.\(^{202}\) Further studies by Gough, Levin, Grainger, Trapnell, and Heitzman confirmed this fact in a variety of conditions.\(^{203}\) The nature of linear shadows in the lungs including plate or linear atelectasis, sometimes referred to as Fleischner's lines, was further elucidated by Fleischner in 1958.\(^{204}\) Trapnell described the anatomy and pathology of the pulmonary lymphatics and their radiologic relevance.\(^{205,206}\) During this period George Simon elucidated the pathology that leads to the radiographic appearance of chronic obstructive pulmonary disease.\(^{207,208,209}\)

The 1950s and 1960s were years of enormous productivity in the basic understanding of the radiographic appearance of chest disease. We were achieving a much better understanding of what was seen in chest radiographs, thus opening new diagnostic vistas. In the final analysis, Leo Rigler said it best: A well studied radiograph is an "autopsy in vivo."\(^{210}\)

**Physiologic correlations with thoracic radiology**

During this period, there was also renewed interest in the physiological deductions that could be made from chest radiography. These studies complemented and often supported correlations that were being made with anatomy and pathology.

In 1949 Healey, Dow, Sosman, and Dexter correlated some aspects of pulmonary hemodynamics with the radiographic appearances of the pulmonary artery.\(^{211}\)

Robert Barden, working at the University of Pennsylvania with Julius Comroe, correlated several aspects of abnormal pulmonary function with chest radiographs, including bronchial air flow in carcinoma of the lung and pulmonary blood flow in arteriovenous fistula.\(^{212,213}\) He commented further on oligemic pulmonary infarction originally described by Nils Westermark in 1938.\(^{214}\) Barden astutely observed, "We have found that, in many instances, the well trained, alert radiologist can evaluate function with surprising accuracy and in some cases can identify the specific nature of the abnormality which has been characterized only in more general terms by the physiologist."\(^{215}\) In his landmark Caldwell Lecture on functional roentgen diagnosis in 1958, Rigler urged radiologists to think in physiological terms to reach diagnoses made from radiographs deductively.\(^{216}\) Rigler's discussion of shunt physiology and the influence of the Müller and Valsalva maneuvers emphasizing fluoroscopy remains essential reading for every radiologist.

Another area of intense interest during the 1950s and 1960s was the study of how gravity affects pulmonary blood flow and how the radiograph could effectively predict pulmonary vascular pressure and flow. To Morris
Simon goes the credit for the initial observations that upper lobe pulmonary veins dilate in mitral stenosis while the lower lobe veins do not and that this change can be correlated with pulmonary venous pressures. Simon reported his observation correlating pulmonary physiology and radiology in a lecture to the Faculty of Radiologists on 16 October 1956, while he was a senior registrar at Guy’s Hospital, London. This work was augmented by the physiological studies on blood flow distribution and ventilation perfusion ratios reported in 1960 by West and Dollery. Simon postulated reflex vasoconstriction of lower lung vessels as the physiologic mechanism for redistribution of flow. Today, cause for redistribution of blood flow with elevated pulmonary venous pressure remains controversial. Further expositions of the hemodynamics of blood flow and distribution have been given by Simon and by Milne.

Carcinoma of the Lung

In 1950 carcinoma of the lung had an age-adjusted death rate for men of about twenty-five per one-hundred thousand, roughly equal to that of cancer involving the stomach, the prostate, and the colon and rectum. Since that time cancer of the lung has markedly grown in incidence among men, and in 1965 a similar sharp upward trend in women began.

As interest in lung cancer grew among the medical community in general, radiologists also began an intensive study of the disease and, in the postwar years, made many important observations that led to better understanding of the condition and its diagnosis.

Leo Rigler and Henry Garland were leaders in the establishment of the parameters for the growth of lung cancer. In 1953 Rigler pointed out from a study of serial radiographs that lung cancer grows slowly and that as it enlarges it becomes more readily visible in central bronchi. He expanded on this theme in a classic 1957 article titled “A Roentgen Study of the Evolution of Carcinoma of the Lung.” Garland in 1953 also commented on the slow growth of lung cancer and in 1966 reemphasized that, because of this slow growth, peripheral lung tumors became visible on radiographs only very late in their life cycle. Earlier, Spratt had pointed out that a lung cancer 6 millimeters (mm) in diameter (considered to be the threshold of radiographic visibility) represents 26.7 doublings of an original 1,000 cubic micron cell. A 200 mm tumor represents 40.8 doublings and, without treatment, will generally kill the patient in the interval of the next doubling time.

Although it has been estimated that even the smallest radiographically detectable pulmonary neoplasm is in the last third of its life span, the surgical five-year survival rate is sufficiently good to make early detection of such lesions a worthwhile goal. As early as 1955, however, Garland reported that screening for carcinoma of the lung using photofluorography detected only ten cancers for every one-hundred thousand persons studied. He felt that this yield was so low as to make screening for lung cancer impractical. In 1973 the United States Department of Health, Education, and Welfare developed a policy statement indicating that screening by chest radiography for carcinoma and tuberculosis was not advocated. The policy was endorsed by the American College of Radiology.

Rigler, among others, often emphasized that attempts to evaluate the pathology of solitary pulmonary masses radiologically is less significant than is the detection of early lesions. Unfortunately, many lung lesions, including carcinomas, are missed on chest radiographs because of observational error. In 1958 Yerushalmi reported a study in which 32 percent of “suspicion worthy” lesions were missed on chest radiographs. One year later Garland produced his often quoted article “Studies on the Accuracy of Diagnostic Procedures.” He found that experienced radiologic observers missed about 30 percent of detectable abnormality on chest X rays.
Interobserver error was found to be about 33 percent and intraobserver error about 20 percent. Several writers emphasized that dual reading was the single most valuable tactic to minimize observer error.235,236,237 These articles are landmark citations that served not only to underscore reader fallibility but also to emphasize the care and concentration which must underlie each roentgen interpretation.

The decade immediately after World War II provided many classic descriptions of lung cancer. Liebow and Nohl described the pathology underlying the radiologic appearances of carcinoma of the lung.238,239 Rigler and Ochsner provided general descriptions of the radiologic findings.240,241 In 1952 Rigler described the radiographic features of central lung cancer involving the hilum.242 Edwards discussed the preoperative diagnostic accuracy of lung cancer presenting as a solitary pulmonary nodule.243

Thus, in the years after World War II radiologists were at the forefront of the study of growth characteristics and diagnosis of carcinoma of the lung.

**Special procedures in thoracic radiology**

As technical advances in radiology progressed during this period, radiology began to expand its horizons into what has been referred to as "special procedures." Although early isolated efforts in this arena did take place before 1940, the postwar years saw the beginnings of interventional radiology as we know it today. Notable among these early interventional endeavors in the chest were the development of thoracic angiography and techniques such as bronchial brushing and needle biopsy to establish histologic diagnosis of thoracic lesions.

**Thoracic angiography**

The Portuguese, pioneers in the field of angiography, were early leaders in the radiographic demonstration of the lung vasculature. In 1931 Egas Moniz demonstrated the pulmonary vessels in several conditions, and in 1937 Castellanos reported angiographic findings in a number of congenital cardiac anomalies.244,245,246 In the United States Robb and Steinberg introduced their technique for radiographic visualization of the heart and pulmonary vessels in the late 1930s.247 Further progress awaited the postwar period. Chavez introduced direct intracardiac injection for angiography in 1947.248 Although Farinas as early as 1941 described abdominal angiography performed via a urethral catheter placed through a trocar into the exposed femoral artery, it was not until 1948 that Radner reported a technique for catheter angiography of the thoracic aorta.249,250

It was Seldinger in Sweden who in 1953 introduced a technique for percutaneous catheter placement.251 This innovation, now known as the Seldinger technique, revolutionized angiography, including thoracic angiography. Bjorn Nordenstrom, also from Sweden, described contrast studies of the bronchial and mediastinal arteries in 1967.252

At this time the value of pulmonary arteriography for the diagnosis of pulmonary embolism was championed by several authors, notably Williams and Cooley.253,254 Charles Dotter and Israel Steinberg described their technique for pulmonary arteriography and its diagnostic potential in their book *Angiocardiography*, published in 1951.255 The value of magnification angiography of the pulmonary vasculature was introduced by Takaro in 1964 and by Greenspan in 1967.256,257

**Needle biopsy and bronchial brushing**

Although needle biopsy of lung lesions was performed as early as 1939, it was in the postwar period that a flurry of papers described techniques for this diagnostic procedure.258 In 1949 Gledhill reported his experience with needle aspiration in 75 cases of carcinoma of the lung.259 Bjorn Nordenstrom described the technique of fine needle (0.6 mm. outer diameter) biopsy in 1965.260 The experience of the group at the Karolinska
Sjukhuset in Stockholm with needle biopsy was described in 1966 in a classic monograph by Dahlgren and Nordenstrom. They reported the results of biopsies on 365 patients done in 1963 and 1964; a diagnosis was established in 86.6 percent. They emphasized the benign nature of the procedure; a pneumothorax rate of 15 to 20 percent was encountered, which the operator managed by withdrawing the intrapleural air by needle or catheter.

MacLean described an early approach to bronchial brushing with a new instrument in 1958. Hattori, in Japan, described a brushing method under television fluoroscopy in 1964. The experience at the University of Chicago, including the introduction of an improved brushing instrument, was reported by Fennessey in 1966.


**Technical Advances in Thoracic Imaging**

Several observers have noted that the 1960s were a period of consolidation and refinement of equipment and techniques. One important advance, however, was the adaptation, in 1968, of rare-earth phosphors for use in intensifying screens for general radiography. Calcium tungstate phosphors had been used exclusively in screens since 1896, but because rare-earth phosphors are at least twice as efficient absorbers of X rays as calcium tungstate, they virtually replaced tungstate screens during the 1970s. This benefit was, of course, felt in chest radiography, improving film speed and reducing patient dose. Another advance at this time was the development of better stationary fine line grids having greater than one hundred lines per inch. These grids improved the quality of portable chest X rays, particularly in heavy patients. The 1970s produced several further advances; tubes with small focal spots (0.1 to 0.3 mm.) were developed, automatic collimation was mandated, and the daylight film loading system was introduced.

Without doubt, however, the major advances in the 1970s were related to the development of new cross-sectional imaging techniques. CT evolved during this decade, and MR imaging had its beginnings.

**Computed tomography**

The 1970s were especially notable for the development of CT. The evolution of this remarkable technology has been nicely chronicled by Hendee, but because this advance has so significantly altered radiology and with it chest radiology, a brief history of its development is included here.

During the 1950s A.M. Cormack, a South African physicist, noted that radiation therapy dose distributions could be predicted if the distribution of attenuation coefficients was known across a body region. He also realized that such a distribution could be displayed as a gray-scale image. His original work in Capetown was later continued at Tufts University in Boston. Several years later Cormack’s work was recognized as representing a group of fundamental physical observations leading to the development of CT, and he would share the 1979 Nobel Prize in medicine and physiology with Godfrey Hounsfield.

Hounsfield, who was not aware of Cormack’s work, was almost solely responsible for taking basic physical information and creating a practical CT unit. His first unit used americium as a radiation source, but he soon switched to an X-ray tube in order to increase the radiation intensity and greatly reduce imaging time. His first image of the brain, made at the Atkinson-Morley Hospital in London in October 1971, had a slice thickness of 1 cm. and an acquisition time of four and one-half minutes; it clearly demonstrated a frontal lobe tumor. Subsequently, four separate generations of scanners were developed within four years, and scan time was reduced from five minutes to two minutes.

CT has had an enormous influence on medical diagnosis; through its use, radiologic interpretation has taken a
AUTHORS, TEACHERS, MENTORS, AND LEADERS

In a world of outstanding physicians and radiologists it is difficult and indeed presumptuous to single out individuals for recognition. Few authors have attempted to do this; one who has is David Trapnell, who reviewed the history of chest radiology in an outstanding 1982 article. 265 Admitting the problems of selection, the careers of six individuals will be discussed. Although each of these men could be characterized as a great radiologist, the most lasting attribute they shared was their unparalleled abilities as teachers.

FELIX FLEISCHNER (1893-1969)

Felix Fleischner was one of the great chest radiologists of the past century. 265 He was born in Vienna and received his medical degree in 1919. He began his career in 1920 at the Clinic in Internal Medicine under the supervision of Karl C. Wenkebach. During this time he was influenced by such radiologic pioneers as Haudek, Holzknecht, and Kienbock. For a time he was chief of the X-ray department at the Children's Hospital in Vienna and subsequently head and professor of the second Medical Radiologic Clinic of the University of Vienna.

In 1937 he traveled to the International Congress of Radiology in Chicago and met George Holmes of Boston. Displaced from Vienna after the annexation of Austria by Germany in 1938, Fleischner joined Holmes at the Massachusetts General Hospital in 1939. In 1942 he became head of the department of radiology at the Beth Israel Hospital in Boston and was appointed to the faculty of the Harvard and Tufts Medical School. He became clinical professor of radiology at Harvard University and professor emeritus in 1960. After reaching emeritus status, he continued to work as a consultant at the Peter Bent Brigham and Massachusetts General Hospitals focusing primarily on graduate and undergraduate teaching in radiology.

Felix Fleischner was one of the most prolific and innovative clinical researchers in radiology. He wrote more than one hundred and fifty articles on a wide variety of subjects, most of which had to do with thoracic radiology. Particularly noteworthy are his papers on the air bronchogram, which he initially described in 1927 and amplified in an article entitled “The Visible Bronchial Tree,” and the patent bronchus sign which he described in an article on the pathogenesis of bronchiectasis. 265,257,269 He also wrote extensively on the subject of linear shadows in the lung fields, including linear atelectasis, which came to be known as Fleischner's lines. 269 In 1963 he wrote a classic article on the atypical arrangement of free pleural effusion in which he described the meniscus configuration of free pleural fluid on an anatomic basis. 270 He was also interested in the radiologic features of pulmonary embolism and wrote extensively on this subject. 271 He speculated on the central “butterfly” or “batwing” distribution of pulmonary edema on chest radiographs. 272

Toward the end of his life, two international symposia were dedicated to Felix Fleischner, one in 1964 on the subject of pulmonary embolism and one in 1967 on the frontiers of chest radiology, which initiated discussions that led to the formation of the Fleischner Society. A true Renaissance man, Felix Fleischner was fluent in Latin and ancient Greek and knowledgeable in classic archaeology. We were privileged to have him as a leader in thoracic radiology.
Peter J. Kerley (1900-1979)

Peter J. Kerley was an early, highly respected leader of chest radiology in Britain. Born in Ireland in 1900, he studied medicine at University College, Dublin, and attained his medical degree in 1932. Like Felix Fleischner, he also studied in Vienna, where he first became interested in radiology of the heart and lungs, and at Cambridge in England. At a relatively early age, he was appointed as a consultant at the Westminster Hospital and rose to become director of the X-ray department at that institution. He also was associated with the Royal Chest Hospital in London. During these years he became known as one of the world's leading cardiothoracic radiologists and was adviser on radiology to the Ministry of Health. During World War II he served as a radiologist in India and Singapore and, upon his return to England in 1944, assumed charge of the mass radiographic service then being established.

Kerley first noted and described abnormal horizontal linear shadows in the costophrenic angles on chest roentgenograms in 1933.\textsuperscript{273} In 1951 he described longer linear shadows in the upper lobes and described a "spider web" network of lines, which in some patients seem to cover almost the entirety of each lung.\textsuperscript{274} These lines are now widely known as Kerley's A, B, and C lines.

In 1933 Kerley began a collaboration with Seymour C. Shanks to edit a textbook of X-ray diagnosis, commonly referred to as The British Authors.\textsuperscript{275} This text was enormously popular and expanded through four editions to a total of six volumes. In his early years, Kerley wrote an article titled "Primary Carcinoma of the Lung with Special Reference to X-ray Diagnosis," in which he pointed out the rapidly increasing incidence of lung cancer.\textsuperscript{276} In 1952 he and Sir Clement Thomas diagnosed the cancer of the lung that ultimately led to the death of King George VI. This initiated Peter Kerley's long association with the British royalty, which led to knighthood in 1972.

Kerley received many awards, both at home and abroad. He served as editor of the Journal of the Faculty of Radiologists, was president of the Faculty of Radiologists from 1952 to 1955, was knighted in 1972, and was awarded the gold medal of the Royal College of Radiologists in 1976.
George Simon (1902–1977)

George Simon was widely respected as a clinical radiologist with dominant interest in chest disease and as an author, clinical investigator, and lecturer. Simon decided at an early age to become a doctor and had a brilliant undergraduate career at Cambridge. In his twenties he was afflicted by progressive deafness and decided to turn his medical career toward radiology. He became clinical assistant to the X-ray department at St. Bartholomew’s in 1927, chief assistant in 1928, and assistant radiologist (consultant) in 1946. He became a radiologist at the Brompton Hospital and worked for many years at the Institute of Diseases of the Chest. He was the consummate teacher, regularly giving tutorials at St. Bartholomew’s, Hammersmith, King’s, the National Heart Hospital, Northwick Park, and the University College Hospital. He was beloved by students and colleagues alike for his brilliance, energy, intelligence, and wit. He was also an exceptional clinical investigator. The eminent pathologist, Lynne Reid, with whom he collaborated on numerous projects, is quoted as saying he would never accept circumstantial evidence, but only a direct correlation, which is still the only proof of what structure is responsible for certain shadows. 277

Simon wrote incisively and extensively. His textbook, Principles of Chest X-ray Diagnosis, was published in 1956. 278 The book was unique for its time, presenting classical descriptions of pathology underlying certain chest radiographic findings. The book underwent three editions. During the latter part of his life Simon was intensively interested in the radiographic findings of chronic obstructive pulmonary disease. 279 He also wrote on the subject of cystic fibrosis. 280 Like Felix Fleischner, Simon was interested in the radiographic basis for long line shadows in the lung. In 1970 he wrote an article titled “Further Observations on the Long Linear Shadow Across the Lower Zone of the Lung,” in which he suggested that sometimes these shadows may be produced by thrombosed veins. 281 Simon was very versatile, and his interests in thoracic radiology were protean. He published papers on the radiology of Hodgkin’s disease, on pulmonary embolism, and on mitral stenosis. 282,283,284 In this last paper Simon observed that upper lobe vessels were not dilated in a small percentage of patients with tight mitral stenosis. With Lynne Reid, Simon produced some landmark papers on lung anatomy and development. 285

Simon’s intelligence, energy, and enthusiasm elevated radiology in England and around the globe. His sparkle and charm were captivating, and he continued to work and teach until his death.
One of the greatest radiologists of the modern era was Benjamin Felson. Born in Newport, Kentucky, in 1913, he was a graduate of the University of Cincinnati and received his medical degree from the College of Medicine there in 1935. Following an internship at the Cincinnati General Hospital, he studied pathology and took his residency training in radiology at the medical college there.

Felson entered the United States Army Medical Corps in 1942, serving as the chief of radiology with the 28th General Hospital in Europe. After the war, he returned to the department of radiology at the University of Cincinnati College of Medicine and, in six years, was named professor and director of the department, a position he held for twenty-two years.

Ben Felson was the author of some one hundred and fifty articles and seven books, most related to chest disease. His prose was always simple, lucid, and to the point, often with a liberal infusion of humor. His *Chest Roentgenology* and *Gamuts in Radiology*, written with Maurice Reeder, are used daily by every radiology resident. His approach to film analysis was also innovative. He made a large number of fundamental observations in chest radiology that are used every day in film interpretation. In 1959, in a classic article in Coleman Robins's *Roentgenology of the Chest*, he described many "Special Signs in Chest Roentgenology"—his own and those attributable to others. Among his own signs several are worth mentioning. He thought that his most important publication described the "silhouette" sign.

He described the hilum convergence sign in three publications, the hilum overlay sign in two publications, the cervicothoracic sign in *The Mediastinum* and in *Chest Roentgenology*, and the thoraco-abdominal sign in *Chest Roentgenology*.

If Felson's interests in radiology were extremely broad, so were his interests in chest radiology. In 1958 he reviewed the subject of noninfectious necrotizing granulomatosis. He also discussed the two types of right aortic arch, "downhill varices" and pulmonary sequestration. He founded the journal *Seminars in Roentgenology* and was its editor until his death.
Robert Fraser is one of the most prolific writers and teachers in contemporary radiology. He was born in Winnipeg, Manitoba, in 1921. He graduated from the University of Toronto in 1939 and from the medical school at the University of Manitoba in Winnipeg in 1945. He studied pathology at Washington University School of Medicine in St. Louis, Missouri, before taking up a radiology residency at the Royal Victoria Hospital in Montreal. He was certified in diagnostic and therapeutic radiology by the Royal College of Physicians and Surgeons of Canada in 1951 and by the American Board of Radiology in the same year. He was awarded a fellowship in diagnostic radiology from the Royal College of Physicians and Surgeons of Canada in 1956. He spent fifteen years as a member of the department of radiology at McGill University in Montreal, was named professor of radiology in 1968, and became chairman of the department of diagnostic radiology in 1971, a position he held until 1976. Since that time, Fraser has been professor of radiology in the department of radiology at the University of Alabama at Birmingham, achieving emeritus status in 1988.

In addition to being active in many radiologic organizations, Fraser was a founder of the Fleischner Society, an international and interdisciplinary society devoted to the study of the chest, and served as its first president from 1970 to 1972.

Fraser is perhaps best known for his efforts in radiologic education, particularly relating to chest disease. His bibliography includes eighty scientific articles, two scientific exhibits, and seven books. His multivolume text, Diagnosis of Diseases of the Chest, initially written with J. Peter Pare and later with both of the original authors' sons and the late George Genereux, is now in its third edition. This work, initially published in 1970, has become the standard reference in pulmonary radiology. One of the most successful texts in pulmonary medicine in the past century, it is widely recognized as being well written, comprehensive, and authoritative. Its bibliographic citations are carefully selected, exhaustive, and current.

Fraser is an enormously popular lecturer and has made multiple presentations throughout the world. Through his teaching, whether at the viewbox, during his lectures, or through his voluminous writings, he has influenced modern day chest radiology as only very few have.
Leo G. Rigler was one of the greatest radiologists the specialty has produced. Born in 1896 in Minneapolis, Minnesota, he graduated from the University of Minnesota and from the University of Minnesota School of Medicine, receiving his M.D. in 1920. He interned at the St. Louis City Hospital. Although at that early time he was attracted by the fledgling specialty of radiology, he decided to enter general practice in North Dakota. After one year, however, he returned to the University of Minnesota as a teaching fellow in internal medicine and pathology at the Minneapolis General Hospital. His interest in radiology continued to grow, and during the mid-1920s the University of Minnesota made it possible for him to work with such radiologic pioneers as James T. Case and Preston J. Hickey. He also studied in Europe, spending a year at the Karolinska Institute in Stockholm and some time in Vienna, Austria.

He returned to Minneapolis in 1927 and was appointed associate professor of radiology, the first full-time faculty member in radiology at the university. He was made professor in 1929 and chairman of the newly created department of radiology in 1933. In a relatively short period, he built the Minnesota department into a model of academic radiologic practice.

In 1957 Rigler left Minnesota to become executive director of the Cedars of Lebanon-Mt. Sinai Hospitals in Los Angeles, negotiating the merger of these two institutions. In 1963 he returned to teaching as professor of radiology in residence at the University of California at Los Angeles (UCLA) and director of the postgraduate training program in diagnostic radiology.

Rigler contributed more than two hundred articles and four books to the radiologic literature. Many of his contributions are classics in the field, particularly those having to do with the evolution of bronchogenic carcinoma and physiologic deductions from plain chest radiographs. Early in his career he was interested in the radiographic evaluation of pleural fluid, and in 1931 was the first to describe the decubitus position for the evaluation of free pleural fluid.

Rigler generally is credited with development of the first postgraduate course in radiology, presented initially at the Center for Continuing Education at the University of Minnesota in 1937.

Rigler received many honors, awards, and medals. He presented innumerable named lectureships. Lectureships in his name have been established at the University of Minnesota, at UCLA, and at the Tel Aviv University in Israel. UCLA established the Leo G. Rigler Center for the Radiologic Sciences at the UCLA Medical Center in 1971. The University of Minnesota named the Rigler Library in his honor, and the University of Tel Aviv named a teaching center for him.
quantum leap forward. In thoracic diagnosis the influence of CT has been revolutionary. Smaller lesions are seen with greater clarity than before, and mediastinal disease is more readily identified and diagnosed. Cancer staging, notably for carcinoma of the lung, has been greatly facilitated. Noninvasive diagnoses of many forms of heart disease, notably congenital heart disease, are possible, and lesions of the aorta are readily demonstrated. In fact, virtually every form of thoracic pathology lends itself to CT study.

In a large number of significant articles published in the 1980s and 1990s, several researchers, notably Gordon Gamu, Nestor Muller, David Naidich, Richard Webb, and Elias Zerhouni, emphasized the value of high-resolution CT of the lung parenchyma. During this same period the advent of CT apparatus with a continuous spiral or helical motion allowed images to be made in a single breath hold. Scan times of one second are possible with image thicknesses as small as 1 mm. Obviously, scanning of infants, children, and debilitated persons is facilitated. Disease involving pulmonary vessels, including pulmonary emboli, can be demonstrated, and three-dimensional images of outstanding quality can be obtained.207,508

In his Nobel acceptance speech in 1979, Hounsfield made an interesting comment on the evolution of cross-sectional imaging.309 He remarked that much development was needed in the field of MR imaging, but that ultimately it would become a technique complementary to, not competitive with, CT.

Magnetic resonance imaging

The prospect of using MR (then called nuclear magnetic resonance) technology to produce images was introduced in the early 1970s by R. Damadian and F. C. Lauterbur. In 1972 Damadian, in a patent application, raised the possibility that the human body might be scanned for clinical purposes by MR.310 In 1973 Lauterbur published the first MR image of a heterogeneous object—two tubes of water. The first image of a part of the human body was of a finger.311 The first image of the thorax appeared in a paper by Damadian in 1977.312 Further pioneering work was done on MR imaging in the late 1970s and 1980s at the Hammersmith Hospital in London and at the University of California, San Francisco.313 A comprehensive review of the subject was provided by Ralph Alfidi and his coauthors in 1982.314 To date, MR imaging has had less of an impact in the thorax than it has in neuroradiology and musculoskeletal radiology. It is generally conceded to be equal to CT for the diagnosis of mediastinal disease and cancer staging but is used less frequently than CT because of its greater cost. The negative signal produced by flowing blood has been exploited to evaluate the heart and great vessels in a noninvasive way without the need to use a contrast agent. Thus far, respiratory motion has frustrated evaluation of the lung parenchyma, but studies are now in progress which may significantly minimize this problem.315

Digital imaging

During the 1980s technological advances in radiology included improvements in conventional radiographic devices, sonographic equipment, and in CT and MR devices.

Major advances occurred in digital radiography, digital fluoroscopic equipment, and in computer storage, viewing, and recording systems. Krohmer has stated that “this direction reflects the widely held opinion that the field we have known will, in the future, change to one in which images are mainly digital, computer stored and electronically retrieved, viewed, and recorded.” He adds, however, that the important questions are, “Will all of this take place and, if so, when?”316

In all digital systems the X-ray beam exiting from the patient is captured by a detector. The information is digitized by an analog-to-digital converter, processed, and viewed. During the 1980s several variants of this technology were developed.
In 1983 Sonada, Takano, Miyahara, and Kato introduced a scanning-laser-stimulated luminescence technique using photostimulable phosphors. A paper discussing this technology appeared in 1984. The phosphor, a Europium-activated barium fluorohalide compound, is applied to a reusable plate. During exposure the phosphor captures electrons; when scanned by a high-intensity laser, the energy is released as light, and balanced exposure results. This technique has been rather widely used for portable chest radiography, where repeat examinations have essentially been eliminated. If a picture archiving communication system (PACS) is being introduced into a department, this type of storage phosphor technology is preferred.

In the early 1980s a prototype for a scanned-projection digital chest X-ray unit was described by Tesic, Mattson, Barnes, Sones, and Stickney. The device passed a vertical fan beam through fore and aft slit collimators before striking a detector array composed of 1,024 photodiodes coupled to a gadolinium oxy sulfide screen. This system presented some advantages, but the prototype unit had the disadvantage of a relatively long scan time (four and one-half seconds) and a film dose about double that of conventional radiography.

In 1983 Flewes and his colleagues discussed computer equalization radiography and introduced scanning equalization radiography (SER). A variant of this system is available commercially and is sold as the AMBER system (Advanced Multiple Beam Equalization Radiography). Early experience with AMBER technology suggests a major improvement in film quality.

Templeton described an image intensifier-based system in 1987. This system uses a large field-of-view image intensifier; images are recorded on a video display terminal or on film. Film digitization, yet another digital imaging technology, requires that a film be made and its information content be digitized. These two approaches to digital radiography have not achieved wide popularity.

InSight technology

In the early 1990s a new film-screen system called InSight, based on the development of a zero anti-crossover film, was introduced. Previous anti-crossover film actually had a crossover of 18 to 20 percent. Two separate film emulsions, with different H and D curves, can be applied to the same base. In chest radiology this film allows one emulsion to register mediastinal information and the other, lung information. The system uses conventional X-ray generating equipment; the only additional cost is the film-screen system itself. For this reason the system has become competitive with AMBER, but current data indicate that InSight produces only 40 to 50 percent of the improvement in contrast and signal-to-noise ratios routinely provided by AMBER.

Diagnostic Breakthroughs

Once again, a determination of which non-technological advances in medicine and radiology since 1965 are the most significant rests with the beholder. We have selected six areas of interest for discussion here. Although the selection is somewhat arbitrary, most observers of the medical scene over the past quarter of a century would almost certainly include some, if not all, of these topics as breakthroughs.

Adult respiratory distress syndrome

Although adult respiratory distress syndrome (ARDS) undoubtedly has existed for centuries, credit for its recognition as a distinct entity is usually given to Ashbaugh, who described twelve cases in 1967. Various definitions of the syndrome have been proposed, some requiring more rigid criteria than others. Murray has defined the syndrome as being composed of three major elements:

1. Occurrence usually associated with a serious injury that may not affect the image initially;
2. Latency for a period of a few hours or days before respiratory symptoms develop; and

3. Development of acute respiratory failure that may progress relentlessly.383

The evolution of our understanding of the pathophysiology of ARDS has been the subject of an interesting historical review included in an article by Rinaldo and Rogers.394 Initial theories implicated surfactant deficiency, but subsequent experimental studies suggested that the primary pathophysiological defect was leakage of fluid from the capillary bed, a thesis ultimately confirmed by Pratt.395 Other researchers, including Marianne Bachofen, Hans Bachofen, and Ewald Weibel in Bern, Switzerland, confirmed this observation.396 Subsequently, other factors have been found to play a role, among them intravascular thrombosis, a finding described by Reginald Greene.397,398 Other radiologists in addition to Greene have made notable contributions to our understanding of ARDS. Dyck and Zylak gave an early description of the radiographic findings in ARDS.399 In 1974 Norman Joffe, working at the Beth Israel Hospital in Boston, reviewed the radiology of ARDS in an article in which he correlated radiographic findings with the three pathologic stages (exudative, organizing, and fibrotic) of the syndrome.400 Progress in the management of ARDS has evolved slowly, and the condition remains one of the major scourges of the intensive care unit in hospitals everywhere.

**The mediastinum**

Although some early workers such as Gladnikoff and Marchand made notable contributions to our understanding of the radiographic appearances of the mediastinum (Marchand, for example, established the concept of the continuity of the perivisceral space of the mediastinum with that of the neck and with the bronchovascular connective tissue investure), relatively little was written about this area until recent years.411,412 An exception is *The Mediastinum*, by Leigh and Weens, published in 1959.413 Later, key articles by Lane and Carsky, Felson, Berne, and Genereux appeared.414

A comprehensive study of the radiology of the mediastinum based on correlations with anatomy and pathology was provided in E. R. Heitzman’s book, also called *The Mediastinum*, in 1977; a second edition appeared in 1988.415 CT opened new doors to our ability to study and understand the mediastinum and is discussed extensively in Heitzman’s book and in a volume by Naidich, Zerhouni, and Siegelman.416

**Acquired immunodeficiency syndrome**

In 1981 the initial reports of what is now known acquired immunodeficiency syndrome (AIDS) were made to the Centers for Disease Control.417,418 At the same time, two articles appeared in the *New England Journal of Medicine* describing a new form of acquired cellular immunodeficiency.419,420 These commentaries presaged one of the most devastating and tragic epidemics in modern history. Immediately, thoracic radiologists, along with physicians representing all disciplines, were called on to identify and explain a continually expanding array of bewildering findings. The limited nature of our early understanding of AIDS was underscored in a radiological CPC discussed by Lee Theros in 1983.421 Although we are still far from controlling the epidemic, a tremendous amount of new information about the problem has been uncovered in the last few years. Thoracic radiologists have contributed their share of this new data. Many excellent review articles on the radiology of chest disease in AIDS have appeared. As early as 1982 Gamsu gave a comprehensive review of pneumocystis carinii pneumonia occurring in homosexual men.422 McCauley provided an early description of Kaposi’s sarcoma involving the lung in these young men, and Sivit later provided radiologic-pathologic correlative material concerning the disease as it involves the lung.423,424 Naidich pointed out that “[Thoracic] adenopathy should not be interpreted as manifestations of the dif-
fuse lymphadenopathy syndrome or AIDS related complex. In their experience, intrathoracic adenopathy in the homosexual male suggests Kaposi’s sarcoma, lymphoma, or mycobacterial infection. Sandhu and Goodman were the first to emphasize the common occurrence of pulmonary cysts in AIDS. Although Pitchenek is generally given credit for pointing out that massive hilar and mediastinal lymphadenopathy is a common manifestation of mycobacterium tuberculosis infection in patients with AIDS, several radiologists have supported this association, among them Kent Ellis, who emphasized this observation at several recent Fleischner Society courses.

Carcinoma of the lung

The past three decades have shown a considerable advance in our understanding of lung cancer. Antismoking campaigns are vigorous, surgical technique has improved, and chemotherapeutic management has progressed. Nevertheless, deaths from lung cancer continue on the rise. Bronchogenic carcinoma accounted for 157,000 of 514,000 cancer deaths in 1991. The sharp rise in frequency among women continues. In 1991 lung cancer replaced coronary artery disease as the principal cause of excess mortality in smokers.

Interestingly, some aspects of the pathology of the disease have evolved. Auerbach and Garfinkel have pointed out that lung cancer recently has presented more often as a peripheral mass than formerly; before 1978 31 percent of cancers were peripherally located, while between 1986 and 1989, 42 percent were found in the periphery. They also reported change in the frequency of terminal bronchiol-alveolar cell carcinoma, which more than doubled in the periods before 1979 and between 1986 and 1989.

One of the major advances in understanding and managing lung cancer in the past twenty-five years has been the development of a staging system for the disease. In 1959 the American Committee for Cancer Staging and End Results reporting was formed. Shortly thereafter this committee adopted the Tumor–Nodes Metastasis (TNM) system of cancer staging advocated by the committee on clinical stage classification of the International Union Against Cancer. More recently, a modification of the TNM system was developed. In the years following the introduction of the original TNM system, it became evident that some patients classified by the TNM system as having Stage III disease because of mediastinal lymph node involvement had relatively extended survival. Tisi raised the question as to whether the N characteristics needed further refinement. As a result, spread to lymph nodes that can be removed surgically (N2) is now distinguished from those that cannot (N3). In addition, the American Thoracic Society charged a committee to “develop a map of regional pulmonary lymph nodes that would be acceptable to all physicians who care for the patient with lung cancer.” In part to take into account the 1986 revision of the TNM system, additional modifications were published by Paul Friedman. Staging has made an important contribution to the management of lung cancer, improving communication between radiologists, surgeons, and others who care for these patients and providing a standard for judging management and outcomes.

Unfortunately, the past ten years have brought rather sobering data to bear on the subject of the accuracy of lung cancer staging by radiologic methods. Original optimistic assessments of both sensitivity and specificity of detecting hilar and mediastinal lymph node metastases by using size criteria determined from CT have not been confirmed in several recent carefully controlled studies. In most of these series, both sensitivity and specificity was found to be about 60 percent. MR imaging did not improve these statistics. Certainly, it has been established that, although CT can supply much important information, it is not a substitute for surgical staging.

Another unfortunate observation of recent years is that although radiologic sophistication has grown remarkably,
our ability to detect lesions, including cancers, on plain chest films has not. The concerns of the 1950s in this regard remain equally strong today. In 1983 Muhm reported that 90 percent of the cancers in a screening program could be seen in retrospect on previous films.\textsuperscript{365} In 1982 Austin reported that an astonishing mean of 26 percent of cancers were not seen by observers who were told that cancer was present on the film.\textsuperscript{367} Woodring also has recently commented on these dismal detection rates and has offered suggestions for improvement.\textsuperscript{368} This area appears to be fertile ground for further basic investigation of observer performance.

Early detection of lung cancer, an area in which radiology is clearly falling, seems to be increasing in importance. More lung cancers are peripheral in location than in the past, and Flehinger has reported a 70 percent five-year survival for Stage I patients.\textsuperscript{369,370} For these reasons Flehinger's group suggests annual chest X rays for patients at high risk.\textsuperscript{371,372} Thus the question of screening for lung cancer has again become a topic for discussion. Clearly, our detection rate is poor, but the rewards of early detection seem great enough to justify another look at this problem. Reginald Greene has suggested recently that radiologic screening does have benefits, and that it appears that the National Cancer Institute will institute a multiphasic screening trial to assess the value of radiography in decreasing lung cancer mortality.\textsuperscript{373}

\textit{Special procedures in thoracic radiology}

As indicated earlier, many of the special procedures in chest radiology were initiated before the modern period, but the last thirty years have witnessed considerable increase in the sophistication of some techniques and the development of others.

\textit{Transthoracic needle aspiration biopsy}

Transthoracic needle aspiration biopsy came of age in the late 1970s and early 1980s, when several large studies were reported.\textsuperscript{374} Each series reported a very low complication rate. On average, a positive diagnosis of malignancy was achieved in more than 90 percent; specific benign diagnosis was proved in quite varying percentages: 40 percent in the series of Greene and 69 percent in the series of Khouri.\textsuperscript{375,376} Although early papers\textsuperscript{377,378} reported success with percutaneous needle biopsy of mediastinal lesions, refinements in technique for biopsy of central hilar and mediastinal lesions reported in the early 1980s by Westcott, Gobien, and van Sonnenberg improved the value of the technique.\textsuperscript{379,380,381} In Westcott's experience with one hundred cases, successful completion of the procedure was accomplished in ninety-one patients with a diagnosis of malignancy established in 96 percent.

\textit{Empyema drainage}

Catheter drainage of the pleural space for empyemas was established as a worthwhile technique in the mid-1980s. Important papers were published by van Sonnenberg, who reported the successful treatment of fifteen of seventeen patients, and by Westcott.\textsuperscript{382,383}

\textit{Thoracic angiography}

Early reports of the management of pulmonary bleeding by embolization techniques came from France in the early 1970s. Notable among these studies was the work of Jacques Remy and his colleagues, who by late 1975 had managed 104 patients with lung hemorrhage by bronchial artery embolization.\textsuperscript{384,385} Later papers by this group describe their subsequent experience.\textsuperscript{386,387}

The first embolization of a pulmonary arteriovenous malformation using Gianturco coils was apparently performed in 1978 by Taylor, Cockerill, Manfredi, and Matte.\textsuperscript{388} This procedure has now received wide acceptance as appropriate management of pulmonary arteriovenous fistula.\textsuperscript{389,390}

\textbf{IN CONCLUSION}

Since Röntgen's discovery in 1895, history has witnessed an unparalleled
century of development in the science of imaging technology. Radiology is
now positioned in the forefront of medical diagnosis and can only grow more
diverse and more valuable. Thoracic imaging, of course, plays a major role in
the dominant position held by diagnostic imaging. The host of researchers,
teachers, and leaders, some of whom have been mentioned in the preceding
pages and some who have not, deserve our admiration and gratitude for the
achievements of the past. We can confidently predict that their successors will
lead medical imaging to new, exciting, and even more valuable heights.

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