Radiology
Radiology

Medical School

The University of Michigan: An Encyclopedic Survey
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Roentgenology (1942)

Fred J. Hodges and Carleton B. Peirce

THE Department of Roentgenology was officially created by the Regents in July, 1913, when a budget of $1,000 for current expenses was allocated to it and an additional $360 was appropriated for repairs in the X-ray quarters in the Hospital. Long before, however, the medical application of Roentgen rays at the University had been begun, and it was the importance which activities in this field eventually assumed that culminated in the establishment of a separate department.

On April 26, 1896, only five months after the announcement of Roentgen’s discovery, occurred the first recorded medical use of the newly described “X rays” at the University. Mr. Stanislas M. Keenan, of Eloise Hospital, who had become interested in Professor Henry S. Carhart’s work with X rays, brought to Ann Arbor a patient with a bullet in his foot. Using X rays produced in the Physics Laboratory, Professor Carhart and Dr. William James Herdman (’72, ’75m, LL.D. Nashville ’97), Professor of Diseases of the Mind and Nervous System and of Electrotherapeutics, photographed the foot and demonstrated the presence of an opaque foreign body.
At that time there was no X-ray equipment at the University Hospital, but Herdman, who for some years had conducted a course in electrotherapeutics begun by Professor John W. Langley in 1880, was in the habit of demonstrating to his students with the static machine in his office the production of X rays and their medical uses. Sometime about 1900 the first piece of equipment for the production of X rays in the Hospital was purchased personally by Dr. Charles B. G. De Nancrède and Dr. Cyrenus G. Darling. This original induction coil was preserved by Dr. D. Murray Cowie and sometime before his death was presented to the Department of Roentgenology. X rays were first mentioned in the University Calendar in 1901-2, in a revised description of the electrotherapeutical laboratory. The late C. Perry Briggs, for many years Pharmacist of the University Hospital, is credited with having developed the technique employed during the early years when the original equipment was in use, having first familiarized himself with the subject in the laboratory of Professor Carhart.

The first X-ray equipment purchased with University funds was acquired in 1903 with $1,000 appropriated by the Regents (R.P., 1901-6, p. 65). This apparatus was placed in the custody of the Department of the Diseases of the Mind and Nervous System and Electrotherapeutics, then directed by Herdman, and a small X-ray laboratory was set up in the basement of the Palmer Ward building. Additional small appropriations were authorized by the Regents from time to time, the “Treasurer’s Report” of June 30, 1907, listing an expenditure of $514.63 for the Roentgen Laboratory during that fiscal year.

Vernon Justin Willey (Michigan Agricultural College ’93, A.M. Michigan ’02, ibid. ’09m), appointed Instructor in Electrotherapeutics in 1901, was given the additional title of Director of the Roentgen Laboratory in 1906, and in the same year Almus A. Hale was appointed his assistant in the laboratory and clinical photographer. Willey continued in charge of the laboratory, after attaining considerable prominence in the field of roentgenology, until 1909, when he resigned to join the staff of the Mayo clinic. In 1907 Carl Dudley Camp (M.D. Pennsylvania ’02) was appointed Clinical Professor of Diseases of the Nervous System and assumed immediate supervision
of electrotherapeutics and consequently of the Roentgen Laboratory, and Dr. James Gerrit Van Zwaluwenburg ('98, '08m), later identified with the work in roentgenology at the University, was appointed second assistant in internal medicine. Through close association with Almus Hale, Van Zwaluwenburg became deeply interested in the clinical use of Roentgen rays.

During the two years after the resignation of Willey in June, 1909, Lyle Steen Hill ('08e, M.D. Detroit College of Medicine and Surgery '14), previously an assistant in the electrotherapeutics laboratory, was Director of the Roentgen Laboratory. Van Zwaluwenburg, who was made Instructor in Internal Medicine and Demonstrator of Clinical Medicine upon the resignation of Dr. Frank Smithies in 1908, took a special interest in the use of X rays in examinations of the heart and of the stomach. His interest, combined with the desire of De Nancrède, of the surgical service, to make greater use of the possibilities of Roentgen apparatus, resulted, early in 1910, in the transfer of the supervision of the laboratory to the departments of Internal Medicine and Surgery, acting jointly. Van Zwaluwenburg took over direct charge of activities, and De Nancrède represented the laboratory in meetings of the faculty. Under the new arrangement, X-ray examinations were becoming so numerous that the Regents established an X-ray fee schedule in September, 1912.

When the full-fledged Department of Roentgenology was established in July, 1913, Van Zwaluwenburg was chosen as the first Clinical Professor of Roentgenology. He brought to this newly developed clinical specialty of the University a rare combination of background and point of view admirably suited to the work in hand. His preliminary training in engineering, his sound grasp of internal medicine, and his inquisitive attitude all came into play in the development and firm establishment of roentgenological methods in the clinical activities of the Hospital. “Van,” as he is affectionately remembered by colleagues, assistants, and students, rapidly attained a national reputation in his field through his energetic and untiring efforts as a Roentgen diagnostician, a teacher, and an investigator; and, in recognition of his accomplishments, the Regents appointed him Professor of Roentgenology in July, 1917. During the war
the new department, in conjunction with the United States Army and the Michigan Antituberculosis Society, took an active part in the examination of men discharged from Camp Custer because of suspected tuberculosis.

From correspondence and reports of the period, the need for additional equipment to meet increasing clinical demands appears to have been ever present. There was but a single generator, a ten-kilowatt high-tension transformer, one radiological table with a tube stand, and a Groedel fluoroscope with orthodiagraphic attachment. Gas-filled X-ray tubes were costly and unreliable. The number of examinations conducted each year had risen from less than 600 in 1911 to 4,203 in 1917-18, by which time the activities of the department had far outgrown the quarters which it occupied in the basement of the old Palmer Ward. Late in 1918 a separate machine was acquired for the production of medium-voltage X rays to be used therapeutically. A new scale of charges adjusted to the financial status of patients, the adoption of which had been advocated by Van Zwaluwenburg to avoid unfair competition by the University with private practitioners, was approved by the Regents in 1920.

Heedless of his own personal welfare, unsparingly devoted to medicine, Van Zwaluwenburg died of pneumonia on January 5, 1922, after a very brief illness, and thus the formative period of the department came to an abrupt and untimely end. More than ten thousand X-ray examinations were made by the department in the year of his death. His boundless energy, his wholehearted devotion to clinical roentgenology, his great human kindliness, his important contributions to the examination of the heart, of the great vessels, and of the organs of the abdomen by Roentgen methods, and his insistence that Roentgen diagnosis of disease must be primarily objective led American roentgenologists to regard him as one of this country’s outstanding pioneers in his field.

After Van Zwaluwenburg’s death the Regents placed Samuel Wright Donaldson (Tennessee ’12, Michigan ’16m), a senior assistant, in temporary charge of the department. Donaldson was assisted by Elmer Forrest Merrill (’20m) and later by Clyde Knapp Hasley (’15, ’18m), formerly an instructor in dermatology.
Preston Manasseh Hickey ('88, M.D. Detroit College of Medicine '92) was appointed Professor of Roentgenology in the fall of 1922. An outstanding clinician of Detroit, Hickey had previously been a professor of pathology and otolaryngology in the Detroit College of Medicine and Surgery and had won international acclaim as a roentgenologist. His interest in the subject had developed from his hobby — photography. Together with Dr. Augustus Warren Crane, of Kalamazoo, Dr. Henry Hulst, of Grand Rapids, Dr. James Case, of Battle Creek, and Dr. J. G. Van Zwaluwenburg, Hickey had already achieved recognition as one of the five great Michigan radiologists who had distinguished themselves in the early years of roentgenology.

During the war years Hickey had rendered unusual service to the Army Medical Corps by participating in the organization of specialty schools for roentgenologists and by serving as chief consulting roentgenologist to the American Expeditionary Forces. Outstanding pioneers in roentgenology in England, France, Sweden, Germany, Italy, Austria, and Canada were his personal friends. He founded the Roentgenology in 1906 and for ten years was editor of this publication, which in the meantime (1913) became the Roentgenology. With this rich background he was ideally equipped to be a teacher of roentgenology, and as such he is remembered and revered.

Under Hickey’s forceful guidance the department expanded rapidly. From his appointment in 1922 until the new University Hospital was occupied in August, 1925, he devoted much time and attention to planning the new quarters for the department. High-voltage therapy equipment was installed temporarily in the basement of the Palmer Ward. The professorial staff of the department was enlarged in April, 1925, when Ernst Albert Pohle (M.D. Frankfurt [Germany] '20, Ph.D. Michigan '28) took up his duties as Assistant Professor of Roentgenology and was placed in charge of the work in radiation therapy. In August, 1925, the Department of Roentgenology was moved into spacious new quarters in the present Hospital building (Hickey, pp. 113-25).

Clinical photography, a hospital activity of constantly growing importance, had been fostered first by Van Zwaluwenburg and
then by Hickey as a part of the Department of Roentgenology. When the new Hospital was opened, Harry Franklin Minkley, a former commercial photographer, was placed in direct charge of this work in the new studio provided for the purpose. Burr Anderson, technician for many years, resigned in 1925, and the technical work was distributed among assistant residents assigned to the department — an important feature of the training program instituted by Dr. Hickey.

Instructional and research activities were materially accelerated during Hickey’s incumbency; interdepartmental clinical conferences were established, and formalized teaching of roentgenology to undergraduates was further developed and extended. There was an increase in the number of graduate students, most of whom remained for two years of postgraduate instruction after their internship. Other physicians holding fellowships from various national foundations were attracted to the department.

The first radium owned by the department was purchased in 1928. Previously, the only stocks available had been owned privately by members of the faculty, or had been rented.

In 1927 Pohle had been promoted to an associate professorship in recognition of his experimentation with ultraviolet light, high-frequency currents, X rays, and the radiations of radium. Before Pohle’s departure in 1928 these activities led to the formation of a subdepartment of physical therapy, later combined with the physiotherapy section of the Department of Surgery. Closely adjacent to the Department of Roentgenology was the work in hydrotherapy and in electrotherapy, supervised by Dr. Hickey and conducted by Willis Seamans Peck (Syracuse ’22, M.D. ibid. ’24), who in July, 1928, had become Instructor in Physical Therapy, Assistant Director of the Department of Physical Therapy of the University Hospital, and part-time physiotherapist in the Health Service. In March, 1929, all physical therapy activities were amalgamated to form a new department of the Medical School (R.P., 1926-29, pp. 939, 1020), administered by Dr. Hickey and an advisory committee consisting of Dr. Warthin and Dr. Huber. Courses for medical students and technicians served as models for similar work in other institutions.
Hickey’s intensely active and valuable service to the University came to a close with his death on October 30, 1930. Because of his gentle kindliness, he will long be referred to by former assistants, students, and colleagues as “Pop” Hickey — a form of endearment accurately expressing the character of his relationship to a large band of physicians. Hickey’s influence upon American roentgenology was nation-wide, and he earned recognition for the University as an outstanding teaching center in this subject. On the wall of what once was his private office hangs a memorial bronze bas-relief presented by his associates in the name of the American Roentgen Ray Society as a testimonial to his eminence in American medicine.

Carleton Barnhart Peirce ('20, '24m, M.S. '27) was appointed Acting Director of the Department of Roentgenology immediately after the death of Dr. Hickey, under whom he had begun his specialized training in 1926 as an instructor. He had resigned to take a position at the University of Nebraska, but returned early in 1929 as Assistant Professor of Roentgenology, relieving Carl Lewis Gillies ('26m), who left to become an associate professor of roentgenology at the University of Iowa. In 1928 Dr. Pohle resigned to accept a professorship of roentgenology at the University of Wisconsin, and until 1930 the work in radiation therapy was supervised by John McGregor Barnes (B.S. Med. '24, '24m), Instructor and later Assistant Professor, whose colleague and successor, William Macauley Gilmore (M.D. University of Western Ontario '27), was in charge of this work at the time of Hickey’s death. Dr. Gilmore was in turn succeeded by Daniel Maurice Clark (M.D. Minnesota '27), who supervised the work in radiation therapy during the first three months of 1931.

On January 23, 1931, the Regents appointed Fred Jenner Hodges (Wisconsin '17, M.D. Washington University [St. Louis] '19) Professor of Roentgenology, effective April 1. Hodges had been a lecturer in roentgenology at the University of Wisconsin and roentgenologist to Saint Mary’s Hospital and to the Wisconsin Memorial Hospital in Madison. Vincent Clifton Johnson (M.D. Wisconsin '27), who was Associate Professor in 1940, was appointed Instructor in Roentgenology July 1, 1931.

Peirce became Associate Professor in 1933 and continued in that
Harold William Jacox (B.S. Med. ’26, ’28m), just completing his specialized training, was placed in charge of the work in radiation therapy in 1931. He resigned as Assistant Professor of Roentgenology in December, 1935, to become radiation therapist to the Western Pennsylvania Hospital, Pittsburgh, and Willis Peck, who had been Assistant Professor of Physical Therapy since 1931, succeeded him. In September, 1937, Dr. Peck was transferred to an assistant professorship of roentgenology, and he continued in diagnostic and later in therapeutic roentgenology until September, 1939, when he entered practice in Toledo.

At the time of Hickey’s death the splendid plant conceived and developed under his direction had been outgrown because of increasing departmental activities, and in the next year, 1931, it was extensively repaired and altered. An additional four hundred square feet of floor space was acquired by the transfer of the medical illustrator’s quarters to another part of the Hospital. The highly specialized departmental activities were provided for by the careful subdivision of floor space and by the acquisition of new equipment. Dental roentgenology was transferred to the oral surgery service, a fluoroscope was installed in the newly opened Tuberculosis Unit of the Hospital, and filming for urological diagnosis was provided for in the urology outpatient quarters. On April 4, 1932, about fourteen months after the appointment of Professor Hodges, the redesigned departmental quarters became available. In the interim the varied activities had been conducted under most trying conditions in temporary quarters on the ground and basement floors. For the first time there were well-arranged facilities for patients needing radiation therapy. These activities had been constantly increasing until patient visits had reached the total of 9,446 annually. In July, 1935, the medium- and high-voltage machines which had been transferred from the old Hospital ten years before were replaced with shockproofed 200-kilovolt instruments, and in the following year, because of the constantly increasing number of cancer patients, equipment
limited to the treatment of superficial skin lesions was provided in the dermatology outpatient quarters.

In the 1932 reorganization the work in clinical photography ceased to be a subsection of the Department of Roentgenology, and all hydrotherapeutic and electrotherapeutic activities were united to constitute a subdepartment of physical therapy, which was later, in 1937, transferred to the Department of Surgery. In the meantime, many somewhat disconnected activities in this field had been brought together in quarters specially developed for them on the basement floor of the southeast wing of the main Hospital. An exercise pool for poliomyelitis patients, contributed by the Rackham Foundation, was built. After the remodeling of 1935, when the adjoining Hospital stores addition was erected, the department was better able not only to carry its ever-increasing clinical load efficiently, but also to provide greater opportunities for its graduate and undergraduate students. An entirely new method of case reporting, film filing, and cross indexing was established, and the departmental business office, film-processing facilities, film storage, and viewing rooms for the staff were brought into close proximity to conserve effort and permit rapid service. Dressing rooms for the specialized technical branches in therapy and diagnosis were installed close to the exposure rooms, and transformers were housed in closed lofts to conserve floor space. A student laboratory for the demonstration of X-ray physics was built and equipped, and one room was utilized for a departmental library designated as the Hickey Memorial Library and maintained largely by Dr. Hickey’s bequest of $1,000.

The teaching of roentgenology has also been changed since 1932. Previous efforts to train nonmedical technicians were discontinued in order that undergraduate and graduate medical students might be more thoroughly trained in roentgenology. In a typical year, 1939-40, thirty-two hours of lectures for juniors were offered in the first semester, augmented by thirty-two hours of required clinical instruction conducted on the block system throughout the year. Several courses were discontinued as electives and were replaced by a six-week summer course of intensive laboratory, lecture, and clinical instruction open to students and practitioners alike.
The plan of interdepartmental clinical conferences already instituted was materially expanded. In 1933 the program for postgraduate students in roentgenology was revised and was placed upon a three-year-training basis. Carefully selected medical graduates who had completed a year of internship were accepted as assistant residents in roentgenology, eligible for reappointment for a second year as residents and for a third year as instructors. Modest stipends provided by the Hospital and the University made it possible for more than forty young men of limited means to obtain this training in the next ten years. The plan previously in vogue, of delegating trainees in rotation to a month’s service at Detroit Receiving Hospital, outgrew its usefulness and was discontinued in 1933.

Some ten nonprofessional workers brought together under Hickey’s direction before 1931 readjusted themselves to the rapidly changing conditions and, with but few exceptions, remained in the employ of the department. They have contributed greatly to the successful provision of roentgenological service to the University Hospital, as have the less numerous veteran workers in physical therapy.

The Department of Roentgenology has assisted in the extensive reorganization of the general Hospital records since 1932 by actively participating in the development of a mechanical tabulation system.

The department has made important contributions to the establishment and maintenance of the concerted program of the University’s cancer committee, having taken an active part in the two tumor conferences conducted by the Department of Obstetrics and Gynecology and in the two general tumor conferences held each week in conjunction with the departments of Pathology and Surgery. In succession, Dr. Jacox, Dr. Peck, and Dr. Isadore Lampe (Western Reserve ’27, M.D. ibid. ’31, Ph.D. Michigan ’38), who became Assistant Professor of Roentgenology in 1938, have served energetically and efficiently in this field. In association with the Department of Physics, the Department of Roentgenology began to participate in 1935 in the University’s nuclear physics program centered about the construction of the University’s cyclotron and its subsequent employment in research. As an outgrowth of this venture, which
was supported by the National Cancer Institute and the Rackham Foundation, both Lampe and Hodges have been associated with Professor E. O. Lawrence and the radiation laboratory at the University of California, where Hodges served as a research associate while on sabbatical leave for one semester.

Interested in the broad-scale investigation of the incidence of pulmonary disease in general, the departments of Roentgenology and Internal Medicine have since 1931 been actively concerned with various mass surveys. As a result, a periodic X-ray chest examination has become a routine practice for all Hospital employees as well as for all students entering the University. In June, 1935, chest filming of all patients registering at the University clinics during a two-week trial period proved convincingly that this procedure should be instituted, but it was not until July, 1941, that, through the financial assistance of the Kellogg Foundation, a plan of chest survey based upon the use of photofluorography was put into effect. Facilities were installed in the Hospital admission office, and during the first twelve months nearly 23,000 patients were so examined, of which 10 per cent showed sufficient evidence of intrathoracic abnormality to warrant more extensive X-ray examination.

Charged with the supervision of the X-ray activities at the University Health Service, the Department of Roentgenology took an active part in the planning of the X-ray Laboratory in the new Health Service Building, completed in 1939, and has provided medical supervision of the work of this laboratory.

The Neuropsychiatric Institute building, long under contemplation, was finally opened for patients in April, 1939. Direct communication with the main Hospital building made it necessary to alter the central section of the X-ray quarters materially to provide a corridor thoroughfare. As a by-product of this remodeling, the business office of the department was enlarged, and space for the stenographic staff and for film-interpretation facilities was added.

The amount of work in the Department of Roentgenology has steadily increased, the annual number of patient visits having risen from 33,803 in 1932-33 to 54,750 in 1938-39.

Since the private purchase of primitive X-ray equipment by
De Nancrède and Darling in 1900, the medical use of X rays at the University has undergone a phenomenal and constantly accelerated development, naturally divisible into four major periods — the formative period before 1913 and the three administrations of Van Zwaluwenburg, Hickey, and Hodges as professors of roentgenology and heads of the department. New and immature as a full-fledged clinical department of the Medical School, the Department of Roentgenology has risen to a position of unquestioned importance in a relatively short period.

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In July of 1965 Dr. Fred Hodges, chairman of this department, began retirement furlough and was succeeded by Dr. Walter Whitehouse. During the first semester of 1941 Dr. Hodges spent a sabbatical period as research associate in the Radiation Laboratory at the University of California. Through this contact Dr. Hodges brought back to Ann Arbor the first consignment of radioactive phosphorus, which was turned over to the Simpson Institute for experimental treatment of leukemia. This was followed by $^{32}p$ shipments at regular two-week intervals until the outbreak of the war. At Berkeley Dr. Hodges completed experimental neutron exposures of animals, begun in Ann Arbor with Dr. Lampe, using the Michigan cyclotron.

In 1941 this country’s first program of admission x-ray chest surveying was begun at Michigan, funded by the W. K. Kellogg Foundation. Dr. Hodges, on leave in Stockholm, participated daily in radiological activities at the Karolinska Hospital. This contact with Swedish radiology was the first step in the development of close relations between the departments in Stockholm and Ann Arbor. In 1956-57, Dr. Bjorn Nordenstrom,
now chairman of radiology at the Karolinska, spent a year in the department in Ann Arbor. In 1954, funded by a sizeable research grant from the Atomic Energy Commission, and in part by the University Hospital, the General Fund of the University, and the Alice Crocker Lloyd Memorial Fund, a Center for Radiation Therapy was created, directed by Dr. Isadore Lampe. Utilizing carefully accumulated statistical data concerning the results of cancer treatment obtained with conventional 200KV x-ray equipment, Dr. Lampe was able to compare with those results subsequent accomplishments with isotope teletherapy (cobalt 60 and Cesium-137), comparable to x-rays produced with super voltage generators.

In 1950 the radiology staff developed and built a motor driven, roll-film camera for rapid sequential filming of the heart, following opaque injection. The shop also produced important modifications of equipment, unobtainable commercially, and x-ray film-numbering devices.

In 1956 an angiographic unit was developed within the main department in conjunction with thoracic surgery and the cardiovascular group in pediatrics. In 1957 the department installed mechanical film-processing equipment and, in 1961, fluoroscopic image intensifiers with television monitors.

Over the years the department has developed and maintained a workable system of filing and indexing to make accumulated radiologic diagnostic information available for clinical investigations and for teaching. Dr. Lampe has maintained a detailed system of recording results obtained with therapeutic radiation.

Since 1965 space remodeling has continued to achieve greater utility of existing space. Expansion into limited square footage previously assigned to blood chemistry and the transfer of pediatric radiology to the new Mott Hospital has been accomplished. Excellent and badly-needed technical facilities have been provided for peripheral angiography and for neuroradiology. Jointly, with the urology section of surgery, efficient new facilities for all aspects of urologic diagnosis were established on the third level.
Edited by N. Reed Dunnick and James H. Ellis

The Department of Radiology, 1965-2016

In 1965, Walter M. Whitehouse was appointed chair of the Department of Radiology at the University of Michigan, succeeding the long-serving Fred Jenner Hodges II, who had been chair for over 30 years. Whitehouse would serve as chair for 14 years.

Whitehouse was well liked by the faculty and viewed as a benevolent leader, loyal to the University. Trained at Michigan, he had joined the faculty in 1952. His fields of expertise included pulmonary, gastrointestinal and obstetric radiology. He detailed the use of biliary contrast agents, advocated chest film surveys to detect disease, and pointed out the radiation risks involved in obstetrical radiography. In 1975, he served as president of the Society of Chairs of Academic Radiology Departments. He was a founding member of the Society of Gastrointestinal Radiologists, and served as president of this subspecialty society in 1977.

Whitehouse recruited talented radiologists and encouraged
them to focus in subspecialty areas, although only later would the Department be formally organized into diagnostic subspecialty divisions. Under Whitehouse, William Martel was appointed as director of diagnostic radiology. Juan V. Fayos succeeded Isadore Lampe as director of radiotherapy. In 1966, Wayne County General Hospital (WCGH) affiliated with the University of Michigan, and Whitehouse recruited Harry W. Fischer from the University of Iowa to direct the WCGH radiology department; Fischer would become well known as an expert in radiographic contrast media.

In 1969, the new C. S. Mott Children’s Hospital opened, and Whitehouse named John F. Holt as director of pediatric radiology. Later, Andrew K. Poznanski was recruited from Henry Ford Hospital as co-director of pediatric radiology. Poznanski would introduce novel pediatric radiologic techniques. In 1971, Stewart R. Reuter succeeded Fischer as director of radiology at WCGH, and was himself succeeded by Ray Brinker when Reuter moved to University Hospital three years later.

Fischer, Reuter and Brinker would all become chairs of departments of radiology: Fischer at the University of Rochester, Reuter at the University of Texas, San Antonio and Brinker at the Medical College of Ohio.

Ultrasound came under the purview of the Radiology Department in 1972. The clinical applications of ultrasound grew dramatically under the leadership of Terry M. Silver. Silver contributed to techniques of neonatal cranial ultrasound and intraoperative sonography. Silver began a long-running postgraduate course in ultrasonography in 1977; this brought national visibility to the Department’s sonography program and helped in the recruitment of fellows and faculty.

Whitehouse became the editor of the *Yearbook of Radiology* in 1971, succeeding Hodges. This book, annually summarizing the advances in the field, brought national attention to the Department throughout Whitehouse’s tenure.

Early in Whitehouse’s term, fellowship training began in angiocardiography and neuroradiology. Fellowship training would subsequently be expanded to all subspecialties.

In 1968, the Medical School’s curriculum was revised. Many
formal courses, including a course in radiology for all third-year medical students, were eliminated to expand elective opportunities for the medical students. Clinical teaching was increased in the first and second years in the form of interdepartmental joint efforts. Whitehouse appointed Martel as the Department’s coordinator of these endeavors. Initially minuscule, the Department’s teaching time slowly increased until radiology presented approximately 25 lecture hours in the first two years of medical school, which were focused on classroom learning with clinical rotations in the third and fourth years. Additionally, senior radiology residents taught radiologic anatomy to small groups of students in the anatomy laboratory portion of their anatomy course.

In 1972, a request from the Department of Radiology to institute a required radiology course for medical students was denied. The Department then developed a semi-structured elective, The Role of Radiology in Clinical Medicine, which became a very popular elective chosen by 70-80 percent of senior medical students.

Under Whitehouse, the Department initially accepted six residents into each incoming class, but the class size was later expanded to 12. Although much learning would continue at the point of image interpretation and procedure performance, increased formal teaching activities were offered, including weekly clinical interdisciplinary conferences and daily diagnostic radiology conferences. A successful program of daily imaging rounds with individual clinical services (primarily internal medicine ward teams) continued for many years; each team would meet with a radiologist to review all the recent radiology studies for their patients.

In 1974, the clinical Departments of the Medical School adopted a new financial structure, the medical service plan, that brought change to the Department of Radiology. Faculty were required to assume direct responsibility for radiologic procedure performance and interpretation and residents and fellows were more closely supervised. At first, research and teaching time declined as the faculty became more directly involved in clinical work. However, Departmental revenue increased when the Department began its own professional fee
billings. This increased income supported teaching and research, as well as the recruitment of new faculty.

By the middle of the 1970s, the inadequacy of the physical plant began to become obvious, made evident by the struggles to service an expanding clinical load and the obsolescence of the radiologic equipment in the face of increased sophistication in imaging techniques. For example, computed tomography (CT) began with units that could image only the head; the first in the U.S. began service in 1973. A similar unit was installed in University Hospital in 1975. Advancements in scanning technology led to the ability to scan the chest and abdomen in 1976. However, it was not until 1980 that a body CT unit was finally installed at University Hospital. Fortunately, a body CT unit had been acquired by the Ann Arbor Veterans Administration Hospital in 1977, giving the faculty and residents an opportunity over the intervening years to gain experience with this expansion of CT imaging. University Hospital patients could be transported to the VA for abdominopelvic CT imaging when required.

In 1979, Whitehouse resigned as chair of the Department. The following year, the Walter M. Whitehouse Lectureship was established by grateful colleagues and former trainees.

In July 1979, Douglass F. Adams became the new chair of Radiology. Adams had graduated from the Bowman Gray School of Medicine and completed his radiology residency at Stanford University. An expert in cardiovascular radiology and body computed tomography, Adams came to Michigan from Harvard Medical School and the Peter Bent Brigham Hospital. During his short tenure, he began a departmental reorganization into formal clinical divisions and started to create a basic science division. He began a process to provide faculty with dedicated research time. He formalized a contract with the Veterans Administration Medical Center to provide faculty professional services. He resigned the chair in 1981, in part due to disagreements with the Medical School over commitments made to him at his recruitment.

The earliest commercial MRI scanners were produced in 1980. It quickly became clear that this technique would contribute further to the revolution in medical imaging, based
in part on the experience of CT scanning, which had quickly blossomed from medical curiosity to indispensable diagnostic tool. MR obtains cross-sectional images using magnetism and radio waves rather than x-rays; by employing completely different physical principles than CT, MR offered a new look into the body. Controversy arose over which department in the Medical School would control magnetic resonance imaging equipment. Some of the basic physics that applied to MR imaging had been long used in non-imaging devices to analyze chemical substances, a technique called nuclear magnetic resonance. Due to these origins, MR imaging was originally known as nuclear magnetic resonance imaging. In part, this nomenclature led to efforts by the Division of Nuclear Medicine, then within the Department of Internal Medicine, to compete for control of this imaging technique, even though MR imaging did not employ the radioactive radiopharmaceuticals that were the typical imaging agents forming the basis for nuclear medicine. As part of the appointment of William Martel as acting chair of Radiology in July 1981, the Department of Radiology assumed control over MR imaging. Over time, the term “nuclear” was dropped nationally and internationally, and the technique was referred to simply as MR imaging. The first clinical MR imaging system in Michigan, a 0.35 Tesla unit manufactured by Diasonics, was installed in November 1983 in the Kresge building, where space that could accommodate the size and equipment weight requirements for MR imaging could be found.

William Martel was appointed as chair of the Department in October 1982, and in 1985 he was named the first Fred Jenner Hodges Professor of Radiology. Martel received his bachelor’s and medical degrees from New York University, and joined the Michigan faculty in 1957 after a radiology residency at Mount Sinai Hospital, New York. A superb radiologist, Martel had broad clinical and research interests and became known for his scientific contributions in gastrointestinal and musculoskeletal radiology. He was the first to advocate tubeless hypotonic duodenography, in which the barium contrast agent was administered by mouth and the duodenal peristalsis slowed with drugs; this saved the patient the placement via the nose or
mouth of a tube into the duodenum to administer the barium. He was a pioneer in the radiology of joint diseases, publishing many papers that informed current concepts in the differential diagnosis of arthropathies. Widely recognized as an outstanding teacher and lecturer, he was the first and only member of a clinical department of the Medical School to receive the University’s prestigious Amoco Award for outstanding teaching and he participated annually in instructional course programs of national radiologic societies for more than 20 years. He was a founding member of the International Skeletal Society and was awarded the Gold Medal of the Society in 1993, and the Schinz Medal of the Swiss Society for Medical Radiology in 1994.

When Martel assumed the acting chairmanship in July 1981, the Department was understaffed; equipment and space were inadequate in the 1920s-era University Hospital; research activity was low; and morale was poor. The report of an external review committee noted the situation was serious enough to “place in jeopardy the tertiary care mission of the entire Medical Center.” Responding to this crisis was a major challenge. A program of short-term renovations and acquisition of incremental clinical space and equipment, including sonographic and CT facilities, was begun to meet clinical obligations and to recruit faculty. Martel recruited 14 faculty members in his first year, reorganized the Department’s administrative structure, and finalized the establishment of subspecialty divisions according to body system and imaging modality. Terry M. Silver, recognized for his outstanding contributions in uroradiology as well as ultrasonography, was appointed associate chairman. The number of publications in peer-reviewed journals rose from 44 in 1982 to an average of 95 during the next five years.

In 1981, Paul L. Carson, whose recruitment Adams had begun, joined the faculty to lead the creation of a basic radiological sciences division. Carson, nationally recognized for his work in ultrasonography, attracted faculty, graduate students and postgraduate fellows. Over time, the division would expand to include faculty with backgrounds in medical physics, bioengineering, biochemistry, medicinal chemistry, biostatistics, microwave and optical imaging, magnetic
resonance and magnetic resonance spectroscopy. The establishment of the Basic Radiological Sciences (BRS) division enhanced the overall research capability of the Department by facilitating close collaboration between these scientists and clinical radiologists. In 1987, Carson became president and chairman of the board of the American Association of Physicists in Medicine.

Hospital physics, instrumentation and design support for the Department were directed sequentially by Larry R. Griewski, James A. Mulvaney, Loren T. Niklason and Mitchell M. Goodisitt. Niklason went on to co-develop digital breast tomosynthesis at Massachusetts General Hospital. Goodisitt later became the imaging physics editor of the journal *Medical Physics*.

During the period 1982-1989, departmental research space increased from 400 to 7,500 net square feet. In 1983, wet laboratory space was acquired in the new Medical Science Research Building for investigating and developing new contrast agents. In 1985, the animal imaging laboratory was relocated and expanded with replacement of obsolete imaging equipment. In the same year a 2 Tesla MR imaging unit for animal research (20-cm bore) was acquired, and a digital image processing laboratory was established under the direction of biomedical engineer Charles R. Meyer. In 1991 a 7 Tesla MR imaging and spectroscopy animal imaging system (11-cm bore) was acquired. During a 10-year period the Department’s external funding support for research doubled, much of it from industry, reaching an annual level of $800,000.

The Division of Nuclear Medicine had been under the auspices of the Department of Internal Medicine since its founding by William H. Beierwaltes. Beierwaltes had been interested in thyroid disease, which had led him to investigate the use of radionuclides to study thyroid metabolism. In 1952, Beierwaltes was appointed head of the new Clinical Radioisotope Service. In 1957 he published *Clinical Use of Radioisotopes*, one of the first textbooks devoted to the field that later would be called nuclear medicine. In the early 1960s, nuclear medicine became a division of the Department of Internal Medicine with Beierwaltes as its first chief. Beierwaltes helped form the nuclear medicine fellowship at U-M, one of the
first such programs in the U.S. The division thrived, attracted outstanding faculty, provided excellent clinical service, and developed an outstanding research program. Alumni of this division became leaders in nuclear medicine throughout the world.

Physicians from three different disciplines have participated in nuclear medicine. Internists were attracted to the field for the endocrinology and later cardiac applications. Pathologists saw the utility of nuclear agents in laboratory tests, and radiologists recognized the imaging potential. As the imaging applications grew and began to outpace the other applications, nuclear medicine became part of departments of radiology in most academic medical centers. In 1983, when Beierwaltes announced his intention to retire as chief of the Division of Nuclear Medicine, the dean appointed a committee of Bernie Agranoff, Julian Hoff and Robert Kelch to address the question of the administrative status of the Division of Nuclear Medicine. The committee recommended no change in the location of the Division, but did recommend that the search for a new chief include consultation by Radiology and that the training needs of Radiology be met. The committee recommendations were accepted by the dean and Medical School Executive Committee. In 1985, David Kuhl, a radiologist specializing in nuclear medicine, was named to succeed Beierwaltes.

In 1989, an external review committee was appointed by Dean Joseph Johnson to provide recommendations about the Department’s educational, research, and patient care activities. This included three external consultants, two of whom were chairs of academic departments of radiology — Ronald G. Evens of the Mallinckrodt Institute of Radiology at Washington University School of Medicine in St. Louis and Charles E. Putman of Duke University. The external consultants stated that the location of nuclear medicine within internal medicine was detrimental to radiology. Their report was accepted but no action was taken.

As the clinical workload increased, the slow manual system of dictating reports on cassette tapes, the travel of the tapes to the typists, and the return of the typed reports on paper to the radiologists for signature had become cumbersome. In
1983, the manual system was replaced with a combination of early versions of a centralized digital dictation system and a computerized radiology information system (MARS II). This enabled radiologists to dictate over phone lines to the central dictation system which could be accessed by transcriptionists; the text typed by the transcriptionists was entered into the MARS system; and the radiologist could read and edit the reports from terminals across the Department. Although paper reports would still be printed for the medical record and used by clinical services, the physical transfer of dictation and transcription within Radiology had ended.

To provide more complete pediatric imaging services, ultrasonography and CT equipment was added to the Radiology Department at C.S. Mott Children’s Hospital. Cardiac imaging, both pediatric and adult, had been the province of the Department of Internal Medicine (Cardiology) since 1975. With the recruitment of Ramiro J. Hernandez, an expert in pediatric cardiac imaging, as director of pediatric radiology in 1983, ties with pediatric cardiology were strengthened and radiology once again played an integral role in pediatric cardiac imaging. Shortly thereafter, the floor space assigned to Radiology within Mott Hospital doubled, and the space was rearranged for greater efficiency and installation of new equipment.

James H. Ellis was appointed chief of the radiology service at the affiliated Ann Arbor Veterans Administration Medical Center in 1984. Ellis worked to strengthen patient care and teaching activities. Obsolete imaging equipment was replaced, and an MRI system, shared with U-M’s Radiology Department, was acquired in 1987 and placed in the Kresge Research Building.

Upon assuming the chair, Martel was faced with a conflict between previously developed plans for the Radiology Department in the replacement University Hospital and his vision of how the Department should function. Working closely with his division directors and administrative staff, Martel directed a radical revision of the plans for the Department in the new hospital. Space was reorganized into subspecialty cores, placing the imaging rooms, film handling and interpretation activities near each other. A daylight film-processing system was
installed throughout the entire Department in the new hospital, eliminating the need for centrally placed darkrooms and markedly reducing the transfer of cassettes and film throughout the Department; the resulting efficiencies were remarkable. Plans were developed for an MRI subspecialty core in the basement of the new hospital, one floor below the main Department, with space for two MRI systems and potential space for two additional systems. The limited space allocated for a radiology facility in the A. Alfred Taubman Health Care Center outpatient building (which was constructed as part of the hospital replacement project) was a disappointment, and the inadequate space proved to be a major problem.

The new University Hospital and outpatient center were opened in February 1986. Compared with the situation in the old hospital, clinical space for radiology doubled (to 70,300 net square feet) and imaging capability was state-of-the-art.

Martel requested that radiation oncology, then part of the Radiology Department, be established as a separate department to facilitate its development as a vigorous academic unit with modern patient care and research facilities. Allen S. Lichter, appointed chair of the new Department of Radiation Oncology in 1984, was educated at Michigan and completed a residency in radiation oncology at the University of California, San Francisco. He was recruited from the National Cancer Institute and was an innovator in using computerized techniques for three-dimensional radiation treatment planning, a technology that enabled higher treatment doses to cancerous tissue while minimizing damage to surrounding normal tissue. In 1993 Lichter was named the first Isadore Lampe Professor.

Between 1982 and 1989 the faculty increased from 38 to 54 full-time equivalents (46 physicians and eight basic scientists). Faculty members were given dedicated time for research and other nonclinical activities. A practice of modified subspecialization was developed, with faculty members working in one or two divisions; this provided faculty enrichment and administrative flexibility while preserving the academic benefits of subspecialization. Continuing a historical trend of Michigan faculty becoming chairs of radiology departments, in 1989, Gary Glazer was appointed chair of the
Radiology Department at Stanford University while Barry Gross assumed the chair of radiology at Henry Ford Hospital.

The total number of house officers was 36 in 1982, but when radiation oncology became a separate department, only 28 diagnostic radiology residency positions were allowed. The number of fellows gradually rose from four in 1982 to 16 in 1989. The postgraduate teaching program now included more interdepartmental conferences, an expanded noon conference schedule for residents and fellows and weekly divisional subspecialty teaching conferences. The number of radiologic examinations increased by 33 percent, totaling 270,000 in 1989.

The Department was selected as one of five centers to participate in the first Radiologic Diagnostic Oncology Group (RDOG) project, funded by the National Cancer Institute and the American College of Radiology, to study the role of various imaging modalities in patients with prostate and lung cancer; it was also one of a few centers involved in two subsequent trials for staging pancreatic, colorectal, ovarian and pediatric neoplasms.

With the appointment of N. Reed Dunnick as chair in 1992, Martel returned to clinical practice and academic activities. Dunnick completed his medical education at Cornell University and his radiology residency at Stanford University, and was a staff radiologist at the National Institutes of Health before joining the faculty at Duke University, eventually rising to the position of professor and director of diagnostic radiology; from that position he was recruited to Michigan. His research work and clinical effort centered on abdomen CT and uroradiology, and he had served as president of the Society of Uroradiology (now the Society of Abdominal Radiology) and the Society of Computed Body Tomography & Magnetic Resonance. As chair, Dunnick led a departmental improvement and expansion program for over two decades. During this period, he also found time to contribute to national radiology organizations, with a secondary effect of increasing the prominence of the Department on the national scene. He participated in the leadership of various radiology organizations culminating in being, at various times, president of the Academy of Radiology Research, American Board of Radiology, American Roentgen
Ray Society, Association of University Radiologists, Michigan Radiological Society, Radiological Society of North America, Radiology Research Alliance and Society of Chairs of Academic Radiology Departments. In these leadership roles, he mentored and encouraged many of his faculty to become involved in these national radiologic societies, and many Michigan faculty would themselves ascend to the presidency of these prestigious organizations.

In recognition of his contributions to and leadership of radiology on the national scene, Dunnick would be awarded the Gold Medals (highest honor) of the American Roentgen Ray Society in 2006, the Society of Uroradiology in 2008, the Association of University Radiologists in 2012, the Michigan Radiological Society in 2013 and the American College of Radiology in 2014.

When Dunnick became chair in 1992, the Department of Radiology operated one off-site imaging center, a facility adjacent to Briarwood Mall in south Ann Arbor where plain radiography, ultrasound and screening mammography were offered. As the Medical Center began to appreciate that patients preferred to be seen at a facility that offered easy access, free surface parking and was small enough that they could easily find their way to their destination, ambulatory care units were built at several sites around Ann Arbor and as far away as Brighton. Because imaging is such an important part of each medical encounter, imaging was often a part of the ambulatory care center. In 1997, the new Cancer Center opened; this allowed breast imaging to move from the Taubman Outpatient Center to improved and expanded facilities in the Cancer Center. Also in 1997, the major outpatient facility at East Ann Arbor opened, with Radiology providing breast imaging and both CT and magnetic resonance imaging. Other offsite imaging cores were modest in size, such as the Briarwood clinic that opened in 1998 or the South Main facility that opened in 2000, offering only radiography, ultrasound and/or mammography, but CT was added to some, such as the Canton and Livonia facilities (opened in 2000 and 2010 respectively). In 2014, a new ambulatory care center in Northville opened that offered fluoroscopy, musculoskeletal ultrasound and MRI.
Growth in clinical activity was not limited to the off-site centers, but also occurred on the main campus. In 2007 when the new building housing the Cardiovascular Center was opened, Radiology acquired the space previously occupied by cardiology adjacent to the radiology clinical space on the B1 level of University Hospital. Cardiology had used this area for cardiac catheterizations, and the space was redesigned for radiology use as cost effectively as possible consistent with a well-functioning facility. The three angiography suites were converted to use by neuroradiologists, with one single plane room, one biplane room and a third room with biplane angiography and CT. Space was allocated to two new CT scanners and the patient holding area was preserved, as was the patient waiting room.

This new area for neuroangiography was ideal for neurointerventional radiology. This burgeoning field offered minimally invasive treatment for patients with life-threatening vascular lesions such as high-grade carotid artery stenoses or aneurysms in vessels of the head or neck. Soon the team of neurointerventionalists grew to four faculty and included two neuroradiologists and two neurosurgeons.

Expanding into the space vacated by Cardiology provided additional space for angiography and CT, but did not help with magnetic resonance imaging, which was limited not only by space, but also by restrictive certificate-of-need rules in the state of Michigan. In 2004, the hospital relocated its store of plumbing and electrical equipment to allow expansion on the B2 level of University Hospital. This allowed the addition of one MR unit and the construction of much needed office space. Over the ensuing decade, MR capability was increased with the addition of offsite imaging facilities and a new C.S. Mott Children’s Hospital, such that by 2014 the Department managed a 3 Tesla research scanner and 10 clinical scanners (1 Tesla open scanner and a mix of 1.5 and 3 T whole-body scanners). In 2014, plans were approved to move additional hospital employees out of the B2 level of University Hospital and create space for two additional MR units.

As the volume of imaging studies increased, it became increasingly difficult to use traditional x-ray film as the medium
with which to obtain, store, and share diagnostic imaging information. This problem was further exacerbated by the ever-increasing numbers of images obtained per examination with cross-sectional imaging techniques, especially CT and MR. As the Department and hospital developed “offsite” imaging facilities (at a distance from the main hospital), use of film for imaging while maintaining subspecialty review of the examinations required either impractical stationing of multiple subspecialty radiologists at offsite locations or inefficient physical transportation of films back to the hospital for interpretation. A longstanding issue with film was that there was only one copy of most exams; there was constant competition among various clinical services to view the images for consultations, tumor boards and other conferences, and primary care. Films could be lost, misfiled or even hoarded. Even simple storage of patient imaging studies became an issue, as storage space was limited in the hospital. Vendors were contracted to store older studies in warehouses, but when one of these studies was needed for patient care, it was slow and expensive to retrieve.

Since medical imaging was converting to digital rather than analog imaging, an electronic solution was practical. For cross-sectional imaging, the images were digital to begin with; they had traditionally been converted to analog images when photographed onto film. For analog images such as plain radiographs like a chest x-ray, new electronic plates had come on the market where the image was digitally read from the exposed plate, eliminating film and creating a digital image from the start.

In 1995, the Department installed its first picture archive and communication system (PACS). This product, made by Siemens Medical System, was based on 1993 technology and served the Department well until 2005. Imaging studies were routed to workstations where subspecialty radiologists provided timely interpretations. Since the images were digital, many users could access them at any one time. Furthermore, the imaging studies were not lost, misplaced or “borrowed” by others.

Most radiology departments began their forays into PACS by starting with always-digital CT and MR images; the Department
at Michigan began with portable chest and abdomen radiographs, converting them from analog imaging to digital plate technology. The reason was simple: this was a particular pain point for the system. Unlike most inpatient radiographs in which the patient came from the ward to the Radiology Department for imaging, most of the plain radiographs on ICU patients were obtained using portable x-ray machines; the examinations were performed with the patient still in the ICU bed. Each patient floor of the hospital had its own subspecialty ICU, and the films had been displayed in small rooms in the ICU areas where clinical teams could see them as soon as they were developed without having to make the trek to the Department of Radiology in the basement. To provide interpretations, radiologists and residents would move from ICU to ICU to view the images, an inefficient process. With the advent of PACS, the images came to radiologists, who could interpret the images from any ICU as soon as they were done. Over time, PACS became the workflow engine for interpretation and storage of digital images from CT, MR, and ultrasound, and other analog imaging areas were converted to digital imaging acquisition and PACS workflow. Although it took several years and PACS expansions and improvements, eventually all imaging in the Department was electronic and traditional x-ray film was no longer used.

Along with the expansion in clinical facilities and effort, the Department made significant strides in research expenditures and space. In Dunnick’s first year as chair, research expenditures broke the $1 million mark and continued to climb throughout the 1990s, exceeding $3 million in 1999. The addition of Nuclear Medicine in 2000 expanded the Department’s research portfolio significantly. In 2001, research was a $9 million segment of the Department. In the years from 2002 to 2014, research expenditures exceeded $10 million every year, with a high of $19 million in 2010. Research space also increased: available data for 2000-2014 shows an increase from 29,000 net square feet in 2000 to 37,000 net square feet in 2014; the high water mark was some 45,700 net square feet in 2007.

With the continued growth in the Department’s efforts in clinical care, research, and teaching, Dunnick saw the need to
modernize the administrative structure of the faculty. Ellis, who had been serving as clinical director of the Department since July 1992, had his title changed to associate chair for clinical services on July 1, 1997. A new associate chair for research title was created, and Robert L. Bree was the first to occupy the position. Richard H. Cohan who had been residency program director since arriving at Michigan, became the first associate chair for education. Shortly thereafter, Dunnick foresaw the increasing importance of digital information systems as the backbone infrastructure of the Department; clinical radiology was increasingly becoming an “information business.” Dunnick appointed Ellis as the first associate chair for information technology on September 1, 1998. Successor associate chairs for clinical services were Barry H. Gross, Caroline E. Blane, Ronald O. Bude and Ella A. Kazerooni.

When Dunnick was appointed chair in 1992, he had been told that the Division of Nuclear Medicine would remain within Internal Medicine until there was a change in leadership. In 1996, Tadataka “Tachi” Yamada, chair of the Department of Internal Medicine, left the University and H. David Humes was appointed interim chair. At this juncture, Dunnick formally requested Interim Dean A. Lorris Betz to transfer the Division of Nuclear Medicine to Radiology. After additional review, it was decided to retain Nuclear Medicine within Internal Medicine. However, three years later, under the guidance of Dean Allen S. Lichter, the move of the Division of Nuclear Medicine from Internal Medicine to Radiology formally took place on July 1, 2000. Cooperation from David E. Kuhl, a radiologist and chief of the Division of Nuclear Medicine, facilitated a smooth transition.

Among the first changes in Nuclear Medicine were the acquisition of a new research PET scanner and the replacement of the cyclotron. Siemens was the vendor of choice for nuclear medicine and the new PET scanner devoted to research was purchased from Siemens Medical Systems. The original cyclotron at the hospital was manufactured by the Cyclotron Corporation, which went bankrupt after delivery of the machine but before acceptance testing was completed. The hospital accepted the cyclotron, although recognizing that it
might not be supported by the vendor. The Cyclotron Corporation was reorganized as Computer Technology and Imaging Inc. and ultimately became partners with Siemens Medical Systems. The old cyclotron had provided service for more than 20 years, but the vendor had stopped supporting it. As parts wore out, new parts had to be individually machine tooled for replacement.

The challenges to acquire a new cyclotron were significant and compounded by the location of the cyclotron in Kresge III, a building scheduled to be torn down. A new location was needed that would allow the creation of safe “rabbit runs” to transport the radionuclides to the B1 level of University Hospital where they would be used. The site finally selected was between wings of the Medical Science I building. Michael R. Kilbourn designed the new facility, and the vault was built large enough to house two cyclotrons, though it was expected that one would be sufficient. The new facility included not only the cyclotron vault, but also hot cells, a quality control laboratory, faculty offices and a conference room. Funding came from the Department of Radiology, the hospital and an NIH extramural research facilities construction project through the National Center for Research Resources written by Kilbourn.

Speech recognition in radiology, in which spoken dictation by radiologists is converted into text by computer processing applications, had begun experimentally in the late 1980s. Practical systems awaited faster computers and better algorithms. Michigan began investigating products in late 1999, and a decision was made in early 2000 to implement the PowerScribe product from vendor Lernout & Hauspie. Lernout & Hauspie had acquired Dictaphone, a maker of traditional dictation equipment, and Dragon Systems, a developer of speech recognition technology. The marriage propelled the company into a leader in speech recognition transcription. By September 2000, the product had been installed in the Department and the first reports generated using speech-to-text technology. Not long afterwards, Lernout & Hauspie unexpectedly went bankrupt in 2001; however, their technology was purchased by Nuance Communications and the PowerScribe product was continued and advanced through
several generations. Over time, the Department converted to exclusively speech-to-text computer transcription, and radiology human transcriptionists were transferred to the hospital transcription pool where general clinical dictations were transcribed the traditional way. Not only did the conversion to computerized transcription save money, but the time it took for radiology reports to be signed and printed (routine printing was later discontinued as the electronic medical record became widely available) or uploaded to the hospital clinical information system was markedly reduced. In 2001, Sean K. Kesterson, medical director at the UMHS Brighton Health Center, wrote a note of “thanks for great service … in providing timely interpretation…. We have stories where the doctor has been given the x-ray result even before seeing the patient…. This represents a substantial change from the status quo of only a few years ago.”

With the advent of PACS, the Department initially printed film for use by clinical services and also provided major image-using clinics with standalone PACS workstations. Later film was replaced by digital images on CD. As the hospital electronic information system expanded, more PCs were distributed throughout the clinical space, and more clinics requested images on CDs and/or viewing workstations, the Department realized that an enterprise viewing system that could use the intranet (or even internet) to show images would be beneficial to patient care. In 2005, technical and clinical teams were formed to evaluate possible products. The leading contenders were Siemens, which sold an enterprise viewer that was separate and different from its radiology PACS product in use within radiology, and Stentor, which sold a product through the Department’s radiology information system vendor IDX. The Stentor product was chosen, and a complex year-long installation ensued that included the ability to open the Stentor product from within the hospital’s home-grown electronic data repository CareWeb.

In the summer of 2005, the main radiology (Siemens) PACS began to experience severe problems. These were temporally related to an electrical storm from which the system never seemed to recover. The system was composed of several semi-
independent archives; the archive handling MR imaging malfunctioned and could not be repaired. The speed with which imaging studies could be retrieved from the other archives deteriorated. During the 10 years in which the Siemens PACS was operating, the number of imaging studies increased by 32 percent, but the amount of data contained in those studies increased by 360 percent. In addition to the acute problems, the system had simply been outgrown. This adversely affected all aspects of the clinical operation of the medical center and clearly demonstrated the need to upgrade the system.

After instituting temporary countermeasures, including upgrading the electronic infrastructure and expanding archive capacity, the Department embarked on a PACS replacement project. Selecting the vendor — writing the Request for Proposal (RFP), allowing time for vendor response, reviewing the responses, and making a decision — took almost two years. In view of the importance of the PACS to the clinical operation of the entire medical center, two committees were formed to review the vendor responses, a technical group and a clinical users group. After significant effort in analysis, both groups convened to create a short list of potential vendors which were then further evaluated with site visits. McKesson was chosen as the preferred PACS vendor, and in February 2008, a contract was signed to deliver and install a new PACS at Michigan. Work began in earnest to install and test the new system, and to transfer images from the Siemens PACS to the new PACS. In June 2009, radiologists began to use the new McKesson PACS for clinical work. In addition to a more modern architecture and faster workstations than the previous PACS, the new PACS featured integration among the image display, the worklists (of cases ready to be interpreted) maintained by the radiology information system, and the speech recognition software. It was finally possible for reading rooms to go paperless for regular examination-interpretation workflow.

**Education**

As one of the three main missions of the Department (along with clinical care and research), the education of future
The Department of Radiology has been formally training residents in radiology since the early 1940s. At the conclusion of World War II, resident classes of two to four residents per class were organized. Among the luminaries in those classes were Melvin Figley, Theodore Keats, Edward Singleton, Eugene Klatte, Alexander Margulis and Philip Rubin, all of whom went on to become chairs of departments of radiology or radiation oncology. The training program has continued to train luminaries in the field, including leaders in research education and administration. Michigan trainees and faculty have served as presidents of many of the major professional radiology societies.

Although the number of years of training has been prescribed for many years, specific requirements were not spelled out. Over time, detailed conditions of residency training have been enumerated, such as specified resident time on specific rotations, required numbers of cases, specific requirements for advanced cardiac life support, and specifics of training in nuclear medicine safety. Designation of a formal residency training director became a requirement; prior to that, Department chairs had oversight of the training programs. Terry Brady was the first residency training program director at Michigan. He was followed by Barry Gross in 1983, then by Mark Helvie in 1989. When Dunnick succeeded Martel as chair in 1992, he brought Richard Cohan, with whom he had worked at Duke University, with him to become the residency training director. After 10 years of outstanding service during which time the residency program was expanded from 28 residents to 44 residents, Cohan passed the baton to Janet Bailey.

Radiology residents rotate on all clinical services and spend time in University Hospital, the Mott Children and Women’s Hospital and the Ann Arbor Veterans Administration Hospital. For many years, a clinical year has been required before beginning the four-year radiology residency. Virtually all Michigan radiology residents take a fellowship following residency training.

Certification by the American Board of Radiology required
successful completion of the prescribed training program and passing both written and oral examinations in imaging physics, general knowledge and specific interpretation of imaging studies as well as knowledge of image guided interventional procedures. This examination structure was changed, effective in 2014, to make all examinations image rich and computer-based. A core examination is offered at the end of the third year of residency and the Certifying Examination may be taken 15 months after completion of the residency. Medical physics is integrated into both examinations.

Training in nuclear medicine is more varied, reflecting the different pathways to practice. Medical students may enter nuclear medicine after a clinical year. The residency for those physicians is three years in duration. Physicians may also enter a nuclear medicine residency after completing training in another field, usually internal medicine. The residency is two years in duration for those candidates. Radiologists may also enter nuclear medicine after completion of a radiology residency, in which case the program is one year in duration. Under special circumstances, radiology residents may qualify for board certification by the American Board of Nuclear Medicine at the completion of their four-year radiology residency.

Radiology Department alumni (residents, fellows, and faculty) have always been intensely loyal to Michigan, and many would return each year for football games or other events on campus. In 2013, the Department of Radiology celebrated its centennial with a weekend of activities that started with a welcome reception Thursday. On Friday morning, radiology faculty gave brief presentations of their work, and tours of the research laboratories were conducted. The day concluded with a gala dinner in the new North Campus Research Center. Former resident Murray Howe's father, Gordie Howe, the famous Detroit Red Wing known as “Mr. Hockey,” attended. Saturday featured a tailgate party prior to the afternoon football game. The weekend was so successful that the tailgate party prior to a Saturday football game has become an annual tradition.
The Divisions

Many of the achievements of the Department of Radiology come from the subspecialty divisions that have developed since the 1970s under the leadership of chairs Adams, Martel and Dunnick. The following divisional histories illuminate the accomplishments during these years.

Abdominal Imaging Division

For decades after the discovery of the x-ray by Wilhelm Roentgen in 1895, imaging of the abdomen was primarily obtained using plain film radiography, with just the contrast of the body’s natural contents to produce an image. Gradually, however, the natural contrast of the body was supplemented by exogenous introduction of contrast agents that altered the otherwise expected attenuation of the radiographic beam. Barium-based agents were swallowed, or administered per rectum, to visualize the gastrointestinal tract, including esophagrams, upper GI series, and barium enemas. Specifically designed iodinated agents were concentrated in the bile to visualize the gallbladder; these could be administered orally (for oral cholecystography) or intravenously (for intravenous cholangiography, allowing visualization of the main biliary ducts in addition to the gallbladder).

Iodinated contrast agents were injected intravenously for intravenous urography, in which they were subsequently concentrated and excreted by the kidneys to view the urinary tract. These agents could be injected directly into the lumens of organs, such as the urinary bladder, to visualize these organs. Iodinated agents could also be injected directly into arteries and veins for arteriography and venography to directly visualize these vessels. Arteriography also enhanced the visualization of the organs supplied by the injected artery, and tumors within organs such as the liver could be identified, although these examinations produced two-dimensional images of three-dimensional objects and were not without some mild to moderate risk of complication.

For decades, these techniques composed radiological imaging of the abdomen. In the 1970s and beyond, medical imaging
was revolutionized by the invention of devices that could image in three-dimensions: ultrasonography, computed tomography (CT), and magnetic resonance imaging (MRI). Although true three-dimensional images can be produced by these devices, the workhouse images are “slices” through the body, as if the patient were sliced like a loaf of bread. The radiologist then creates a mental image of the three-dimensional body by “stacking” the slices in his or her mind. Most importantly, a lesion can be located precisely in space by its appearance at a specific location within a slice of known position. The history of radiology in the latter quarter of the twentieth century and beyond became the story of cross-sectional imaging techniques.

John R. Thornbury took charge of urologic radiology following the departure of Anthony F. Lalli in 1970. Lalli had had great influence on the technique of intravenous urography based on his principles of the “tailored urogram,” later elucidated in a book of the same name. Thornbury would continue leadership in uroradiology and collaborate with Dennis Fryback on early work on the use of decision analysis in imaging and patient management.

In the early 1970s, ultrasonic high-frequency sound waves became widely used in medicine for imaging. Early ultrasound imaging was crude, but the technology improved dramatically, albeit slowly. For abdominal imaging, the ultrasonic transducer, which emitted the high-frequency sound waves and received the echoes back that created the image, would be placed on the skin of the patient; the distance from the skin to the organs of interest, as well as intervening bone and bowel gas that obscured the ultrasonic beam, limited the results. Nevertheless, in part due to the physics of the ultrasonic beam and in part because the technique imaged “slices” through the patient, ultrasonography was able to make diagnoses not previously possible. In 1972, the Radiology Department was granted jurisdiction over sonography, and Terry M. Silver took on the role of division director. Silver advanced the technique of neonatal cranial ultrasonography to study the infant brain and pursued intraoperative sonography; with the latter technique, radiologists were able to image organs when the abdomen was...
surgically opened and the organs were directly exposed to the ultrasound transducer without intervening tissues.

The advent of computed tomography in the 1970s revolutionized imaging in medicine. Relying on the well understood physics of x-rays supplemented with new computer techniques, CT scanners produced cross-sectional images through the human body. In addition to the improved spatial localization of lesions, CT scanners were able to resolve smaller differences in radiographic attenuation than had been possible with classic film radiography. For example, CT could separate the white and gray matter of the brain, or the liver from the kidney, based on only very small differences in radiographic attenuation, thus showing features never seen before without cutting open the patient for direct inspection. Initially, CT scanners could only image the human head, with the brain as the area of interest, and an EMI head unit was installed at University Hospital in 1975. By 1976, however, faster scanners and improved computing technology allowed imaging of the chest and abdomen.

The first whole body CT scanner in Ann Arbor, an EMI whole body scanner, was not installed in University Hospital, but instead at the nearby Veterans Administration Hospital in 1977, with which the University Medical Center had faculty staffing and teaching agreements. Patients who required body CT scans would be transferred by ambulance from University Hospital to the VA to be imaged under an agreement between the two hospitals. Competition for the available scan time was tight. Often a U-M radiologist, Lawrence Kuhns, would interpret the body CT studies off hours. In 1980, an early General Electric whole body CT scanner was installed at the University Hospital; with this, it was no longer necessary to send UMHS patients to the VA for CT scans.

Adams appointed Gary M. Glazer, a brilliant radiologist and outstanding investigator and mentor, as head of the Body CT Division in 1981. Glazer oversaw rapid expansion of CT with more scanners and more clinical applications as the technology improved and scans became faster and gained higher resolution. (Initially, CT capacity was limited mostly by the institution’s hesitancy to invest in such expensive equipment
and was also limited by building constraints in the 1920s-era hospital.) Glazer recruited outstanding fellows, including Isaac R. Francis, who was a fellow from July 1981 to June 1982, and would go on to become a long-time faculty member and one of the most prolific authors of scientific articles in the Department. Francis became the Department’s associate chair for research in 2000.

L. Paul Sonda, a U-M-trained urologist who would become a U-M radiology resident and Radiology faculty member, became closely involved with the Abdomen Division early in his urology career. In the early 1980s, Sonda created the state’s first program in percutaneous renal stone extraction using fluoroscopic guidance in what now would be called minimally invasive surgery. Sonda and abdominal radiologist Marco Amendola had traveled to the University of Minnesota to learn the technique. Later, Sonda partnered with abdominal radiologist Terry Brady and, after Brady’s departure, Edward Woolsey. The procedure was begun by the radiologist accessing the stone-containing kidney in a fluoroscopic room in radiology and dilating a tract large enough to admit an endoscope. The procedure would then be turned over to Sonda, who would use the endoscope to either extract the stone whole (if small enough) or break the stone into smaller pieces that could be extracted or passed. This replaced open renal surgery in an operating room, and in addition to quicker patient recovery and avoidance of general anesthesia (almost all percutaneous cases were performed under conscious sedation), the procedure being done in a radiology room offloaded some cases from the operating rooms at a time when operating room time was limited. Eventually a general fluoroscopic room was replaced with a special procedure room to facilitate the cases. The development of extracorporeal shockwave lithotripsy that began in the late 1980s reduced the need for the percutaneous procedure, but it continues to be performed for patients in whom external shockwave lithotripsy is not appropriate. In the late 1990s, the radiology portion of the procedure was turned over to the Vascular/Interventional Division.

Jonathan M. Rubin joined the Department in 1984 and became co-director of the ultrasound division in 1987. Rubin
began expanding research into ultrasound imaging, and would eventually become a National Institutes of Health (NIH)-funded principal investigator and receive the Society of Radiologists in Ultrasound Lawrence Mack Lifetime Achievement Award.

After Martel was appointed chair in October 1982, he continued the efforts begun by Adams to establish subspecialty divisions according to organ or body system and modality. Certain imaging modalities, such as CT and ultrasound, were considered sufficiently new or complex to be regarded as subspecialties in their own right. The general theme of abdomen imaging was spread across the then-divisions of Gastrointestinal Imaging (primarily plain radiography and barium studies), Genitourinary Imaging (plain radiography, intravenous urography, fluoroscopic studies of the genitourinary tract, and interventional GU procedures), Ultrasonography, and Body CT; the latter two divisions also imaged the chest and extremities. Although initially well accepted, this later led to conflict. As the Department expanded, newer recruits who had trained in all modalities did not want to be limited to just one modality; crossing over among multiple Divisions was accepted for some faculty and resisted for others.

Martel combined the Divisions of Gastrointestinal and Genitourinary Imaging with the division of Body CT to form a newly created Abdomen Division in July 1987, appointing James H. Ellis as the first Abdomen Division director. Ellis had been recruited in July 1984 by Martel to be the chief of the Radiology Service at the Ann Arbor VA Medical Center and was proficient in all the studies and procedures of the new division, including the percutaneous nephrostomies and stone extractions that Ellis inherited from Woolsey on the latter’s departure. With the creation of the new Abdomen Division, Glazer became the first division director for the newly designated MR Imaging Division.

In the late 1980s, Joel F. Platt, then a young faculty member, led a team of Rubin, Ellis, and Michael A. DiPietro (of the Pediatric Radiology Section) that began investigating new uses of the ultrasound renal resistive index, a measure of the resistance within the kidney to arterial blood inflow. Although the technique had been in use to evaluate transplant kidneys,
this group pioneered the application of renal resistive index within native kidneys to distinguish whether kidneys with dilated collecting systems had physiologically significant obstruction to urine outflow or were dilated for other reasons. Over the years, additional applications of the renal resistive index were investigated, including whether variations in the index might distinguish various medical renal diseases without collecting system dilatation.

In 1989, Melvyn T. Korobkin, an outstanding academic radiologist in body CT who had gone into private practice, was recruited back into academia by Martel and given a co-director role in the Abdomen Division. He became the sole director in July 1992 when Ellis was appointed clinical director for the Department by Dunnick, then the incoming chair.

When Gary Glazer left the Department to become chair of the Department of Radiology at Stanford University in 1989, it left a large hole in the Department’s MR imaging leadership. The Department also had lost its most powerful advocate for abdominal MR imaging. The MR division continued as a quasi-independent division under the leadership of neuroradiologists, given that the majority of applications of MR were in neuroimaging. Additionally, Michigan’s certificate-of-need laws restricted the number of MR units that could be installed, leading to a chronic shortage of patient slots on the MR scanners and long wait times. Preference was often given to patients with neurologic problems because the advantages of MR over CT were clearer for neuroimaging, and some neuroimaging could only be done with MR. Later, applications in the abdomen for MR would become more widespread in radiology.

Rubin and coworkers published a landmark article in 1994 (Rubin JM, Bude RO, Carson PL, Bree RL, Adler RS. “Power Doppler US: A potentially useful alternative to mean frequency-based color Doppler US.” *Radiology* 1994; 190:853-856) that demonstrated the use of Power Doppler in abdominal imaging. Color Doppler ultrasound was a widely used ultrasound technique to assess vascular flow, both to visualize vessels directly and to demonstrate blood flow within organ tissue. Power Doppler had been used by cardiologists to evaluate vessel stenoses. The Michigan radiologists applied the technique in the
abdomen and showed advantages over standard color Doppler, including extended dynamic range that improved visualization of blood flow in low-flow states. Within a few years, power Doppler became standard on ultrasound units produced for the radiology market.

By the early 1990s, chest CT studies were absorbed into the Chest Division and musculoskeletal CT studies were absorbed by the Musculoskeletal Division. In the late 1990s, the interventional genitourinary procedures were transferred to the vascular/interventional division, which put Michigan more in line with other academic radiology departments. The Abdomen and Ultrasound Divisions continued to perform procedures guided by CT and ultrasound, respectively (primarily tissue biopsies, fluid aspirations, and abscess drainages).

In 1992, Dunnick recruited Richard H. Cohan to join the Abdomen Division. Cohan was interested in the use, effects, and complications of contrast agents in imaging, and began a long collaboration with Ellis that produced many publications on the topic. Cohan and Ellis advanced the training of residents and fellows in contrast issues and the management of contrast reactions, and started an annual course in 1995 that employed simulation of contrast reactions as part of the instruction. The course evolved over many years, with Matthew S. Davenport and Jonathan R. Dillman (both former residents who became faculty) joining the training team beginning in 2010. The simulations were taken to a new level in 2012 when the course took advantage of the Health System’s Simulation Center to use high-fidelity patient manikins as practice “patients” experiencing simulated contrast reactions for residents to treat.

Martin R. Prince was recruited from Harvard and Massachusetts General Hospital in 1993 to bring MR angiography to Michigan. Prince’s collaboration with Department MR physicist Thomas Chenevert and Thomas K. Foo, a research scientist at General Electric, led to the development of a bolus triggering gadolinium-contrast-enhanced MRA technique which GE commercialized as “MR Smartprep.” Together with Michigan radiology resident Jeffrey H. Maki, he described the artifacts on 3D gadolinium-contrast-enhanced MRA that were related to contrast concentration
variations. Working with Michigan MRI fellow James F. M. Meaney, Prince developed the concept of bolus chase MR Angiography which became widely used for performing peripheral MR Angiography.

By 1995, Korobkin had begun to investigate whether CT scans could provide true tissue diagnosis in one specific situation. The adrenal glands were common sites of metastasis from cancer, but they were also a common site of benign adrenal adenomas. The treatment of many cancers was quite different depending on whether the cancer had metastasized or not, but many cancer patients had an adrenal adenoma posing as a metastasis. Both conditions presented as a nodule in an adrenal gland, and earlier attempts to differentiate them by their morphologic appearance at CT scanning had not produced sufficiently accurate separation. Thus differentiating a benign adrenal adenoma from an adrenal metastasis typically required image-guided biopsy that was difficult and presented some risk to the patient, or long term follow-up that might delay appropriate treatment. Korobkin expanded on and refined earlier work showing that CT scanning might be able to demonstrate that some of these nodules represented a benign adrenal lesion native to the adrenal gland based not on lesion morphology but on lesion radiographic density, potentially obviating the need for biopsy. Korobkin knew that most of the benign adrenal adenomas had cells containing intracellular lipid (“lipid-rich adenomas”), and lipid was lower in density on CT scans than cancer cells that did not contain lipid. But did the adenoma cells contain enough lipid to lower the density sufficiently to make the diagnosis with reasonable certainty? Korobkin et al. compared the CT scans of patients with adrenal adenomas and patients with nonadenomas (primarily metastases), and was able to show that threshold values for CT attenuation could be identified that were sufficiently specific for adrenal adenomas that the diagnosis could be made and biopsy foregone based on noncontrast CT scanning alone (Korobkin M, Brodeur FJ, Yutzy GG, Francis IR, Quint LE, Dunnick NR, Kazerooni EA. “Differentiation of adrenal adenomas from nonadenomas using CT attenuation values.” American Journal of Roentgenology 1996; 166:531-536). The determination of intracellular lipid in these
adrenal masses could also be made using specific MR techniques (Korobkin M, Giordano TJ, Brodeur FJ, Francis IR, Siegelman ES, Quint LE, Dunnick NR, Heiken JP, Wang HH. “Adrenal adenomas: relationship between histologic lipid and CT and MR findings.” Radiology. 1996 Sep;200(3):743-747). Although this research enabled lipid-rich adenomas to be diagnosed noninvasively, lipid-poor adenomas still could not be differentiated from metastases. Later, Korobkin and co-workers were able to show that many of the lipid-poor adenomas could be distinguished from metastases by using a different approach. Observing that intravenously administered iodinated contrast medium washes out of adrenal masses at different rates over time, Korobkin and his colleagues developed a quantitative method that accurately and consistently distinguished adenomas from metastases, even those lipid-poor adenomas that did not meet the noncontrast-CT criteria for being an adenoma (Korobkin M, Brodeur FJ, Francis IR, Quint LE, Dunnick NR, Londy F. “CT time-attenuation washout curves of adrenal adenomas and nonadenomas.” American Journal of Roentgenology 1998; 170:747-752). Together, these noncontrast and contrast-enhanced CT techniques have become the standard of care for evaluating adrenal nodules.

As cross-sectional imaging became more and more important in clinical medicine, older traditional abdominal imaging techniques became less favored. Fortunately, the Department was able to maintain expertise in traditional genitourinary imaging by the long tenure of a large number of faculty with this interest: Cohan, Dunnick, Ellis, and Platt. Newer faculty such as Davenport became expert as well. In gastrointestinal imaging, the Department recruited graduating resident L. Paul Sonda in 1997 to take a leadership role; the Department funded a six-month fellowship at outside institutions (Hospital of the University of Pennsylvania, Beaumont Hospital) to sharpen his skills in traditional gastrointestinal imaging. Sonda had been a urologist at the University of Michigan since 1977; he began his residency in radiology at Michigan in July 1993.

Like Korobkin, Robert L. Bree was a radiologist who returned from private practice to an academic career at Michigan and thrived. An expert in ultrasound imaging and imaging
utilization, Bree also was a talented leader and administrator. He recognized that image-guided biopsies, fluid aspirations, and abscess drainages were split between the ultrasound and CT sections of the Abdominal Imaging division, leading to fragmented service and difficulty with scheduling (sometimes clinical services would be bounced back and forth between ultrasound and CT as each side thought the other was better suited to perform the procedure). Furthermore, the performance of these interventional procedures of uncertain length interrupted the efficiency of the interpretation of regular diagnostic imaging studies. Bree not only saw that a specialized image-guided cross-sectional procedure service would improve patient care, but he also recognized that, over time, caseload would increase as obtaining procedures became easier and new applications could be introduced. He also shifted many of the procedures from CT to ultrasound, freeing up slots in the Michigan certificate-of-need-limited CT scanner resources. In yet another insight, Bree appreciated that mid-level providers could deliver service continuity and could perform procedures under guidance that would increase case numbers beyond what could be provided by radiology faculty alone. This led to the recruitment of the Department’s first physician assistant (PA), Ellen Higgins, MS, PA-C in 1998. Once the contributions of PAs to patient care, service efficiency, and quality improvement were recognized, the number of PAs in the Department expanded rapidly, and by 2014 there were 11 in the Department.

Prior to Bree’s recruitment to become chair of the Department of Radiology at the University of Missouri (Columbia), he had acquired the equipment and had introduced radiofrequency ablation (RFA) to the cross-sectional interventional service. This was a minimally invasive technique that used percutaneous probes, placed under imaging guidance, to heat and destroy unwanted tissue (primarily cancers). With Bree’s departure, the Department recruited Hanh V. Nghiem to continue and advance tumor treatment via image-guided percutaneous techniques. These cases rapidly expanded in number and complexity, and additional faculty were added. Major applications were the biopsy and ablation of renal tumors, precluding the need for resection, and ablation of liver
cancers as either primary therapy or as a method to keep patients alive and well enough for liver transplantation.

In 1999, the Department recruited Hero K. Hussain from the Mallinckrodt Institute of Radiology at Washington University in St. Louis to take charge of abdominal MR imaging. Although abdominal MR imaging would remain administratively a part of the abdomen division, Hussain rapidly became the “go-to” person in abdominal MR, setting protocols and directing workflow. She took on the responsibilities of a division director without the title. Hussain quickly focused abdomen MR on liver imaging, a field where MR was clearly superior to CT for lesion characterization, although other applications, including MR urography and later MR enterography, were not ignored. Hussain worked with clinical and transplant liver specialists to develop imaging criteria for the non-invasive diagnosis of hepatocellular carcinoma, a primary liver malignancy. Many patients needing liver transplantation have cirrhosis and are at risk for hepatocellular carcinoma, and many of these patients have liver lesions that enhance on CT during the arterial phase of contrast administration, but not all of these lesions are cancers.

With the appointment of Platt as director of the Abdomen Division in July 2002, the Ultrasound Division was folded into the Abdomen Division.

In 2005, Hussain published a seminal paper describing highly specific MR imaging features for the diagnosis of hepatocellular carcinoma in the cirrhotic liver (Marrero JA, Hussain HK, Nghiem HV, Umar R, Fontana RJ, Lok AS. “Improving the prediction of hepatocellular carcinoma in cirrhotic patients with an arterially-enhancing liver mass.” Liver Transpl 2005; 11:281-289). These criteria were subsequently adopted by all major American and European professional societies dealing with liver disease and the Organ Procurement and Transplantation Network, thus eliminating the need for invasive biopsy confirmation of hepatic malignancy status in most cases.

Under the divisional leadership of Platt and with the contributions of various individuals, new techniques were brought to the patients of the University of Michigan Health System. With the onset of helical and then multi-slice CT, scans
could be obtained faster, enabling better visualization of the intravenously administered contrast material while it was still briefly in the arterial system. For example, CT was able to improve the assessment of patients who were being evaluated as living donors of a kidney to another patient with kidney failure. Previously, in order to decide if these donors were candidates for donation and which kidney to take if they could be a donor, potential donors needed a catheter angiogram and an intravenous urogram to assess both the vessels supplying the native kidneys and the integrity and anatomy of the renal parenchyma and urinary collecting systems. Using CT, the evaluation could be performed in one examination and require only a single intravenous injection of iodinated contrast material (Platt JF, Ellis JH, Korobkin M, Reige K. “Helical CT evaluation of potential kidney donors: findings in 154 subjects.” American Journal of Roentgenology. 1997 Nov;169(5):1325-1330). CT also replaced the intravenous urogram in the evaluation of patients with urinary tract stone disease, and later, with the development of CT urography, in part advanced and refined at Michigan by Cohan and Elaine M. Caoili and others (Caoili EM, Cohan RH, Korobkin M, Platt JF, Francis IR, Faerber GJ, Montie JE, Ellis JH. “Urinary tract abnormalities: initial experience with multi-detector row CT urography.” Radiology. 2002 Feb;222(2):353-360, Caoili EM, Inampudi P, Cohan RH, Ellis JH. “Optimization of multi-detector row CT urography: effect of compression, saline administration, and prolongation of acquisition delay.” Radiology. 2005; 235(1):116-123), essentially completely replaced the intravenous urogram in the evaluation of the urinary tract for all diseases where imaging played a role. Still later, MR urography was added to the imaging armamentarium.

The small bowel was difficult to evaluate, as it was beyond the reach of the gastroenterologist’s endoscope, and the barium- and radiography-based small bowel follow-through primarily imaged only the mucosal surface of the small bowel, and not the small bowel wall where much pathology was located. CT and MR enterography techniques were able to image both the lumen and the wall of the small bowel, adding greatly to the understanding of small bowel diseases such as Crohn disease,
with young faculty members Mahmoud M. Al-Hawary and Ravi K. Kaza taking leadership roles.

Abdominal radiologist Ruth C. Carlos initiated comparative effectiveness research and technology assessment in diagnostic testing, as well as research into health care reform and imaging utilization. In 2010, she was named assistant chair for clinical research in the Department. She became a member of the Board of Review for the General Electric-Association of University Radiologists Radiology Research Academic Fellowships, a renowned national training program for health services research in radiology, and in 2012, she became the chair of the Board of Review.

New techniques and applications in abdominal imaging continue to be developed and refined in the Department of Radiology at U-M, and will likely play an increasing role in abdominal imaging in the future. Vascular imaging continues to expand, and pre-operative planning for tissue flaps is rapidly converting from catheter angiography to noninvasive CT angiography under the leadership of Peter S. Liu. New CT reconstruction techniques that are able to reduce radiation dose to the patient are under evaluation by faculty such as Kaza and Katherine E. Maturen. Dual-energy CT may provide additional ways to improve diagnostic quality and/or reduce radiation dose under the direction of Kaza and Platt. A rejuvenation of MR imaging of the prostate gland began under Davenport’s guidance. MR staging of rectal cancer is being championed by Al-Hawary.

In 2012, Davenport, a former chief resident, was recruited back to the Department after fellowship training from Duke University. Davenport had great interest in the use of radiographic contrast media and published many articles on this topic. Davenport was the lead author on several defining articles from the Michigan contrast interest group that applied a new statistical technique, propensity score matching, to the long-standing question of the renal toxicity of iodinated contrast agents (the agents given intravenously for CT scans, and other uses). Propensity score matching allowed a retrospective analysis to more closely emulate a randomized controlled trial by reducing the selection bias that plagued other
retrospective reviews of renal deterioration in patients who did and did not receive intravenous iodinated contrast agents during their illnesses. One of the publications (Davenport MS, Khalatbari S, Cohan RH, Dillman JR, Myles JD, Ellis JH. “Contrast material-induced nephrotoxicity and intravenous low-osmolality iodinated contrast material: risk stratification by using estimated glomerular filtration rate.” Radiology 2013; 268:719-728) was co-awarded the 2013 Alexander R. Margulis Award for Scientific Excellence as the best original scientific article of the year published in Radiology, the premier radiological journal.

**Basic Radiological Sciences Division**

Following the 1981 recruitment of Paul L. Carson to lead the Basic Radiological Sciences division, the division has seen substantial growth and increase in prominence. Beginning with expertise in ultrasound physics and imaging, the division would subsequently expand to bioengineering, biochemistry, medicinal chemistry, biostatistics, microwave and optical imaging, magnetic resonance, and magnetic resonance spectroscopy.

In ultrasound, Brian Fowlkes, Carson and colleagues including Oliver Kripfgans and Mario Fabilli used ultrasound to create microbubbles in blood vessels and the urinary bladder to enhance sonographic diagnosis and therapy. Later, by using ultrasound to vaporize injected perfluorocarbon microdroplets and then agitate the resulting microbubbles in the location of specific cells, their group targeted these cells for imaging and for the delivery of drugs, hormones, or acoustic energy density if administered to the entire body (Kripfgans OD, Fowlkes JB, Miller DL, Eldevik OP, Carson PL. “Acoustic droplet vaporization for therapeutic and diagnostic applications.” Ultrasound Med. Biol. 2000; 26:1177-1189). This has helped them deliver cancer therapies to specific cells and injectable dyes to study drug release, effects, and retention, among other applications.

The ultrasound group has also made important progress toward the use of 3D automated ultrasound in conjunction with

With the recruitment of Xueding Wang, a new group in optical imaging was created in close association with ultrasound. His work is on the cutting edge of photoacoustic imaging, which processes ultrasound waves generated when laser pulses are applied to biological samples, expanding the optically absorbing tissues. He was the first to direct the technique to imaging of inflammatory arthritis (Chamberland DL, Wang X, Roessler BJ. “Photoacoustic tomography of carrageenan-induced arthritis in a rat model.” J. Biomed. Optics 2008; 13:011005) and has attached gold nanoparticles to antirheumatic drugs to visualize their uptake by inflamed joint tissues. Because photoacoustics is capable of quantifying physiological biomarkers of cancer, like oxygenation and pH levels, Wang and research investigator
Guan Xu are using photoacoustics to study prostate cancer. Wang, Carson and Zhixing Xie built a breast 3D photoacoustic imaging system with the deepest reported breast imaging of 5 cm.

Heang-Ping Chan joined the division in 1989, rapidly establishing her leading work in computer-assisted diagnosis of breast cancer; she would later become the Paul L. Carson Collegiate Professor of Radiology. Recently she and her colleagues have developed what is probably the most advanced CAD system for detection of microcalcifications in digital breast tomosynthesis (Sahiner B, Chan H-P, Hadjiiski L, Helvie M, Wei J, Zhou C, Lu Y. Computer-aided detection of clustered microcalcifications in digital breast tomosynthesis: a 3D approach. Med. Phys. 2012; 39:28-39). Her lab not only develops computerized methods of detection but uses machine learning methods to build decision support systems for risk prediction, diagnosis, and treatment response monitoring. In recent years they have been applying these methods to other diseases and organ systems besides the breast.

A promising CT hepatocyte-specific contrast agent was developed and advanced to a commercial small animal imaging agent by Jamie Weichert. Meyer’s laboratory developed the first practical method for warped, 3D registration and fusion of multimodality data sets (CT, MRI, PET, US) to improve diagnosis and treatment in many conditions (Meyer CR, Boes JL, Kim B, Bland PH, Zasadny KR, Kison PV, Koral K, Frey KA, Wahl RL. “Demonstration of accuracy and clinical versatility of mutual information for automatic multimodality image fusion using affine and thin-plate spline warped geometric deformations.” Medical Image Analysis 1996/7; 1:195-206).

Brian D. Ross, the Roger A. Berg Radiology Research Professor, and Thomas L. Chenevert, the BRS Collegiate Professor of Radiology, collaborated on research using MR imaging to track the diffusion of water through tumor cells as an indicator of chemotherapy response (Chenevert TL, McKeever PE, Ross BD. “Monitoring early response of experimental brain tumors to therapy using diffusion magnetic resonance imaging.” Clin Cancer Res. 1997; 3:1457-1466). Because cancer cells slow the diffusion of water, an increase in diffusion correlates to a
positive response to therapy. P31 spectroscopy was developed to evaluate muscle physiology, and magnetization transfer imaging was used by Scott Swanson to clarify factors that determine MR contrast (Henkelman RM, Huang X, Xiang QS, Stanisz GJ, Swanson SD, Bronskill MJ. “Quantitative interpretation of magnetization transfer.” Magnetic Resonance in Medicine 1993; 29:759-766). Leading edge hyperpolarized xenon MRI research was performed by Swanson in cooperation with the Department of Physics.

Ross developed the molecular imaging center with colleague Alnawaz Rehemtulla, professor of radiation oncology. The large funding for this center, Ross’s program project grant, and regional small animal imaging facility complemented by the consistent ultrasound, CAD, image processing, and nuclear medicine grant support, has placed U-M Radiology and Radiation Oncology in the top tier in National Institutes of Health radiologic research support since 2002. Gary Luker and Kathy Luker, Department faculty and members of the Molecular Imaging Center, specialize in using bioluminescence imaging and intravital fluorescence microscopy (Luker KE and Luker GD. “Applications of bioluminescence imaging to antiviral research and therapy: Multiple luciferase enzymes and quantitation.” Antiviral Res. 2008; 78:179-187) to analyze the signaling pathways regulating tumor growth, metastasis, and drug resistance in cell and animal models of breast cancer. Their work has allowed the visualization of ligand-receptor binding and the activity of proteasomes (cellular organelles responsible for degrading proteins), both of which are targets for chemotherapy. The group made significant progress in analyzing the mechanisms of cancer progression and treatment.

Breast Imaging Division

In the 1970s, mammography was performed with either film screen techniques or xerography. Although each technique had advantages and advocates, the lower radiation dose enabled film screen systems to become the dominant technique. Magnification views proved useful in the detection and characterization of calcifications. A hooked needle was
developed that could be inserted into a suspicious non-palpable lesion and left in place to direct the surgeon to the removal of the cancer.

With improvements in mammography technique, clinical trials were performed that demonstrated the value of mammography as a screening procedure. The Health Insurance Plan of Greater New York project was the first appropriately powered study and demonstrated a significant decrease in mortality among screened women 40 years of age or older. This study and a subsequent Breast Cancer Detection Demonstration Project led the American College of Radiology to develop guidelines for screening mammography in 1976.

U-M was an original participating site of the BCDDP in the 1970s which showed the feasibility of widespread breast cancer screening by mammography. Results of the BCDDP and additional randomized controlled trials from Europe led to national recommendations for routine screening mammography beginning in the mid-1980s.

The original breast imaging facility was located on West Washington Street in Ann Arbor, not at the Hospital, which created some logistical issues. Women needing wire-localizations of non-palpable breast masses traveled from West Washington Street where the localization was performed to the hospital on the other side of Ann Arbor for their surgery. By the mid-1980s, mammographic equipment was located at the main hospital.

Mammographic studies were interpreted by radiologists with additional training in breast imaging. Clinical mammography followed techniques used and developed in the BCDDDP and all women initially had physical examination by nurses followed by mammography. Thermography, an initial component of the BCDDP, was discontinued. Test interpretation usually occurred while the patient waited, and additional studies were completed as needed. In the 1990s, screening mammography was offered; the patients had their mammograms performed but did not see nurses or physicians at that appointment, and the interpretations of the images were performed “off line” in batches; the screening methodology increased efficiency and allowed more patients to undergo mammography at lesser cost.
and resource utilization. In 1998, 35 percent of the mammograms were screening studies. The number of screening examinations relative to diagnostic studies continued to rise, and in 2003, more screening studies were done than diagnostic mammograms.

Breast radiologists not only identify suspicious areas in the breast on mammography, but also characterize the mammographic lesion as well as palpable lesions through additional studies such as ultrasound, fine needle aspiration, needle localization, and core biopsies. In the 1980s, U-M was one of the first sites in the U.S. to offer image-guided percutaneous biopsy based upon techniques brought to U-M by Ingvar Andersson of Sweden. This allowed a less invasive (than open surgery) diagnosis of image-detected lesions. These procedures began in earnest in the late 1980s and by the year 2000, over 2000 procedures were performed annually by breast radiology faculty.

In addition to clinical research, the division has focused upon computer-aided detection and diagnosis (CAD) of breast imaging findings under the leadership of Heang-Ping Chan, advanced ultrasound techniques under the leadership of Paul Carson, and breast MR under the leadership of Tom Chenevert. Many of the clinical research advances and research techniques developed are now in routine clinical use. Faculty helped develop the BIRADS lexicon and establish the scientific basis for its use, now the standard throughout the U.S. and much of the world. Image-guided needle biopsy has largely replaced surgical biopsy. Every mammogram and MR is now “double read” using computer vision technology in addition to the radiologist. Breast ultrasound has evolved from a rarely used tool, to an indispensable clinical tool for screening and diagnosis. Magnetic resonance imaging is highly sensitive in identifying breast lesions, including malignancies. Thus, MR has proven to be useful in screening, in the further evaluation of some breast abnormalities, and for directing breast biopsies. Non-contrast breast MR was shown to be insufficient for clinical use at U-M in the 1980s. Research studies of contrast-enhanced breast MR in the early 1990s at U-M paved the way for clinical breast
MR exams to begin in 2005. MR has become a commonly used modality for specific high risk screening indications.

The Division of Breast Radiology had been directed by Barbara Threatt, who left the University to enter private practice in 1984. Visiting Professor Andersson led the division on an interim basis and trained his successor, Dorit D. Adler. Adler had completed her residency training at Michigan in 1984, and did fellowship training in mammography and MR in the 1984-1985 academic year. In July 1986, she was named director of breast imaging. Mark Helvie was appointed division director in 1992 when Adler reduced her appointment to part-time; Adler continued as associate division director until her retirement in 2009.

The value of screening mammography continues to be debated, especially with regard to the benefit of annual mammography in women less than 50 years of age. Since the preponderance of scientific studies demonstrates benefit, screening mammography continues to grow and is now offered at U-M imaging facilities in Briarwood, Brighton, Canton, East Ann Arbor and Livonia, in addition to the Cancer Center. In a project led by Marilyn Roubidoux, Michigan breast faculty also provide mammographic screening for Native Americans; mammograms are obtained in the northern Great Plains using a van equipped with mammographic equipment, and the images are sent to U-M for interpretation.

Cardiothoracic Imaging Division

Entering the 1980s, the Chest Radiology Division was a small operation concerned only with interpretation of chest radiographs. When computed tomography (CT) was introduced and developed in the 1980s, a Body CT Division was formed to interpret scans of the neck, chest, abdomen, pelvis, and bones, including pediatric body CT studies. However, a major focus of body CT research in the 1980s concerned chest CT, particularly staging lung cancer. Under Gary Glazer’s leadership, many important articles about the technique and accuracy of chest CT in lung cancer staging came from U-M.

For most of the 1980s, the Chest Division consisted of two or
three faculty who did mostly (but not exclusively) chest work. Although originally hired at Michigan in 1982 as a member of the Body CT Division after fellowship training in body CT and ultrasound, Barry Gross became Chest Division director in 1983. Later in the 1980s, Gross helped to start a process of subspecialization within CT to allow David Spizarny, fellowship-trained as a chest radiologist, to read chest CT without being a member of the Body CT division. By the early 1990s, chest CT separated from body CT. Initially, scans of the chest, abdomen, and pelvis were not split apart for reading; instead, if the disease process originated in the chest (for example, lung cancer or esophageal cancer) the study was read in chest CT; if disease was primarily abdominal (for example, colon cancer) the study was read in abdomen CT. After a number of years, it was decided to split almost all combined chest/abdomen/pelvis CT scans, with chest reading all chest CTs and abdomen reading all abdomen and pelvis CTs. As of 2014, the exceptions are aortic CTs (read by chest if ordered by cardiac surgery, cardiology, or prompted by chest symptoms, and read by abdomen if ordered by vascular surgery, general surgery, or prompted by abdominal symptoms) and lung and esophageal cancer cases (because they need to be prepared for presentation at the Multidisciplinary Thoracic Oncology Conference). Today, there are more CT patient encounters in cardiothoracic imaging than in any other division in the Department.

Philip Cascade became the division director in 1991. He brought a significant background in imaging of coronary arteries, even though this was almost exclusively the province of cardiologists throughout the United States (including at U-M). Cascade’s extensive knowledge of the subject and his outstanding interpersonal skills were very helpful over the years, as radiologists assumed a significant role in cardiovascular evaluation because of advances in CT technology. He was also a major driver in the creation of the American College of Radiology Appropriateness Criteria, leading the ACR Task Force that developed all 10 panels. Cascade developed a method of assessing the competence of radiologists by analyzing missed diagnoses. This method was used extensively in the Chest Division before dissemination throughout the U-M Department.
of Radiology. Ultimately, this competency assessment formed the basis for the American College of Radiology Radpeer™ program, used nationally to evaluate the performance of radiologists.

While members of the Chest Radiology division had sporadically trained fellows in chest radiology since the mid-1980s, the fellowship program began to be filled regularly under Cascade’s leadership, and it became a major source of faculty recruitment, particularly in the first decade of the 21st century. Cascade brought in and mentored his successor as division director, Ella Kazerooni, and handled the potentially difficult situation of having his predecessor, Barry Gross, return to the division (after a stint as chair of Henry Ford Hospital Radiology) with aplomb. He turned the reins over to Kazerooni in 2000, and remained a key member of the division until his retirement at the end of 2013.

Kazerooni oversaw a period of unprecedented growth in the division beginning in 2000. This decade saw major expansion in chest imaging, incorporating magnetic resonance imaging (MRI), cardiac CT, and coronary artery CT. Given these changes, the division was renamed Cardiothoracic Radiology. The new technology completely changed the workup of many clinical problems. Pulmonary emboli are now almost exclusively diagnosed by CT, with nuclear medicine and catheter angiography no longer playing major roles. CT scanning of the aorta with detailed aortic measurements is a major supporting component of the University’s large cardiology and cardiovascular surgery program, including trans-catheter aortic valve replacement. Coronary CT angiography plays a growing role in the evaluation of emergent chest pain, and cardiac MRI has grown to support many specialty programs in cardiology, such as the hypertrophic cardiomyopathy program and the adult congenital heart disease program. The Cardiothoracic Division also provides major support for expanded pediatric cardiac MRI services to accommodate increased collaboration with pediatric cardiology and cardiac surgery.

The growth of the division significantly relied on the hiring of fellows who had trained in our own fellowship program. By 2014 there were 14 full-time cardiothoracic radiologists
covering University Hospital and the Ann Arbor VA, and 2 others splitting time with other divisions (one doing some pediatric radiology and one doing some body CT). At one time, all cardiothoracic radiologists did the same assignments, consisting of chest CT, biopsies, and plain chest radiographs. By 2014, a further degree of sub-specialization had been introduced, with the establishment of assignments covering cardiovascular magnetic resonance imaging, led by Gisela Mueller and Prachi Agarwal, cardiovascular CT, led by Smita Patel, and thoracic interventional procedures. Sub-specialization of thoracic interventional procedures under the direction of Baskaran Sundaram allowed the application of advanced interventional techniques such as radiofrequency ablation procedures. With growth in cardiac imaging, cardiology colleagues have been incorporated into our imaging program, beginning with Adam Dorfman in pediatric cardiac MRI.

Kazerooni did an outstanding job of mentoring junior faculty, helping multiple former fellows advance to senior academic ranks. Seven faculty members received an Association of University Radiologists General Electric Radiology Research Academic Fellowship (GERRAF) Award or a Radiological Society of North America or American Roentgen Ray Society Scholar Award as a result. Kazerooni encouraged junior faculty members to enhance their knowledge of research basics and statistics, with many division members obtaining master’s level training from U-M’s School of Public Health to enhance the quality (and quantity) of academic output. She fostered close collaboration of our physician faculty with several groups in the basic sciences division of the Department, which has led to numerous National Institutes of Health-funded grants with radiology principal investigators. This includes working with Heang-Ping Chan’s group on computer assisted diagnosis for the detection and characterization of lung nodules, pulmonary emboli, and coronary artery disease, Charles Meyer’s program in image analysis, and Brian Ross’s lab in the area of advanced chronic obstructive pulmonary disease imaging using the parametric response mapping technique. Kazerooni was also a key player in major research initiatives involving pulmonary
medicine, thoracic surgery, and pathology on the subjects of interstitial and obstructive lung diseases. This program has been recognized as an area of tremendous expertise at U-M. She brought participation in major cardiothoracic imaging trials to the division, including Prospective Investigation of Pulmonary Embolism Diagnosis (PIOPED) II and III trials evaluating CT and MRI for pulmonary embolus detection, the National Emphysema Treatment Trial for lung volume reduction surgery, and the National Lung Screening Trial for early lung cancer detection. The latter is the largest clinical trial conducted by the U-M Radiology Department to date, enrolling over 850 subjects. In addition to her work as the division director, since 2008 she has served as the Department of Radiology’s associate chair for clinical services.

Musculoskeletal Imaging Division

Musculoskeletal imaging has seen significant growth and improvement since the 1980s, largely due to technological advances. Similarly, the number of imaging studies and fellowship-trained musculoskeletal faculty have also dramatically increased. In 1999, Curtis Hayes was recruited as director of the Musculoskeletal Division, and in 2003 Jon Jacobson became division director. From 1999 to 2015, the number of musculoskeletal faculty increased from 3 to 11. In addition to musculoskeletal radiology faculty on site at University Hospital and the outpatient Taubman Center, by 2015 musculoskeletal radiologists were embedded in the MedSport Orthopaedic Clinic at Domino’s Farms and at the newly established Northville Health Center.

While radiography has been and is still considered an essential imaging method in evaluation of the skeletal system, it is MR imaging and ultrasound that has allowed detailed assessment of the soft tissues as well as other areas not adequately assessed with radiography. In addition, advances in CT as well as digital image transfer and reporting have had a significant impact on patient care.

The first clinical MR imaging machine was installed at U-M in 1983. At the time, this state-of-the-art equipment had a
field strength of 0.35 Tesla. Since then, the strength of magnets commonly used in clinical practice has increased to 3 Tesla, which has markedly improved the quality of MR imaging. MR imaging of the joints, such as the knee and shoulder, became routine, followed by intra-articular administration of gadolinium-based contrast material to improve the evaluation of the joints for internal derangement; clinicians came to rely on the imaging information in their treatment decisions. By 2014, the number of MR imaging machines had increased, with 10 located throughout the University of Michigan Healthcare System. Two of these MR imaging machines are designed with a “true open” configuration, which is helpful to patients with claustrophobia. An additional dedicated 3 Tesla research MR imaging machine provides access to patients enrolled in research studies.

Improvements in technology have also directly affected ultrasound and its use in evaluation of the musculoskeletal system. While early machines were limited by the lower frequency transducers, current clinical ultrasound machines have transducers with frequencies greater than 15 MHz. This has enabled ultrasound to provide a detailed assessment of superficial structures, such as tendons and ligaments, with resolutions higher than MR imaging. Another advantage of ultrasound is the ability to dynamically assess anatomic structures, for example during extremity movement or muscle contraction. Musculoskeletal ultrasound has also grown as ultrasound units have been placed in or adjacent to clinics to provide quick and efficient patient access. In 1999, musculoskeletal ultrasound was performed one half day per week. By 2015, there were five dedicated musculoskeletal ultrasound rooms with full schedules each day. A strong clinical, educational, and research focus on musculoskeletal ultrasound resulted in U-M being recognized as a national leader in musculoskeletal ultrasound education and research. In addition to diagnostic ultrasound, there has been growth with ultrasound-guided procedures, such as joint injections, as needle placement is most accurate using ultrasound guidance. Research in ultrasound at Michigan has also had a dramatic impact on clinical imaging. For example, Jonathan Rubin and
his basic science team developed power Doppler imaging in the 1990s, and this technique became part of every clinically-available ultrasound unit. Former Division Director Ronald Adler, former faculty member Marnix Van Holsbeeck and Rubin were early leaders in ultrasound applications in musculoskeletal imaging. Rubin's research team continued to make significant contributions to ultrasound research.

Computed tomography is commonly used in the musculoskeletal system to evaluate for fracture and other osseous abnormalities. Current CT scanners have a multichannel design, which significantly reduces scanning times. For example, it is now possible to scan an entire joint in seconds rather than minutes, and the thinner imaging slices have enabled images to be reformatted in any imaging plane with high resolution. Newer technology has also allowed significant improvements in reducing artifact, which is important when imaging in the presence of metal, such as a hip replacement. New technology has also allowed imaging to be completed with a goal of reducing radiation to a minimum, which is important to younger patients, especially children. CT is commonly used to guide percutaneous biopsy of soft tissue and bone tumors to characterize tumors prior to treatment.

Lastly, technological advances in digital transfer of images and reporting have improved patient care. Images acquired at any site in the medical system can now be viewed almost instantaneously at any computer or imaging workstation, by both the radiologist and clinician. Speech recognition dictation systems allow the radiologist to quickly and efficiently produce a finalized report that immediately is uploaded into the patient medical record. This combination of digital image transfer and speech recognition dictation has reduced the time from imaging to reporting to a matter of minutes. Such “on line” reporting by subspecialized radiologists can have a dramatic impact on patient care.

Neuroradiology Division

Fred Jenner Hodges, chair of Radiology at Michigan from 1931-1965, recognized the need for subspecialization in
neuroradiology. So he arranged for Trygve O. Gabrielsen, who did his residency in radiology at the U-M from 1957-59 and joined the faculty in 1962, to obtain additional training in neuroradiology with Torgny Greitz at the Karolinska Institute in Sweden in 1965. Walter M. Whitehouse, who succeeded Hodges as chair of Radiology from 1965-1979, even more strongly supported subspecialization in neuroradiology and made it possible for Gabrielsen to undergo more highly specialized neuroangiography training with Per Amundsen in Oslo in 1968. This allowed Gabrielsen to modernize cerebral angiography at U-M using femoral arterial access techniques. The result was a switch from surgical direct puncture and injection of the carotid artery to cerebral angiography performed by catheterization of the femoral artery and advancement of a catheter through the arterial system to the point of contrast media injection. Michigan was one of the first institutions in the country to adopt this technique, which is now the standard access technique for angiography. Because of this, neuroradiology was given control of all invasive diagnostic neuroradiologic procedures, and a neuroradiology fellowship program was established at U-M. Gabrielsen spent 24 years as the director of the Division of Neuroradiology. Under Gabrielsen, the first U-M CT scanner, an EMI head imaging unit, was installed in 1975.

Despite disagreements with other departments regarding control of MRI, Radiology retained jurisdiction for magnetic resonance imaging. Under the guidance of William Martel, chair of Radiology from 1982-1992, the first clinical MRI facility in Michigan was established in 1983 using a 0.35 Tesla Diasonics superconducting magnet. This Diasonics unit was one of the earliest superconducting systems installed in a clinical facility in the U.S. As Martel's successor as chair, Reed Dunnick markedly expanded MRI services, including installation of MRI units in outlying clinics.

In 1988, James A. Brunberg was recruited to become director of the Division of Neuroradiology. He left in 1998 to become chair of the Radiology Department at the University of California at Davis, whereupon leadership of the Neuroradiology Division was provided by Stephen Gebarski and then Suresh Mukherji. Gebarski and Mukherji worked to
improve patient care by expanding neuroradiology services, acquire and optimally utilize the most modern imaging devices, and maintain ACGME certification of the Neuroradiology Fellowship. They continued the Gabrielsen tradition of innovative high quality neuroradiological clinical care, teaching, and research. In 2012, Mukherji became chair of radiology at Michigan State University. Ashok Srinivasan became division director of neuroradiology, building on the Gabrielsen legacy.

*Nuclear Medicine Division*

In the years immediately following World War II, intense interest pervaded both government and academia on how to develop peaceful uses of atomic energy. In 1946, publications described how radiiodine treatments, first with I30-I and later I31-I, had eliminated hyperthyroidism and reduced thyroid cancer in patients. The Oak Ridge National Laboratory in Tennessee offered both education in the employment of clinically useful radiation and therapeutic quantities of I31-I to personnel from approved hospitals. The concept was new, and its implementation introduced yet to be fully evaluated hazards: the radiation emanating from patients and their excreta would expose families and the public to this invisible energy. The Atomic Energy Commission, later the Nuclear Regulatory Commission, was charged with the regulation and oversight of diagnosis and treatment of patients with radioactivity.

Cyrus Sturgis, the chair of the Department of Internal Medicine, had treated hyperthyroid patients with thiouracil medications; he recognized the need for a better alternative to surgical thyroidectomy. William H. Beierwaltes, then an assistant professor in Internal Medicine who had also used thiouracil therapeutically, agreed to travel to Oak Ridge and subsequently accept the burden and the opportunities surrounding these radioactive compounds. In 1952, the Radioisotope Service was established in the Department of Internal Medicine with Beierwaltes as director. One of the first books on what was becoming a subspecialty, *Clinical Use of Radioisotopes*, was co-authored by Beierwaltes; a colleague, Phillip Johnson; and the physicist on the service, Arthur Solari.
The diagnosis and treatment of thyroid diseases with 131-I remained prominent components of the Service. But the horizon was rapidly widening. Unsealed radioisotopes in multiple pharmacologic preparations were expanding to permeate diagnosis and treatment of a myriad of human disorders, and by 1959, a number of young physicians at Michigan and across the nation sought education in this subspecialty. In accommodation, the service became the Nuclear Medicine Division with Beierwaltes, then a full professor, as chief.

Under Whitehouse and Martel, nuclear medicine remained within the Department of Internal Medicine. Substantial advancements were made by faculty such as James H. Thrall, who developed radionuclide ventriculography and diuresis renography; Thrall later became chair of radiology at Henry Ford Hospital and subsequently at Massachusetts General Hospital. John W. Keyes, Jr. fabricated the first single photon emission computed tomography (SPECT) unit in Michigan.

David E. Kuhl, who had an illustrious and internationally renowned career in Nuclear Medicine, was recruited to replace the retiring Beierwaltes in 1986. In the same year the Division of Nuclear Medicine, along with all components of the U-M Health Center, moved to the B-1 floor of the new hospital building adjacent to the Department of Radiology. The exception was Pediatric Nuclear Medicine which had been situated on the 4th floor of the Mott Children’s Hospital and eventually moved to the third floor adjacent to Pediatric Radiology. Patient care during the movements was maintained at the highest levels by the assiduous direction of Barry Shulkin.

Laboratory space was made available in the research buildings to accommodate expanding ideas and scope of the basic science in Nuclear Medicine.

In 2000, under the direction of the Medical School dean, Allen S. Lichter, the Nuclear Medicine Division was incorporated into the Department of Radiology.

Kuhl stepped down as chief in 2002, but continued his research inquiries. Barry L. Shulkin accepted the role of interim chief. Kirk A. Frey, already a prolific member of the Division,
was appointed chief in 2004; he subsequently was named the David E. Kuhl Professor of Radiology.

The Radioisotope Service of the Ann Arbor Veterans Administration Hospital began operation late in October 1954 as a small unit on the second floor of the hospital under the supervision of a Radioisotope Committee. Beierwaltes acted as a consultant to the Committee. From 1955 to 1969, Walter DiGiulio was chief of the Service. In 1970 the Radioisotope Service was renamed the VA Nuclear Medicine Service. Rodney Pozderac became chief from 1972 to 1979, and James Thrall served as interim chief from 1979 to July 1980. Then Milton Gross joined the U-M faculty and became chief of the VA Service.

In response to increasing demands for a nuclear medicine service in multiple VA facilities in Michigan and elsewhere, a telediagnostic medicine network was created in the late 1980s. The Ann Arbor VA Nuclear Medicine Service became the interpretative hub for affiliate Nuclear Medicine laboratories located in the Saginaw and Battle Creek VA Hospitals. Expansion subsequently included the Toledo, Ohio, VA Outpatient Clinic; the Fort Wayne, Indiana, VA Hospital; and a private cardiology practice in Flint, Michigan.

In 1990, Milton Gross became the national program director of the VA Nuclear Medicine Service. He was joined in 1991 by Lorraine Fig, as the deputy director, National VA Nuclear Medicine Service and Associate Chief, Nuclear Medicine Service.

After a major renovation and expansion of the Ann Arbor VA Hospital, the Nuclear Medicine Service moved to its present seventh-floor location in 1997. In an innovative VA national program, the Ann Arbor VA, in the early 2000s, began to share a PET scanner with the Nuclear Medicine Division at U-M; the association was one of the first where a Department of Veterans Affairs facility shared a PET scanner sited at its academic affiliate. This enhanced capability at the VA was followed in the mid-2000s by additional clinical innovations: a “mobile” PET/CT scanner in 2011, a fixed site PET/CT, and a SPECT/CT scanner in 2012.

For the Positron Emission Tomography (PET) Center, the
additions of Richard Ehrenkauffer (Radiochemistry) and Richard Hichwa (Physics) saw the U-M PET Program develop visibly as a world-leading enterprise. The scientific “core” of the UM PET Center was then supercharged by the recruitment of Kuhl, and, he, in turn, brought in Robert Koeppe, Gary Hutchins (Physics) and Michael Kilbourn (Radiochemistry).

Two chemists, Raymond Counsel and Donald Wieland, had already been recruited by Dr. Beierwaltes with specific aims of synthesizing radiopharmaceuticals to concentrate in endocrine organs and tumors.

Single Photon Emission Computed Tomography (SPECT) had been introduced by W. Leslie Rogers and John Keyes. Subsequently, Kuhl directed and gave impetus to the research programs especially emphasizing the new emission tomography. Consequently, this attracted talented medical scientists, physicists, chemists and engineers to become full partners. Molecular imaging with emission tomography (SPECT plus PET) soon became essential components in the care of patients with cancer, as well as cardiac, endocrine and brain disorders.

The PET Program had begun with the application to the NIH for construction and equipping of a new facility. Through the efforts of a distinguished triumvirate of Beierwaltes, Sidney Gilman and Bernard Agranoff, a facility equipped with a cyclotron (30 MeV Cyclotron Corporation CS-30), a radiochemistry laboratory and a state-of-the-art human PET scanner was dedicated in late 1982, and marked the beginning of a long-running program of human PET studies of physiology and disease. The size and complexity of the PET program increased with the arrival of Kuhl to head it. He spearheaded the expansion of the facility’s resources, the number of investigators, and the research grant revenues. Upon the acceptance of PET imaging as a valuable clinical imaging tool, additional PET and then PET/CT scanners were added to activities in the Nuclear Medicine hospital site.

In 2003-2005, a new cyclotron (GE PETtrace) was purchased, expanding the research capabilities, and replacement radiochemistry facilities were constructed. The new facility, complete with cyclotron and multiple hot cells for
radiochemistry, became fully equipped and good manufacturing practice (GMP)-compliant, and thus provided the resources for continuing success in radiopharmaceutical development. In turn, deliveries of unique and valuable agents for research and patient care in the Division of Nuclear Medicine were enabled.

Kuhl forecast that, in seeking earlier diagnosis, this research program might be linked to manifold drug development. New pharmacological classifications of patient groups (e.g., spatial patterns of metabolism, neurotransmitters, enzymes, proteinaceous accumulations) might redefine long-established clinical classifications and thus lead to earlier diagnoses and new treatments. Cancer research, hand-in-hand with drug development, gives hope that the targeting of new drugs might be matched to specific features of an individual’s tumor (e.g., proliferation, receptors, angiogenesis, hypoxia) and support personalized treatment that will be more effective. Real benefits to patients will continue to be driven by these kinds of long-term research projects, guided, in part, by lessons learned during this period.

In 2009, Kuhl was awarded the prestigious Japan Prize from the Japan Prize Foundation for the technological integration of medical science and engineering represented by his contributions to tomographic imaging in nuclear medicine.

The development of new brain imaging agents for neurological applications has long been a focus of research in nuclear medicine. Numerous unique radiopharmaceuticals were developed in U-M laboratories and introduced into clinical research studies: of these, four in particular ([123I]IBVM (iodobenzovesamicol), [11C]DTBZ (dihydrotetrabenazine), [11C]PMP (N-methylpiperidinyl propionate), and [18F]FEOBV (fluoroethoxybenzovesamicol)) have been utilized extensively to characterize specific neurochemical changes in studies of neurodegenerative diseases such as Parkinson’s and Alzheimer’s; the preparation and application of these radiopharmaceuticals have been duplicated at institutions world-wide.

A vibrant and innovative radiochemistry group headed by Donald Wieland has been exceptionally productive over
decades. Agranoff supported Kirk Frey in his first novel radiotracer project, targeting radiotracer imaging of myelin in the brain. Lipophilic tracers with radio-iodinated iodobenzene, targeting white matter on the basis of its differential lipid content, were developed. However, since MRI provided outstanding white matter images, the enthusiasm for radiotracer-based imaging approaches diminished. Beierwaltes, Agranoff and Gilman succeeded in obtaining an NIH NINDS Program Grant to explore applications of positron tomography to human neurologic disorders.

As of 2014, the UM PET Center researchers are involved with the bench-to-bedside translations of numerous research radiotracers, imaging and quantifying novel CNS targets of interest in neurologic disease. This era evolved, logically, from an emphasis on proof of imaging feasibility to an increasing emphasis on disease-based image results, applicable to better diagnosis and to better understanding of pathophysiology. A major emphasis of the PET Center scientists, led by Kuhl, was in degenerative dementia — Alzheimer’s disease and related disorders. The group targeted improved understanding of cerebral glucose hypometabolism in dementia, and, with leadership from Satoshi Minoshima, discovered diagnostically-useful early disorders in the posterior cingulate/precuneus cortical region in the brains of AD patients. In addition, the group identified the metabolic distinction of dementia with Lewy bodies on the basis of hypometabolism in the occipital cortex. Members also focused on the introductions of new tracers to explicate the cerebrocortical acetylcholine system and the role of acetylcholine esterase (AChE), which were identified as abnormal in pathologic studies of AD patients. New tracers enabled the identification of the presynaptic acetylcholine vesicular transporters ([I-123]iodobenzovesamicol and [F-18]fluoroethylbenzovesamicol), acetylcholinesterase ([C-11]PMP) and muscarinic cholinergic receptors (scopolamine, TRB and NMPB).

The scientific achievements of the Michigan PET program have involved a long list of accomplished individuals, and, in addition to those mentioned above, have been key to the successes of the program, especially Roger Albin, a neurologist,
who provided decades of leadership in selection, design and implementation of brain imaging projects.

In the early 1970s, Beierwaltes was aware of futile attempts to radiographically visualize the human adrenal glands. To overcome this diagnostic void, he hired a lipid chemist, Raymond Counsell. At the time, Counsell knew that, when injected intravenously, cholesterol labeled with 14-C concentrated in the cortices of adrenal glands in animals. Based on this information, he synthesized 131-I-19-cholesterol or iodocholesterol, also known as NP-59. Following the infusion of this innovative radiopharmaceutical, the adrenal glands of dogs were scintigraphically portrayed. In 1971, with the aid of a number of collaborators, the imaging of the human adrenal glands with a single photon camera became a reality. Subsequently in 1971, aided by the clinical experience of Jerome Conn, chief of the Endocrinology and Metabolism Division, Beierwaltes depicted a small and most-difficult-to-locate adrenal tumor, an aldosteronoma.

Over the following years, 131-I-19-iodocholesterol was found useful in differentiating disorders of the adrenal cortex. Although computed tomography and magnetic resonance imaging have largely replaced NP-59 scintigraphy, at its inception the agent was broadly acknowledged as a large leap in clinical science.

Beierwaltes also brought strategic vision and financial support for investigations of the adrenal medulla and related structures. Pheochromocytomas — neuroendocrine tumors found in the adrenal medulla and in other components of the sympathetic nervous system — became the major focus. These tumors secreted norepinephrine and occasionally epinephrine, hormones that evoked hypertension and devastating symptoms that were not infrequently lethal. Tests to detect the presence of such tumors were becoming more accurate, but their anatomic locations often remained elusive.

Donald Wieland was initially hired to synthesize a radiopharmaceutical that would delineate pheochromocytomas and related tumors. Building on prior research with the anti-hypertensive drug bretylium, Wieland synthesized meta-iodobenzylguanidine, which, when labeled with 131-I, was
found to concentrate in the adrenal medullas of dogs. Now called 131-I-MIBG or MIBG, the agent was selectively sequestered by pheochromocytomas and similar neuroendocrine neoplasms which, when located on scintigraphic images, would direct excisions by skilled surgeons. It was a major clinical breakthrough that was initially reported by James Sisson and the investigational group. Subsequently, 131-I-MIBG in large doses reduced the size and hormonal secretions of malignant pheochromocytomas; a number of these studies were directed by Brahm Shapiro.

Another neuroendocrine tumor, neuroblastoma, is a lethal malignancy not uncommonly found in children. 131-I-MIBG was concentrated and retained in neuroblastomas to an extent that the radiation emanating from the decay of 131-I was therapeutic. Gregory Yanik, a pediatric oncologist, has played a prominent role in national and international studies that are designed to define the optimal doses and schedules for treatments with 131-I-MIBG.

Wieland also synthesized 11-C-hydroxyephedrine which, when infused slowly into children by Barry Shulkin, clearly portrayed endocrine tumors by employing PET technology. The tumor images were clarified by additional imaging with 18-F-fluorodeoxyglucose.

Beginning in the 1970s and early 1980s, there was much interest in scintigraphically displaying the heart and its functions. Edward Carr demonstrated that Rubidium-86 accumulated in the myocardium, but it was soon discovered that Thallium-201 yielded improved images. James Thrall collaborated with cardiologist Bertram Pitt to reveal not only the absence of Thallium-201 in areas of myocardial infarctions, but also Technetium 99m-pyrophosphate concentrations in the infarcted areas to portray the ischemic and dying myocardial cells.

131-I-MIBG readily entered the sympathetic neuron terminals in the myocardia of animals, and thereby hearts of patients were scintigraphically displayed. As expected, MIBG was absent in regions of denervation such as infarcts and diabetic neuropathy. For more precise information, the higher fidelity of PET imaging was sought. Wieland synthesized a pharmacologically
related agent, hydroxy-ephedrine labeled with 11-C and denoted as HED. Markus Schweiger, a nuclear cardiologist, employed PET imaging of 11-C-HED to demonstrate that, as expected, transplanted human hearts manifested no sympathetic innervation. Then in 1991, he reported that over months, transplanted hearts were becoming re-innervated.

Richard Wahl, with a colleague in Medical Oncology, Mark Kaminski, employed 131-I-Tositumomab (Bexxar), a radio-labeled antibody that selectively accumulated in non-Hodgkin lymphomas to develop a therapeutic protocol. These designed treatments led to remissions of this lethal neoplasm.

**Vascular/Interventional Division**

Interventional radiology (IR) is a subspecialty of radiology that diagnoses and treats a variety of disorders using percutaneous methods guided by imaging. Image-guided interventional procedures today are safer, faster, minimally invasive and typically more cost-effective than traditional surgery. These interventional radiologic procedures can be grouped into vascular and non-vascular interventions. Included in the category of vascular interventional procedures are angioplasty, catheter-directed thrombolysis and thrombectomy, transcatheter embolotherapy, venous access, endovascular aneurysm repair (EVAR), and arterial, venous and oncologic interventions. Included in the category of non-vascular interventions are percutaneous image-guided biopsy and drainage, tumor ablation, and hepatobiliary, gastrointestinal and genitourinary interventions.

Vascular and interventional radiology began at the Michigan when Melvin Figley, a faculty member from 1950 to 1961, pioneered angiocardiography, assessment of cardiac physiology and the quantitative analysis of cardiac function. He described the angiographic diagnosis of aortic coarctation, ductus arteriosus, constrictive pericarditis, and congenital heart disease. He also introduced translumbar aortography and splenoportography at the University, and his description of the arteries of the abdomen and pelvis in both normal patients and in occlusive disease was widely used. Over the past 50 years, the
outstanding faculty members in the Division have continued pioneering various interventional radiologic procedures, thereby paving the way for the practice of world-class modern interventional radiology at the University.

Joseph J. Bookstein succeeded Figley as head of the angiography section. He contributed significantly to advancing angiocardiography, diagnostic angiography and magnification angiography. His method of renal pharmacoangiography allowed hemodynamic assessment of renal artery stenosis. In the 1970s, Helen C. Redman and Stewart R. Reuter led the angiography section at the University-affiliated Wayne County General Hospital where they developed techniques of gastrointestinal angiography, selective arterial embolization for control of gastrointestinal bleeding, pharmacoangiography, angiographic diagnosis of pancreatic carcinoma, and angiographic evaluation of portal hypertension. In 1974, Reuter moved to the University, succeeding Bookstein. During these years, the program became nationally known and the fellowship attracted superior trainees.

In 1976, after Reuter moved to California, Kyung Cho headed the angiography division. He provided mentorship and an inspiring role model as well as outstanding leadership in many areas of medical research. These included development of embolization therapy to treat tumors and bleeding of internal organs, and angiographic treatment of renovascular hypertension caused by segmental renal artery stenosis. His investigation of hepatic microcirculation and the peribiliary vascular plexus helped advance the effective use of diagnostic imaging to understand hepatic circulation. Among all of his accomplishments, however, it is perhaps Cho’s work exploring the use of carbon dioxide (CO2) as a contrast agent for diagnostic imaging and endovascular intervention that may have the widest clinical application. CO2 can provide safe vascular imaging in patients who are allergic to the commonly-used iodinated contrast media used in angiography or who may be susceptible to the potential nephrotoxicity of iodinated contrast media; this has the potential to save many lives and prevent long-term complications. To advance this practice Cho wrote the world’s first textbook on CO2 angiography to
demonstrate its safety in comparison with other contrast agents and to educate angiographers about CO2’s advantages, uses, and contraindications.

In the 1980s, the technical ability to record radiographic images digitally had a major impact on catheter-based angiography. Digital subtraction angiography (DSA) became an important imaging tool in the evaluation of vascular diseases. It largely replaced cut film angiography in both diagnostic and therapeutic radiologic vascular procedures. All angiography suites in the Division are equipped for digital subtraction angiography.

The division directors from 1996 to 2013 included Victoria Marx, David Williams, and James Shields. Wael Saad was appointed as Director in 2013. The Division has outstanding faculty members including Kyung Cho, Narasimham Dasika, Joseph Gemmete, Venkat Krishnamurthy, Paula Novelli, Ranjith Vellody, Wael Saad, James Shields, Jonathan Willatt, David Williams, and Zishu Zhang. Cho retired in 2015 after 42 years serving the Department and the patients of the University of Michigan.

Catheter-based angiography remains the most reliable means of visualizing blood vessels. Today, blood vessels in almost any region of the body can be catheterized allowing the use of the circulatory system as a roadway to perform therapies for a variety of diseases. This pioneering quest for minimally invasive image-guided treatment of pathologic conditions represents a core value of interventional radiology. The outstanding interventional radiologists at the University continued to develop new interventional procedures including intravascular ultrasound, endovascular intervention, endovascular repair of aneurysm (EVAR), percutaneous fenestration for the treatment of type 2 aortic dissection with malperfusion syndrome, oncologic intervention, transcatheter embolotherapy, and percutaneous hepatobiliary intervention.

Changes in the health care landscape dictate that in order to remain competitive and thrive as a leading healthcare provider for minimally invasive, image-guided therapy, IR at the University has adapted to a new paradigm that includes both marketing and collaboration. To achieve this model, IR has
undertaken a strategy to advance image-guided therapy, improve clinical care management skills, maintain an outpatient clinic, and promote IR services to the patient.