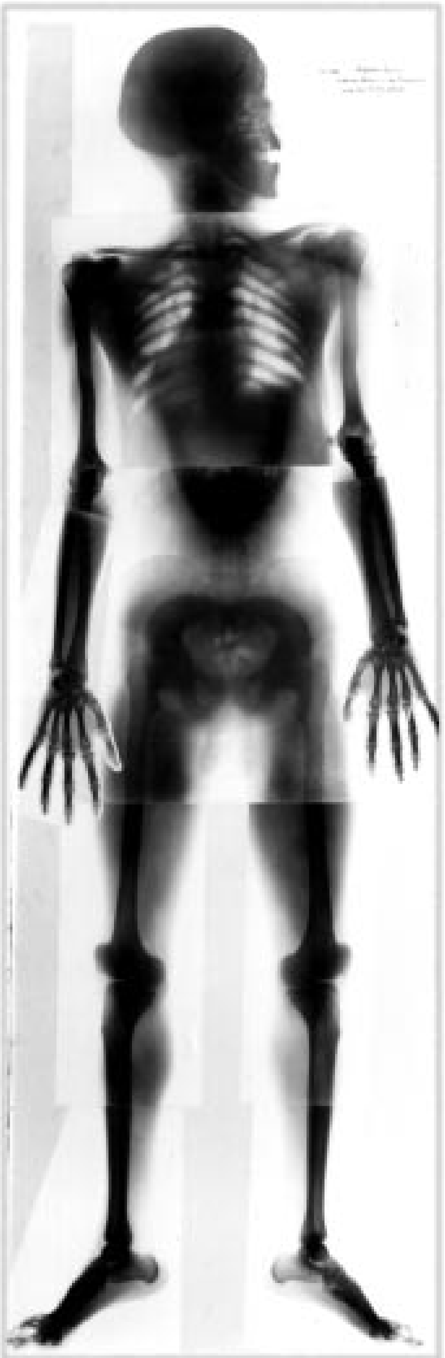
Medical Applications of X Rays

by OTHA W. LINTON

IN THE DAYS following his discovery of a new, invisible ray in November, 1895, Professor Wilhelm Conrad Roentgen experimented doggedly to test its properties. He noted quickly that solid objects placed in the beam between the Crookes' tube and the fluorescent screen serving as an image receptor attenuated or blocked the beam, depending upon their density and structure.



A CENTURY OF RADIOLOGY: 1895–1995

The discovery of the X ray in 1895 was one of the most momentous events in science and medicine, but it was only the beginning of what was to be accomplished in the next 100 years in radiology. What follows are some highlights provided by American College of Radiology.

1895

- German physics professor Wilhelm Conrad Roentgen discovers the X ray on November 8 in his laboratory in Würzburg.
- On December 28, Roentgen announces his discovery with a scientific paper, *W. C. Roentgen: About A New Kind of Rays (preliminary communication)*, that is widely reprinted.

1896

- On January 23, Roentgen delivers his first lecture about the X rays.
- Roentgen's discovery launches a flurry of experimentation around the world with the Crookes' tubes. Researchers study what the X rays will do and tinker with refining the design of the tubes. Although the shapes and configurations of the tubes change, the basic concept will stay the same until 1913.
- Fluoroscopy is invented in January by Italian scientist Enrico Salvioni, while American inventor Thomas Edison, an early and active X-ray enthusiast, works on a similar device. The fluoroscope is a hand-held or mounted device consisting of an oblong box, one end of which fits tightly against the eyes, the opposite end of which is a fluorescent screen. The basic concept is still used today.
- In March, a "Roentgen photograph" is introduced as evidence in a Montreal courtroom by a man suing a defendant who allegedly shot him. The X ray proves the presence of a bullet not detected by exploratory surgery.
- Hospitals begin acquiring X-ray equipment to be used by people with and without medical qualifications.
- One of the first physicians to specialize in X rays in 1896 is Dr. Francis Henry Williams of Boston. He is also a graduate of the Massachusetts Institute of Technology, making him one of the few physicians intimately conversant with the physics that create X rays. He is instrumental in early uses of X rays for medical diagnosis, including the use of fluoroscopy to study the blood vessels. Later this will be known as angiography.

1898

- In December, Marie and Pierre Curie, working in Paris, discover radium, a new element that emits 200 million times more radiation than uranium. In 1903, the Curies and Antoine-Henri Becquerel share the Nobel Prize in Physics for their work on radioactivity.

  "Like the discovery of X rays, the discovery of radium captured the world's imagination," says Nancy Knight, Ph.D., historian and director of the Center for the American History of Radiology. "Scientists knew that the radiation from X rays and radium was similar, but radium was considered the 'natural' version of X rays."

Then, in a heart-stopping moment, he chanced to pass his hand through the beam. As he looked at the screen, the flesh of the hand seemingly melted away, projecting only the outlines of the bones. The hand was intact, unharmed. But on the screen, only the bones showed up. With that observation, the science of medical radiology was born.

A few days later, Roentgen made a photographic image of his wife's hand, using the new rays instead of light for the exposure. Again, only the bones showed, this time on a permanent record which others could see—and believe.

The discovery of a new form of energy that could penetrate solid objects and record their structure excited Roentgen's scientific contemporaries. But it was the skeletal hand that captured the imagination of the public and of physicians, who recognized instantly that this discovery could change medical practice forever.

A century later, the vastly more sophisticated arts of medical imaging are still based upon the recognition that body parts absorb a beam of X rays according to their density, producing an image which allows identification of body structures as well as the recognition of abnormalities reflective of injury and disease conditions.

Take a chest X-ray image, for example. The calcium density of the spine and ribs blocks the most X rays, leaving white areas on a film. No X rays penetrate to expose the film and darken those spots. The water densities of the stomach and liver are grayish. They block less of the X-ray beam than bones. It's easy to see the contrast between them. The fat density of muscles is less than that of the water. They look only slightly darker, but the distinction is there for a trained eye. Finally, the air spaces in the lungs allow penetration of most of the X-ray beam, and look almost black on the films.

Allow that the chest X-ray image looks complex because three dimensions are recorded as two. Muscle tissue overlies the ribs, which in turn overlie the lung cavities. The shapes of blood vessels (water density) and the esophagus, which carries food and liquids to the stomach, can be seen. Fractures of the ribs, abnormal curves of the spine, unusual heart silhouettes are readily visible. Irregular shadows, caused by cancers growing in the lung, may require a sophisticated viewer to pick


German Museum, Munich

The famous radiograph made by Roentgen on December 22, 1895. This is traditionally known as "the first X-ray picture" and "the radiograph of Mrs. Roentgen's hand." However, it was not actually the first X-ray picture (others exposed photographic plates to X rays previously, without knowing the images' significance), and was not labeled as Mrs. Roentgen's hand when it was first published.

up in the welter of overlapping shadows. The pattern of coal particles retained in the lung field of miners may be even more subtle, but is essential to a diagnosis of black lung.

IN THE WEEKS after the first medical X-ray images early in 1896, scientists and physicians began to improve on the faint images produced by tubes and generators like the ones Roentgen used. How they made improvements—borrowing from advances in physics, chemistry, pharmacology, nuclear science, computers, telemetry and information science—is the story of a century of medical radiology.

Those early X-ray experiments also led scientists to observe that the passage of X rays through living tissue could cause changes. The low-energy X rays appeared to have a good effect on many skin diseases. Open cancers shrank and the sores dried up. Arthritis sufferers reported relief from their pains. When exposures were seen to make hair fall out, the X ray was touted as an end to men's daily shaving chores. But just as quickly, workers with X rays noted that repeated exposures seemed to cause skin inflammations, ulcers, sores, superficial and deeper cancers, blood abnormalities, and even death. The question arose: must X-ray workers inevitably forfeit their own health, as some pioneers did, to the promise of this new science?

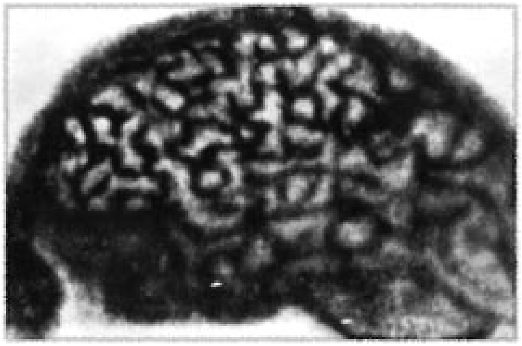
The struggles of radiation scientists to develop radiation safety protocols, to devise measurements, to learn to control X-ray production, and to exploit the seeming paradox that higher energies of radiation kill more cancer cells while sparing normal ones are also parts of this century of remarkable progress.

The earliest X-ray images were more useful to surgeons than to other doctors. Bone fractures or displacements, gallstones, kidney stones, and bullets or other metallic fragments could be located reliably. With the improved tubes and films that relaced the original glass plates, doctors began to see organ shapes. But they still could not see *into* organs, which had the same water density inside and out.

Nevertheless, other advances came quickly. In 1896, the inventor Thomas Edison devised the fluoroscope, a calcium tungstate coated screen which glowed when X rays hit it, allowing direct viewing of any part of the anatomy. In 1913, William D. Coolidge of the General Electric Laboratories devised an improved hot cathode X-ray tube, which produced consistent repeated exposures and was shielded to prevent the scattered radiation that had harmed the early X-ray users. X-rays emerged from Coolidge's tubes only through an aperture in the lead shielding. The patient could then be placed into the beam while others were kept away from it. Additionally, filters were devised to absorb soft, useless X rays, and a device called a grid, placed in front of the film, absorbed much of the X-ray scatter that could cause fuzzy images. Screens similar to the fluoroscope surface were used in film holders to enhance X-ray images.

And the problem of looking within body structures was finally addressed as well. Liquids opaque to X rays were found that could

This much admired "first radiograph of the human brain" from 1896 is actually a pan of cat intestines. Since the X ray was so novel to the public, falsified images appeared frequently after Roentgen's discovery.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Around the world people believe radium to have marvelous medicinal properties. It is said to lessen constipation, lower blood pressure, cure insomnia by soothing the nerves, and increase sexual activity, and is put in skin creams and toothpastes. People flock to radium springs, where the water is mildly radioactive, a craze that lasts into the 1930s, and use 'radium drinkers,' ceramic vessels made of irradiated earth, at radium cocktail parties, where inside everyone's drink is a vial of 'radium emanation'—radon gas—to make the drinks glow in the dark. Also popular is 'radium roulette,' in which the roulette balls and table are painted with radioactive paint.

1900

- German scientists Friedrich Giesel and Friedrich Walkhoff discover that radium rays are dangerous to the skin; Pierre Curie purposely leaves a radium sample on his arm for ten hours and produces a sunburn-like rash. En route to a conference, Henri Becquerel unthinkingly carries a sample in his lower vest pocket and suffers a burn on his abdomen.
- Radiology begins to emerge as a medical specialty. It becomes increasingly clear that producing an X-ray image requires skill and technical know-how, and interpreting the image requires a knowledge of anatomy.

1901

- Roentgen wins the first Nobel Laureate in Physics prize for his discovery.

1904

- Clarence Dally, Thomas Edison's assistant in X-ray research, dies of extreme and repeated X-ray exposure. X rays had already caused severe burns on his face, hands, and arms, resulting in several amputations. From this point on, the risks posed by radium and X rays become more clear. X-ray use begins to be confined largely to doctor's offices and hospitals.

1910

- Eye goggles and metal shields are commonly used to shield X-ray users.

1917

- During World War I, X-ray equipment is an accepted component of aid stations and hospitals in the field.

1919

- Dr. Carlos Heuser, an Argentine radiologist, is the first to use a contrast medium in a living human circulatory system. The compound, potassium iodide diluted with water, is acceptable because it is excreted by the body and causes the blood vessels to appear opaque on the X-ray image. Dr. Heuser successfully injects the compound into a vein of a patient's hand and simultaneously takes an X ray to visualize the veins in the forearm and arm. His discovery, however, is lost on the scientific world because it is published only in Spanish, in an Argentine medical journal.

be ingested or otherwise placed within a patient. For instance, barium sulfate, a common mineral, could be ground up and swallowed to outline the esophagus, stomach, and small intestine. Barium sulfate could also be inserted as an enema to visualize the large intestine. This practice allowed the viewing of strictures, blockages, ulcers, cancers, and other defects. But the development of other radio-opaque liquids, now called contrast agents, which could be used with the kidneys, the brain and spinal canal, the circulatory system and the lungs, took much longer and required far more complex solutions.

ROENTGEN'S DISCOVERY was artificial ionizing radiation. Two years later, a French physicist, Henri Becquerel, discovered that certain rocks emitted natural ionizing radiation with characteristics much like Roentgen's X rays. Becquerel's colleagues Pierre and Marie Curie refined the naturally radioactive ores to derive uranium, polonium, and radium.

Radium was perceived to have a value in treating cancers, already seen to be responsive to X rays. Marie Curie's work produced only tiny amounts, with one ounce of radium being offered for sale at $1 million. The radium salt (usually radium sulfate) was sealed in hollow gold or platinum needles and inserted into or against cancerous lumps to deliver cell-killing doses of radiation. A decay product of radium, radon gas, was used in hollow glass seeds for insertion in tumors which could not be reached with the removable needles.

William Coolidge soon improved his X-ray tubes to deliver energy levels of 200 kilovolts and more, and as doctors used radium coupled with the high energy X-ray beams, they noted the seeming paradox that higher energies killed more cancer cells and spared more normal tissue than lower-energy radiation. Radiobiologists came to understand that the rapid mitosis of cancer cells made them more susceptible to radiation destruction and less capable of regeneration than slower-growing normal cells. But because some normal cells were necessarily radiated in the process of getting the energy to the cancers, the success of treatment depended upon the ability of the radiologist to plan and deliver a dose that would kill all of the cancer cells without destroying an unacceptable amount of normal cells.

X-ray image of coins made by physicist A.W. Goodspeed and photographer William Jennings in 1896, duplicating one they had made by accident in Philadelphia in 1890. When the two made the 1890 radiograph, they did not realize its significance, and the photographic plates lay unnoticed and unremarked until Roentgen's announcement of the X-ray discovery caused them to review the images.

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Optimal dose levels, time intervals for treatment to take advantage of the mitotic cycle, ways of protecting normal parts of the patient, medical care to protect patients against infections, and other products of white blood-cell radiation destruction all began to contribute to improved radiation treatment. Even so, surgery remained the first choice of treatment for many kinds of cancers, leaving radiation as an adjunctive method for destroying cancer cells not removed by surgery and for trying to control metastases from advanced cancers.

DURING THE FIRST four decades of this century, many advances in medical radiation uses came from gradual improvements in equipment and techniques. The availability of X-ray machines in military hospitals during World War I convinced many physicians of the usefulness of X-ray studies in detection of somatic problems, as well as trauma. A chest X ray became the standard method of diagnosing tuberculosis. About all that could be offered the active tubercular patient was nursing care, but isolation of such patients helped to break the spread of the highly contagious disease to other family members and co-workers. Tuberculosis was the target of the first X-ray population screening efforts.

The creation of artificial isotopes in the 1930s by Frédéric Joliot and Irene Curie, daughter of Pierre and Marie, opened new dimensions in radiation science. Soon, Ernest Lawrence was making artificial isotopes in the cyclotron of the Donner Laboratory at the University of California in Berkeley. Lawrence invited Robert Stone, the chief of radiology at the University of California Medical Center in San Francisco, to bring cancer patients for treatment with neutrons produced in the Donner lab. Cancers treated with neutrons melted away. Soon, so did the cancer patients. Neutrons had more energy and different biological characteristics than high energy X rays. Stone discontinued his treatments until the characteristics of neutrons could be understood better.

World War II arrived, and in quick succession Lawrence, Stone, and most of the leading radiation scientists in the free world were drawn into the Manhattan project to develop an atomic bomb. Wartime imperatives drive science more strongly than peaceful objectives. But there was an appreciation within the Manhattan project that biological problems were created by the physical and chemical advances, and after the war, the congress created the Atomic Energy Commission to further peaceful applications of the new radiation science.

FOR PHYSICIANS, these peaceful applications took two directions. One was the development of artificial reactor-produced isotopes as high energy sources for radiation treatment. During the war years, there had been development of Robert van de Graaff's million volt static generators and Donald Kerst's high energy betatron, the first supervoltage therapy machines. But the simplicity of using cobalt 60 or cesium 137 in rotating-head

1920–1929

- Chest X rays are used to screen for tuberculosis—a scourge of even greater concern to the public than cancer. Exposures of up to 1 minute, with 10 to 20 rads (units of absorbed radiation dose) are used.
- Roentgen dies February 10, 1923.
- The first practices of modern angiography are developed in 1927 by a Portuguese physician, Dr. Egaz Moniz, who is the first to create images of the circulatory system in the living brain. He develops a carotid angiography technique, which involves making a surgical incision into the neck, identifying the carotid artery and injecting contrast into the artery, which transports it to the brain.
- Drs. Evarts Graham and Warren H. Cole of Washington University, St. Louis, discover in 1923 how to visualize the gall bladder with X rays by using contrast media, a discovery significant in the diagnosis of gall bladder disease.

  This discovery demonstrates the role of chance in science, in that the doctors tried for four and one half months to visualize gall bladders in dogs by injecting contrast medium into the dogs in the morning, then taking X rays in the evening, to no avail. One day they finally produced a picture of a gall bladder in one particular dog, but for several days thereafter were unable to recreate the results. In their hunt for an explanation for this anomaly, they confronted the kennel attendant—had he done anything different to that one dog? The attendant confessed that due to a severe hangover he had not gotten around to feeding that particular dog on the morning of the test. If he had, the dog's gall bladder would have emptied when the dog's food was digested. Thus the discovery was made.

1930–1939

- In 1934, the American Board of Radiology is officially formed and recognized by the American Medical Association.
- In 1936, the first "tomograph"—an X-ray "slice" of the body—is presented at a radiology meeting. This revolutionary concept, in which the X-ray tube is moved by pulley around the patient in order to take pictures on various planes, can focus on certain internal structures that cannot otherwise be seen clearly. This technique, also called "laminagraphy," foreshadows the development in the 1970s of CT, or computed tomography.
- While higher voltage X rays are being developed, their actual clinical benefit remains untested. Beginning in March 1932, clinical trials are initiated. Results of the studies, comparing 70,000-volt X rays to 200,000-volt X rays used on cancers of the larynx and tonsils, among others, are reported by scientists this way: "The same results [cures] can be obtained using a [higher] dosage which causes considerably less discomfort to the patient." These results encourage further research into super-voltage equipment, although the equipment has some limitations; "patient discomfort" is not well-measured and the tumors evaluated are not the deep body lesions that physicians still want to treat.
- Blue Cross/Blue Shield and other insurance or medical prepayment plans start to cover X-ray services, vastly increasing their availability.

treatment devices soon eclipsed the early electronic generators. Cobalt 60, with an energy of 1.33 million electron volts, emerged in the late 1950s as the workhorse for radiation therapy.

The second direction was the development of lower energy isotopes such as iodine 131 for use as diagnostic tools. Trace amounts of iodine or other isotopes could be given a patient. By measuring the output of urine, for example, using a Geiger counter, a physician could assess kidney function. With scintillation crystal detectors, a doctor could study an image of radioactive iodine uptake in the thyroid gland, to study function and to infer the presence of tumors.

Advances in X-ray techniques continued apace. Russell Morgan at the University of Chicago developed phototiming, a method of matching exposures to physical characteristics of patients. Morgan, Edward Chamberlain of Temple University and, principally, John Coltman of the Westinghouse Corporation are credited with the conceptual development of electronic image intensification, together bringing fluoroscopic studies out of darkened rooms. Reduced amounts of radiation could be fed into a fluoroscopic screen and brightened several thousandfold before being displayed on an output screen. This procedure allowed recording of motion, such as the flutter of a heart valve, on motion picture film or videotape without subjecting patients to unacceptable levels of radiation.

Radiologists and some other physicians began to expand the uses of hollow catheters to inject contrast liquids into the vascular system and other body channels. The skills needed to thread a catheter tip into position to visualize the coronary arteries or the vessels of the head were compared by one investigator to the task of pushing a rope through twisted passageways.

A major advance in isotopic diagnosis resulted from the development by Harold Anger of the University of California of the gamma camera, with its array of photomultiplier tubes and a large crystal which shortened scanning time. This was coupled with the development of various chemical forms of technetium 99m, an isotope with a six-hour half life. Technetium could be tagged to various chemicals to allow concentration in different organs of interest. Given its six-hour decay period, relatively larger amounts of isotope could be used without increasing patient exposures. Soon isotope

This X-ray image of a foot in a high-button shoe was typical of early images reproduced in the popular press after the discovery of the X ray. This image was made by Francis Williams of Boston, one of the first radiologists, in March 1896.

scans were the preferred method of exploring many problems in the brain and liver.

By the late 1950s, investigators including Henry Kaplan and the Varian brothers at Stanford University were working on a device called a linear accelerator to generate high energy X rays or electrons for cancer treatment. Referred to as linacs, the devices soon grew smaller, delivered higher energies and became safer and more reliable. They produced controlled energy beams in ranges from 4 to 25 million electron volts, and gradually displaced cobalt units as the primary radiation therapy sources in most advanced countries.

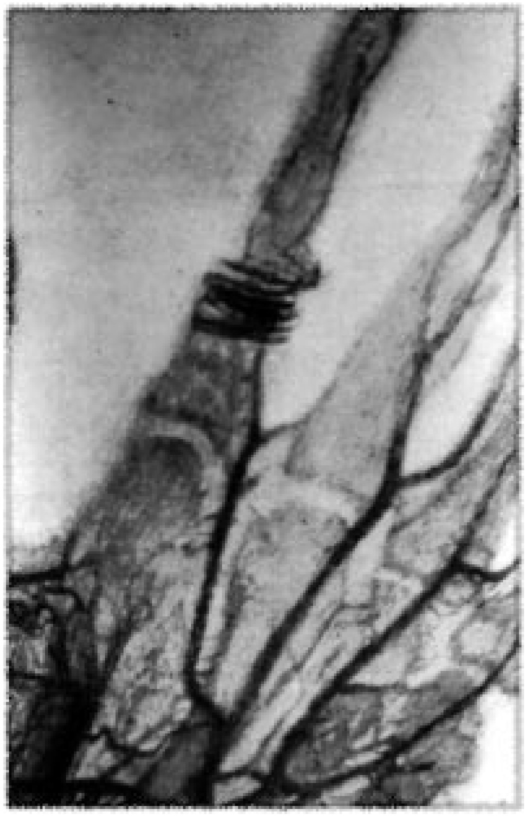
ON THE DIAGNOSTIC SIDE, the 1960s brought the advent of diagnostic ultrasound with great promise. Soon ultrasound devices utilized a crystal transducer that bounced pulses off body structures and displayed the echoes as a scan. Motion was added, and Doppler techniques rapidly allowed study of blood flow and other physiological processes. Even after 30 years, there are still no indications of harmful bioeffects from ultrasound exposures at the energy ranges used for diagnosis.

By this time, some radiologists had begun to inquire into the new information systems based upon huge, ungainly devices called computers. But computers soon shrank in size, grew in power, dropped in price and began to be available in research centers. They were used for complex radiation treatment plans, allowing far more speed and sophistication with isodose curves than was possible with manual calculations. Diagnosticians used computers first for image analysis, coupling densitometers with them to obtain basic data. These efforts met with limited success.

Early in the 1970s, diagnostic radiology made a huge leap into cross-sectional imaging with the development of computed tomography (CT). Earlier, mechanical tomography had been used for limited purposes. But here was a completely new technology, producing what looked like bloodless slices across the body area of interest. The first scanner, devised by Geoffrey Hounsfeld of EMI in England, could image only the head, and required a patient to place his skull into a water bath while the X-ray tube and receptor mechanically advanced around the head. Improvements were swift as other manufacturers replaced mechanical parts with electronic ones. Soon, a ring of X-ray tubes and receptors could obtain images of any transverse body plane in seconds, and complex mathematical algorithms could draw clear, sharp images out of millions of bits of information.

By advancing the plane of the scan in small steps, a three-dimensional construct of a suspect organ could be developed. Elliot Fishman at Johns Hopkins worked out a reconstruction method to give surgeons three-dimensional simulations of crushed or misshapen body parts for guidance in delicate operations. And radiation oncologists used computed tomographic images to plan their treatment fields.

Angiographic work began in January, 1896, with this post-mortem injection of mercury compounds. This image was made by E. Haschek and O. Lindenthal of Vienna.



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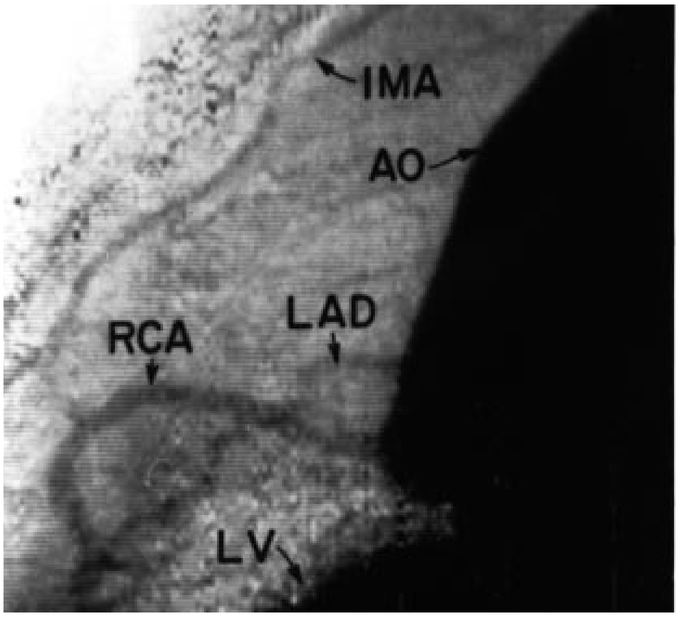


The first image of a human coronary artery recorded in vivo *with synchrotron radiation. This coronary angiogram was done at the Stanford Synchrotron Radiation Laboratory at the Stanford Linear Accelerator Center in May 1986. The identified structures are an internal mammary artery (IMA), the aorta (AO), the left anterior descending coronary artery (LAD), the right coronary artery (RCA), and the left ventricle (LV). (Image courtesy of Edward Rubenstein, M.D.)*

1940–1949

- The Betatron, a circular electron accelerator, is developed by Dr. Donald Kerst of the University of Illinois between 1940–1943. It generates energy (20 million volts or more) by orbiting electrons, faster and faster, through a large "doughnut," a circular glass tube with a heated cathode inside a huge electromagnet.

1950–1959

- Dr. W. Goodwin introduces the concept of X-ray guided percutaneous nephrostomy, in which a needle and then a catheter are inserted directly into a kidney to create a drainage tract above an obstruction (kidney stone, cancer), allowing urine to escape from the kidneys. This procedure allows some patients to be treated without surgery.
- Radioisotopes are introduced as sources of gamma-ray beams for radiation therapy. The process works, for example, by changing harmless cobalt 59 into cobalt 60, a highly unstable nucleus that decays. As that happens, it releases two gamma rays. The gamma-ray beams adequately reach deep cancers without damage to the skin. Cobalt units are easy to make and quickly become a cheaper, safer alternative to the Betatron, though later they will become virtually unused.
- Ultrasound—images created from the echoes of sound waves bounced off tissue—which has its roots in World War II's sonar (sound navigation and ranging), begins to show promise in medical diagnostic applications.
- A Swedish physician, Dr. Sven Ivar Seldinger, refines Dr. Moniz's and Dr. Forssmann's work in angiography from the 1920s when he learns how to insert a catheter into a blood vessel without surgery. He uses a tiny guidewire inserted with the help of a needle into a blood vessel. The catheter is placed over the guidewire and into the vessel, after which the guide wire is removed. He then watches the location of the catheter on fluoroscopy.

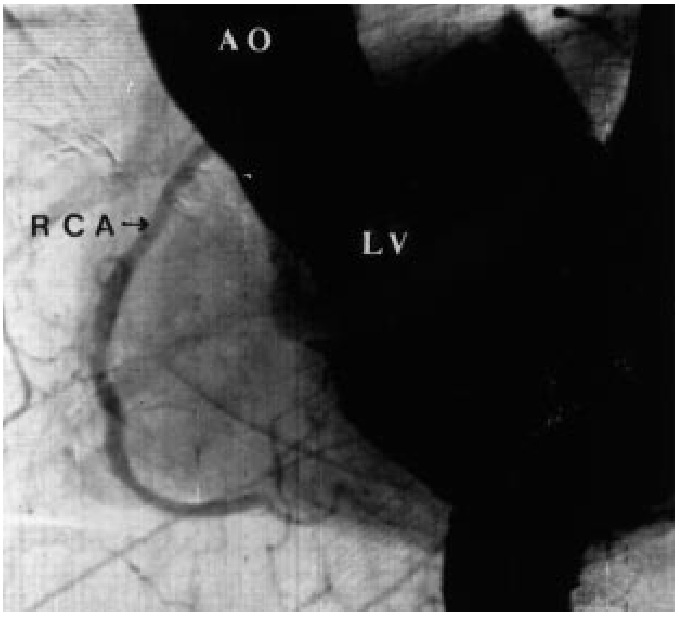
Because of political decisions based on health planning laws, many CT scanners were located outside of hospitals. In just a few years, CT scanning had become state-of-the-art technology. The United States had more scanners than the rest of the world, and Los Angeles alone had more than Great Britain.

There was more to come. In less than a decade, magnetic resonance imaging burst on the scene with even more promising—and even more expensive—technology. MR image analysis technology was comparable to CT, but no X rays were needed. Instead, MR units relied on strong magnets, as much as 8000 times as strong as the earth's magnetic field.

In an MR unit, magnets rim an aperture into which patients slide on a gantry. The strong magnetic field acts upon the inherent magnetism of the trillions of hydrogen atoms in the human body. When the magnetic field is imposed and released, hydrogen atoms emit a faint radio signal. Detection and analysis of these signals produces the image.

MR proved to be complimentary to CT. MR images could be created in any body plane—axial, sagittal, oblique, AP, or all of them. Soft tissue detail allowed better study of glandular systems. And soon, new developments in CT resulted in spiral scanning, with the machine advancing across the chosen body area to produce hundreds of slices at any designated interval. Contrast agents, very different for CT and MR, allowed study of the inside of body organ systems. Various other mathematical tricks allowed the electronic subtraction of other anatomic structures to reveal a vascular system of the head and neck with the shadows of the skull, brain, and other structures erased. Strictures, emboli, kinks, and accumulations of plaque had nowhere to hide.

In the same years, the term "interventional radiology" came into use to describe the ability of physicians using catheters and fluoroscopy to detect and correct vascular insufficiencies and strictures in other body ductal systems. Initially, catheters inserted into arteries or ureters allowed deposit of contrast agents at suspect spots. Then micro-sized tools were threaded through the same catheters to correct problems. Andreas Gruntvig of Emory University refined this process, devising a balloon-tipped catheter that could be advanced within an artery



An image of a human coronary artery recorded in vivo at the National Synchrotron Light Center, Brookhaven National Laboratory, in November 1992. Improvements in the imaging system have increased the quality of the angiogram from the image shown on the opposite page. In this image, the entire length of the right coronary artery (RCA) is shown. (Image courtesy of Edward Rubenstein, M.D.)

to a narrowing. Once in position, the balloon is inflated, compressing the fatty plaque against the artery walls and restoring free blood flow. Soon the balloons were augmented with tiny rotary saws, lasers, and targeted medicines. Researchers also created collapsible baskets to snare kidney or gall stones for removal without an open surgical incision. Recently, stents (metal or plastic sleeves) have been developed for insertion into arteries or other vessels to keep critical spots from narrowing after the angioplastic procedure. Not all patients respond to these procedures, but those who do save considerable trauma and cost, sometimes even returning home the day of the procedure.

Of course, not all new ideas have been as fruitful as CT and MR and linacs. Hopes that the body's natural heat emissions could be a diagnostic tool were dashed when the heat-induced images, or thermograms, could not be correlated with disease problems. The use of oxygen potentiation devices like pressure chambers to treat cancer patients promised to help those with anoxic tumors. But after some years of tests, the results failed to justify the efforts. More recently, radiation oncologists have been experimenting with heat as a radiation potentiator. However, the technical problems of controlled heating of a single body area during radiation have not yet been overcome.

While diagnostic and therapeutic radiology have developed as separate and defined disciplines, there have always been synergisms with other medical specialties. Some two-thirds of all American cancer patients receive high energy radiation as a portion of their treatment. Currently, most cancer centers attack most forms of cancer with a combination of surgery, radiation, cancer-killing chemicals, and even monoclonal antibodies or immunological agents.

FOR THE ENTIRE CENTURY of radiology, physicians specializing in this area have performed most, but not all, of the procedures needed by Americans. Many primary care physicians undertake limited procedures in their offices. Some specialists, such as cardiologists or orthopedists, perform examinations related to their areas of interest. Dentists and podiatrists do likewise. About two-thirds of medical imaging procedures are done by radiologists.

1960–1969

- In 1960, Dr. Robert Egan of the University of Texas M.D. Anderson Tumor Institute, Houston, with the support of the U.S. Public Health Service, publishes the results of an intensive, three-year study of mammography. Although previous studies of X rays of the breast have been done, Egan's study conclusively proves mammography's effectiveness in early diagnosis. With neither physical exams nor any knowledge about the women's medical histories, Dr. Egan examines patients' mammograms and diagnoses whether or not cancer is present. Egan's accuracy in finding breast cancers is remarkable—97–99 percent—and his precisely controlled mammography techniques mean that other radiology facilities can duplicate his results.
- Drs. Charles Dotter and Melvin Judkins of Portland, Oregon, are the first to report performing a transluminal angioplasty, a non-surgical technique to unblock a vessel clogged with plaque. They insert screw-tipped catheters into the narrowed vessel, starting with small diameter catheters and sliding bigger and bigger catheters over them, to push the plaque to the interior walls of the vessel sides. The technique is not well-accepted except in Europe; bypass surgery is still the preferred treatment method in the United States.
- A survey conducted by the U.S. Public Health Service reports that 48 out of every 100 persons receive X rays during any one year, with urban residents having the most X rays (53 out of 100) and farm dwellers (31 out of 100) having the fewest.

1970–1979

- CT, or computed tomography, which takes X-ray "slices" of the body and images them on a computer screen, is introduced. Like the first tomography units introduced in 1936, the X-ray tube rotates around the patient's body, taking X-ray pictures as it moves. With the addition of computer technology, CT images can now be manipulated and the "slices" can even be "put back together" to create more 3-dimensional images.

Still, the growth of managed care as an alternative to traditional medical practice has driven many patients—and their doctors and hospitals—into controlled patterns. One result has been a reduction in the volume of medical services, including radiology, delivered to managed-care plan patients. Much of the reduction in imaging comes as a loss to physicians who self-refer procedures on their own patients. And questions arise: will managed care plans pay for more expensive procedures, if management decides the simpler ones are less expensive, and are adequate?

And with impending cutbacks in federal health spending and downward pressures on costs by private payers, the broader question is whether or not the nation wants and will pay for newer and better technologies. A good example is positron-emission tomography (PET), in which a very short-lived injected isotope is used as the energy source for cross-sectional imaging rather than X rays. PET has proved itself as a research tool. But its acceptance for clinical applications is proving more dependent on cost factors than scientific ones.

Ever since X rays were discovered by a physicist, the growth of radiology has been dependent on the contributions of that discipline, as well as the contributions of engineers, biologists, computer scientists, radiologic technologists, and a broad industrial base. Without these contributions, many of radiology's most important clinical advances would never have occurred. Clearly, radiology has earned a vital place in modern medicine. It may well be that the circumstances in which it will be practiced are uncertain—but then, so are most other things about modern health care.

Historic Whole Body Radiographs

A whole body radiograph of a dead soldier (page 25, left), was taken, in nine sections, by Ludwig Zehnder at the University of Freiburg in 1896 and measures 1.84 meters in height. The exposure time was approximately 5 minutes per film. The faint writing, with an arrow pointing towards the forehead, reads "small arms projectile located in the facing temple at a distance of 20 cm from the dry plate." The second radiograph (page 25, right) is a single-exposure whole body image taken by a Dr. Mulder in Bandung, Java, about 1900, presumably of a living person, wearing knee-length boots, with bunches of keys attached to an unseen belt.
(Courtesy Deutsches Museum, Munich, and Bob Batterman, Cornell University).

- Thrombolysis, which dissolves clots in blood vessels by delivering thrombolytic (clot breaking) drugs to the site or into the vascular system, is introduced by Dr. Charles Dotter. Using a thin catheter, a dose of a thrombolytic agent such as streptokinase is injected into the clot, dissolving it. One drawback of streptokinase is that it can induce allergies with repeated use over time. Later, synthetic thrombolytics that do not appear to induce allergic reactions will be used.
- Swiss physician Dr. Andreas Gruntvig, later in the United States, invents balloon angioplasty. A tiny deflated balloon is placed at the end of a catheter and threaded on a guidewire into a plaque-clogged section of blood vessel. The balloon is inflated, and the plaque is pushed to the sides of the vessel. Then the balloon is deflated and removed. The first applications of balloon angioplasty are all in arteries in the arms or legs. Balloon angioplasty is an instant success, in part because it can be used to open smaller, more fragile arteries.

1980–Today

- MRI (magnetic resonance imaging; also referred to as MR)—the marriage of a strong magnet and a computer—is introduced. Instead of X-ray's ionizing radiation, MR uses a magnetic field around the body and a radio signal to create images. MR works by having a patient lie in a large magnetic tube, which forces the hydrogen atoms in the body to "line up" in a polar formation. Then a strong radio signal bombards the atoms, and protons spinning in the hydrogen atoms are momentarily knocked off course. When the radio signal is turned off and the atoms return to their normal orbit, they emit a faint radio signal, which is used by a computer to measure the speed and volume by which they return to orbit. MR "sees" hydrogen atoms in the body—present in all tissues—and thus is exceptional at imaging both hard and soft tissue.
- Pulsed fluoroscopy reduces radiation exposure by using short bursts of high-intensity X-ray beams (up to 1–2 seconds; anything longer would burn out the tube) alternated with lower intensity beams. The high-intensity beams "linger" on the video screen, allowing the physician to view the anatomy like slow-motion moving pictures.
- PET (positron emission tomography) begins to be used in clinical applications. It watches the way cells "eat" substances such as sugar. The substance is tagged with a short-lived radioisotope (unstable atoms that release stray particles that can be seen with gamma cameras), then injected into the body. The PET scanner watches as the radioactive material "lights up" in cells, identifying areas where cancer cells might be present. Cancer cells have a higher metabolism than normal, healthy cells.
- Teleradiology, the ability to send images through the "information superhighway," is introduced. Teleradiology uses information-networking capabilities to transmit images from one place to another. However, it is more difficult than sending a written document because the digitized, computer radiology image contains so much more information than the printed word.