New materials (like the Teflon catheter in this 1972 image) revolutionized the field of interventional radiology. (Reproduced with permission from Radiology)
This chapter will discuss the development of various aspects of interventional radiology of the vascular system. We have begun with a brief overall history of this subspecialty and then looked at various areas, not necessarily in a chronological order of their development. The section ends with a brief overview of the appropriate societies and thoughts for the future.

**Initial Investigations**

Shortly after Röntgen’s late 1895 discovery of “a new kind of ray,” a young physicist in Vienna, Edward Haschek, with a medical colleague, T. O. Lindenthal, conceived the idea of injecting blood vessels with an opaque material and hence obtaining an angiogram.¹ There was much excitement at this time about the development of roentgenology, and the topic became the talk of Europe. One of Röntgen’s friends was Siegmund Exner, professor of physics at the University of Vienna. On 31 December 1895, at a New Year’s Eve party in Exner’s home, there was much discussion about X rays.

Haschek was present at this party and became interested in this new contribution to physics. He obtained an X-ray tube and physical apparatus and, with his colleague Lindenthal, injected calcium carbonate into the arteries of the hand of a cadaver supplied by an anatomist, Julius Tandler. The resulting radiograph required a fifty-seven-minute exposure! Nevertheless, it represented the first X-ray photograph of arteries—that is, the first arteriogram (Fig. 11.1).² Not long after this arteriogram, William J. Morton, a physician and physicist, and E. W. Hammer, an engineer, published their book, *The X-Ray or Photography of the Invisible and Its Value in Surgery*, in which they alluded to the fact that the arteries and veins of a cadaver might be injected with a substance opaque to X rays and thus might be more accurately dissected and evaluated.³ O. Riebusch, an internationally-renowned German surgeon, did the first arteriogram in a live animal in 1903, in an unusual fashion. He introduced buckshot into the jugular veins of dogs and was able to trace the vessels by radiography into the right heart and to the pulmonary circulation.⁴

Walter Alwens, a German surgeon-internist, and his colleague Otto Franck worked diligently to create some kind of substance that would float in the bloodstream and be opaque to X rays. In 1910, after attempts with various
The Vascular System Before 1895

Prehistoric humans must have wondered about the strange red material that oozed from their bodies with the slip of a flint knife. Not until Harvey put forth his ingenious explanation of circulation in 1651 was the entire relationship of arteries, veins, and capillaries understood. Although ancient medical writings contain many discussions of the blood vessels and their roles, the bases were faulty and founded more on ritual than fact.

Erasistratus (ca. 310–250 B.C.), an Alexandria anatomist and one of the originators of dissection, was quite close to understanding the circulatory system. He perceived the heart as a pump, described the aortic and pulmonary valves, and had some idea of the role of the capillaries, but his conception of circulation was somewhat reversed. He thought that blood flowed from the liver by the arteries to the heart and thence to the lungs by the veins.\(^5\)

Galen (A.D. 131–201), in Rome, continued and expanded Erasistratus’s description of blood flow by using hollow reeds and brass pipes, which were inserted into the arteries. He showed that the arteries contained blood (which was still a question at the time) and proved the power of the heart as a pump by demonstrating that blood pulsed between the heart and a ligated artery, but not beyond it. Galenic theory held that the liver was the place where blood was manufactured. Blood passed from the liver into the cava and its tributaries. A portion of the venous blood contained in the right ventricle sweated through minute pores in the septum of the heart to gain the cavity of the left ventricle.\(^6,7\) There it mixed with air from the “vein-like artery” and distributed throughout the body. Because of the influence Galen was to have on medicine, his concepts of the circulation remained essentially the accepted thought for the next thousand years. Even Vesalius (1514–1564) in his monumental work on anatomy, De Fabrica Humani Corporis, although breaking with Galen on many points of anatomy, maintained the general thought of the time, derived from Galen, on the flow of blood.\(^8\)

Many of the artists of that era also became interested in anatomy. Leonardo da Vinci (1452–1519) in Italy studied the heart extensively by making wax castings of the chambers and eventually constructing a glass model in which he conducted flow studies of the valves.\(^9\) Finally, William Harvey (1578–1657) in England cannulated the inferior vena cava and proved the pulmonary circulation. The French physiologist Claude Bernard, in the notes recorded from 1850–60 in his Cahier Rouge, described many potential experiments in dogs involving the veins and arteries. He introduced the term heart catheterization and performed extensive studies placing semiflexible lead tubes into the cardiac chambers in order to measure various substances in the blood.\(^10\)

Thus by the end of the nineteenth century anatomical dissection and experimental physiology had laid the groundwork for the study of the circulation in the living body. Röntgen’s discovery was to provide a means of conducting and observing these studies.\(^11\)
Fig. 11.1 The first arteriogram of a cadaver's hand, by Hascheck and Linderthal. (Courtesy of T. Doby)

In 1923, Berberich and Hirsch had performed the first angiogram in a human patient using water-soluble contrast material. Because of the pain involved with this injection, however, the investigators were discouraged from pursuing arterial injections. In the same year, A. Dunner and L. Calm, two investigators from Berlin, published investigations of essentially the same experience using 20 percent sodium iodide and found no ill effects.

In the 1920s Barney Brooks, a surgeon at Barnes Hospital of Washington University School of Medicine in St. Louis, was interested in determining vascular levels of obstruction in the lower extremities. He had read about the introduction of sodium iodide for excretory urography in 1920. At the end of the paper reporting their experience in 1923, Berberich and Hirsch wrote that, on occasion, the arm veins (site of injection) stood out like “steel wire” under the fluoroscope. The potential, then, existed for using this agent on the arterial side of the circulation to show arterial occlusions. Brooks began his studies with this contrast agent in experimental animals. In 1923, using 10 cubic centimeters (cc.) of a 100 percent sodium iodide solution, he performed the first femoral arteriogram using a water-soluble contrast agent. Brooks used venous obstruction of the lower extremities and, with a Crite clamp on the proximal femoral artery, produced an obliterated arteriogram of good quality. He published his series of twenty-five cases in the *Journal of the American Medical Association* in 1924.
Egas Moniz

To transfer the theoretical and practical aspects of angiography to humans, vascular radiology was fortunate to have had such a forward-thinking individual as the Portuguese physician and politician Egas Moniz. In his premedical curriculum at Coimbra University, Moniz devoted a significant amount of time to mathematics and engineering; his other interests included music and politics. He was, in fact, elected to the Chamber of Deputies in 1889, the year before he finished his medical training.

In Portugal, as is still true in many parts of Europe, a person who wishes to be accepted as a bona fide medical doctor must write a thesis. Moniz wrote his thesis on "sexual life," and later published two volumes (close to 600 pages) on the same subject. This work became a classic and, over the next several decades, was reprinted nineteen times. Shortly after his marriage in 1901, Moniz began his training in neuroradiology and psychiatry in France. He understood English and German and might have chosen to train in England, Germany, or in Austria, especially since Sigmund Freud was the leading expert in the neuropsychiatric field. But Moniz was also fluent in French and chose France to pursue his studies in the specialties of neurology (with emphasis on the X-ray) and psychiatry. After one year he returned to Portugal, where he became actively involved not in medicine but in politics. Between 1903 and 1912 politics occupied much of his time. He did, however, open a neurology practice in Lisbon and in 1912 was appointed professor of neuroradiology at the university.

To determine whether bromide solutions could be seen in arteries, Moniz did a simple experiment: he filled glass tubes with different concentrations of lithium and strontium bromide and positioned them behind a skull. The tubes were clearly visible on radiographs. This conclusion suggested to Moniz a possible way to perform cerebral arteriography.

Moniz, who suffered from severe gout which limited his dexterity, was fortunate to have as a colleague Pedro Almeida Lima, the son of a physics professor he knew well. Lima, a neurosurgeon with excellent technical ability, joined Moniz in late 1925 hoping to learn clinical neurology and psychiatry.

Moniz knew that A. von Knauer in Germany and L. Benedek in Hungary had injected bromides into the arteries of patients with syphilis, apparently without harm. Because the bromides were opaque to the X-ray, Moniz conceived of injecting the solution into the vascular system. Wisely, he and Lima started with small intravenous injections into animals. After modifying the agent with glucose, Moniz decided they had hit upon the right combination and initiated intracarotid injections on the animals. Moniz and Lima were ready for a clinical trial in humans.

As Moniz was not entirely knowledgeable in cerebral anatomy, he felt he should first familiarize himself with the cerebral circulation of cadavers. The Institute of Anatomy where he worked was not equipped with radiographic facilities, but he received permission to decapitate cadavers and transfer them to the X-ray department of the Santa Marta Hospital in Lisbon, where they could be injected with radiopaque material. In this way he would obtain a baseline normal anatomy of the cerebral and vertebral cerebral circulation, including the carotid and vertebral systems.

Subsequently, Moniz decided he was ready to extend the work to live patients and began with a 70 percent strontium bromide solution. The study was performed percutaneously, but because of dislocation of the needle, Moniz suggested that a cut-down be done and the needle inserted in that fashion. A surgical colleague, Antonio Martins (1892–1930), assisted him with cut-downs, and injections were done under direct vision. The procedure in the first few patients was not successful, possibly because of the concentration of the material and the speed with which the material went through the circulation. Finally, on the sixth attempt, in a forty-eight-year-old man with Parkinson's disease, the investigators were able to see a few branches of the carotid circulation.
Unfortunately, the patient developed carotid thrombosis approximately eight hours after the injection and died. After restructuring the approach to contrast by switching from bromide to iodine as a contrast material and recognizing that the thrombosis might have been caused by compression (which was done to prevent rapid washout), Moniz decided to go ahead with the iodine solution and to eliminate the compression. On 28 June 1927 an arteriogram was performed using 0.5 cc of 22 percent sodium iodide. Well-defined branches of the sylvian group of vessels were seen, and Moniz was satisfied that he had developed a credible methodology of diagnosis of the intracranial vasculature. Only a few days later he announced his findings at the neurology society in Paris.

There Moniz was fortunate to see Joseph Babinsky, probably the world's foremost neurologist at that time. Moniz also visited Sicard and informed him of his work prior to the 7 July meeting of the Society of Neurology. Sicard was mesmerized when Moniz showed him films of the cerebral circulation. Moniz called this "arterial encephalography" and stressed its importance in the localization of brain tumors. Babinsky and Sicard accepted this technique, assuring Moniz of a place in history as the developer of arteriography.

In thinking about this methodology, Moniz believed it could also be used in diseases of the extremities and proposed to Martins that they pursue this idea. For political reasons, however, Martins was not free to work with Moniz at that time, and the idea was to lie dormant until Reynaldo dos Santos's work several years later.

With Almeida Lima, Moniz collected a series of cases by investigators who were using this technique, including researchers from Germany and England. By 1931 he had compiled more than ninety cases and published his first book on cerebral angiography with a preface by Babinsky.21 Immediately after the publication of Moniz's book, dos Santos introduced the contrast material Thorotrast. Moniz, seeing the great advantage of this medium in that it caused no pain or obvious reaction, immediately switched to Thorotrast as his contrast material.

REYNALDO DOS SANTOS

Although Moniz suggested in his writings that his methods might apply to the evaluation of vessels in the extremities, one wonders whether this was not initially Reynaldo dos Santos's idea. Apparently dos Santos was at a lecture in Paris in 1927 when Moniz presented his material. Dos Santos asked Moniz whether his technique could be used for the extremities. Moniz agreed that it might and suggested dos Santos pursue the matter. Moniz himself, with Martins, tried to pursue the idea of extremity study several years later, but well after dos Santos had actually developed peripheral arteriography of the extremities. Unfortunately, Martins was discouraged by his surgical chief from pursuing peripheral arteriography. His work ended when he was accidentally killed while cleaning a rifle.

Dos Santos was born in Villa Franca de Xira and trained in Lisbon University Medical School. Between 1903 and 1906 he traveled to Paris and worked with respected urologists there. He also spent some time in the United States. He studied the systems of the Mayo brothers in Rochester, Minnesota, and visited Philadelphia, Boston, and Johns Hopkins University in Baltimore, where he had the opportunity to learn technical skills from the great surgeon William Halsted. In Boston he met Harvey Cushing and studied his approach to cerebral tumors. Returning to Lisbon in 1906, dos Santos was appointed surgeon at a large hospital and received a professorship in urology.

Dos Santos pursued the work begun by Moniz, perhaps because in administering local anesthetics to the splanchnic nerves through the back, he occasionally punctured the aorta or the inferior vena cava without any serious sequelae. He thought that this method might be a way of performing arteriography, and indeed he did perform transumbar aortography. Dos Santos used 25 percent sodium iodide, which
he thought might be safer than the 100 percent solution Barney Brooks had used earlier. Dos Santos injected the sodium iodide solutions through a syringe by a cut-down into the arteries, either femoral or brachial. Manual injection, however, was not good enough. He subsequently developed an automatic injection apparatus which proved to be extraordinarily valuable.22 No one seemed to be concerned at that time about legal liability for experimentation, but it should be pointed out that people like Moniz and dos Santos had high ethical standards and thus took cautious approaches.

Dos Santos was convinced that his method was now safe and applied it not only to the extremities but to the visceral arteries. In his collection are many arteriograms of the extremities showing tumors and obstructions as well as arteriovenous fistulae. In the 1930s, as Uroselectan was developed as a contrast agent and proven to be safe, dos Santos and his group shifted to this contrast agent for arteriography. At about the same time, a Japanese professor of surgery, Makato Saito of Nagoya University Medical School, was using emulsified Lipiodol in glycerine, alcohol, gum arabic, and lecithin to perform peripheral and cerebral arteriography.23

In 1931 dos Santos, A. C. Lamas, and J. P. Caldas published their first book on arteriography, containing more than four hundred arteriograms.24 Soon the need for serial films to assess the various vascular stages became critical; rapid cassette changers and cine were introduced as early as April 1931 by T. Naegeli and R. Janker, who presented this technique to a meeting of radiologists in Baden, Germany.25 The stage was set for more rapid technical development of arteriography. Contrast material, rapid cassette changers, and cine were in place, and the relative safety was obvious. Now the feasibility of catheter techniques would be tested.

**Catheters**

The history of vascular and interventional radiology is interesting not only from the point of view of incredible innovations in medicine in general, but also because these procedures tended to develop a new subspecialty in radiology. Catheter usage was a critical advancement in selectively studying blood vessels. Fritz Bleichroeder in 1905 developed techniques for passing catheters into the blood vessels (both arteries and veins) of dogs, although he used no X-ray control.26 He also performed venous self-catheterization, again without the use of X rays. A few years later, in 1912, Bleichroeder attempted to inject chemotherapeutic agents directly into the heart for a more rapid delivery of the drugs. He inserted catheters in canine arteries and left them in for several hours. No complications or clot on the catheter were noted. This result led to a clinical trial in four women who suffered puerperal sepsis, a very serious, often fatal, condition. Any possible remedy, even experimental, was considered worth pursuing. In these patients medication was injected through a catheter in the femoral artery; the catheter had been passed up to the bifurcation of the aorta.27

Perhaps the first investigator to popularize catheterization was Werner Forssmann of Germany. In 1929, when he was a junior surgeon at a small hospital in Eberswald, Forssmann opened a vein in his own arm and passed a catheter up to the right atrium under fluoroscopic control.28 The methodology was guided by a mirror held by his nurse in the fluoroscopy room.29 This experiment earned Forssmann the respect of his chief as well as an evening celebration at the “best restaurant” in town.30

As dos Santos had done, direct puncture of the thoracic aorta was being popularized by Innocenzo Nuvoli, an Italian surgeon.31 Because this technique was blind and potentially dangerous, however, other methodologies were investigated. In 1932 Makato Saito and K. Kamikawa first reported retrograde arteriography.32 Their technique was refined and used for other vessels besides the femoral. In 1939 A. Castellanos and R. Pereiras, for example, described retrograde thoracic
aortography by a brachial artery approach. In 1951 E. Converse Pierce developed a method of percutaneously introducing a disposable polyethylene catheter into the femoral artery and passing it in a retrograde fashion to any desired level in the abdominal thoracic aorta. At the same time, D. C. Donald and his co-workers catheterized the common carotid artery with a large bore needle, through which they passed a thin-walled polyethylene catheter, giving the examiner much more flexibility.

In 1953 Sven I. Seldinger, in his classic article in Acta Radiologica, instituted what is now called the Seldinger technique of percutaneous angiography (Figs. 11.2 and 11.3). The relative ease and safety of the Seldinger procedure created an almost explosive interest in the use of arteriography for diagnosis. Seldinger gave multiple reasons why the catheter was far superior to the old methodology. Four of the main points he advanced were: (1) the contrast material could be injected at any level; (2) there was less risk of extravascular injection of the contrast material; (3) the patient could be positioned appropriately; and (4) the catheter could be left within the blood vessel while the images where being developed, allowing for excellent quality control.

Soon many investigators were using the Seldinger technique. Opaque catheters, shaped by heat, made selective arteriography of various organs of the abdomen feasible. In 1962, shortly after F. M. Sones, E. K. Shirey, and W. L. Proudfoot described cine coronary angiography, J. H. Ricketts and Herbert L. Abrams described percutaneous selective coronary cine arteriography using the Seldinger technique. This idea was further refined by M. P. Judkins in 1967. Some aspects of these developments may be found in the chapter on cardiac radiology.

VASCULAR INTERVENTION

Angiographic diagnosis of many entities in the abdomen and thorax, as well as extremity and cerebral evaluation, was considered extraordinarily valuable because it assisted in preoperative diagnosis. Some of the pioneers of angiography were frustrated, however, because therapy had not become part of the armamentarium of the radiologist. The historic breakthrough leading to the development of interventional radiology occurred in 1964. The coincidental recanalization of an iliac artery that had been totally occluded shortly before and even during the passage of an angiographic catheter for routine diagnostic imaging was the stimulus that led Charles Dotter to his idea of percutaneous transluminal angioplasty (PTA) (Fig. 11.4).

Dotter was born in Boston, Massachusetts. After receiving his radiology training at New York Hospital, he joined the faculty of Cornell Medical
almost immediately, and thousands of procedures (particularly on the femoral artery) were performed in Europe and the United States. In Europe excellent results were reported by van Andel, Eberhard Zeitler, W. Porstmann, W. Schoop, and others. In 1973 Porstmann, in an attempt to improve on the Dotter technique, described a caged or corset balloon catheter made out of latex. Fundamentally, this was a latex balloon enclosed in a Teflon dilator. Because of its large size and high thrombogenicity, however, the catheter was not widely used by either surgeons or radiologists in the United States.

In 1974 a student of Zeitler's in Nuremberg, Andreas Grüntzig, and his colleague, H. Hopff, developed a nonexpandable dual lumen balloon that proved to be effective and safe for dilatation of narrow vessels (Fig. 11.6). The actual idea of using a balloon catheter to dilate narrowed vessels had been initially suggested by Dotter and Porstmann. Porstmann used a latex balloon encased in a semirigid Teflon cage, as indicated previously. Grüntzig was definitely influenced by Porstmann and

In 1994 Helen Redman commented, "I don't think people today realize how much finger strength it took to do a Dotter dilatation." In Wilfrido R. Castañeda-Zúñiga's 1986 lecture at the University of Minnesota, several other points relative to the Dotter technique were discussed. T. W. Staple and G. J. van Andel found that the excessive shearing and so-called snow-plowing effect produced by the Dotter technique significantly injured the vasculature. They thus modified the technique to some degree. In essence, however, the Dotter technique became popular

Fig. 11.4 Charles C. Dotter (1920-1985). (Author's collection)

Fig. 11.5 Charles C. Dotter viewing the arteriogram of the first successful percutaneous transluminal angioplasty in an eighty-four-year-old woman. (Courtesy of Department of Radiology, University of Oregon)
Andreas Grünzig died in an airplane crash in the mid-1980s and, although his life was cut short, his influence is still felt quite dramatically in interventional radiology. He is considered one of the great physicians in this area of intervention, and a society bearing his name was established in the early 1990s and meets annually.

The application of radial forces against plaque in the arterial wall had a lasting effect. Hence, many different groups began to use the Grünzig catheter and its offsprings for the dilatation procedures. With the advent of PTA and percutaneous transluminal coronary angioplasty (PTCA), investigators such as Kurt Amplatz, A. Formanek, J. E. Edwards, and Christoph L. Zollikofer studied the mechanism of improvement in the caliber of the lumen of the artery. In 1978 they described fracture of the intima and the stretching of the muscular layer. This remodeling of the intima and retraction as a mechanism of improvement was a hallmark in the physiologic and pathologic explanation for the eventual alteration of the vascular lumen.²³

**PHARMACO-ANGIOGRAPHY**

Dr. Ronald L. Eisenberg has summarized the development of pharmaco-angiography.²⁴ In an attempt to improve the vessels delineated in arteriography of the extremities, in 1937 M. Sgalitzer injected a vasodilator, papaverine, with excellent results.²⁵ This innovation has been modified over the years with various drugs including Priscoline and nitroglycerine. At the same time, M. Ratschow, relying on physiologic rebound, attempted reactive hyperemia in the lower extremities to improve runoff, with similar results.²⁶,²⁷ During the performance of arteriography, H. R. Bierman, K. H. Kelly, and R. L. Byron in 1961 attempted to use vasoconstrictors (epinephrine) in the hepatic arterial circulation to search for metastatic disease to the liver.²⁸,²⁹ With the basic knowledge that neoplastic vessels have little or no muscleature and hence are unresponsive to epinephrine or any vasoconstrictor, they thought that the
normal vessels would constrict and contrast with the neoplastic vessels, which would remain full of contrast material and hence stand out. This physiologic pharmaco-angiographic approach laid the groundwork the following year for Herbert L. Abrams, E. Bojsen, and K. E. Borgstrom to study in detail the effects of epinephrine on renal arterial circulation. Various drugs are now commonly injected intra-arterially via catheter to manage gastrointestinal bleeding and low-perfusion states in the intestine, as well as bleeding from the arterial system.

**Splenopertography and Arterial Portography**

Until 1945 the problem of portal hypertension, bleeding varices, and the degree of involvement of the intrahepatic vasculature with various liver pathologic states was difficult to assess. In 1945, however, A. H. Blakemore and J. W. Lord, during a laparotomy, conceived of the idea of visualizing the portal vein by injecting contrast material directly via needle puncture. In this way the main portal vein and its branches within the liver could be delineated and pressures could be obtained. In 1951 S. Abatoci and L. Campi, in their classic experiments in splenopertography, injected the spleen in dogs with contrast material, and this practice yielded an excellent splenopertogram. In the same year L. Leger performed the first human splenopertogram.

Leo G. Rigler, world-renowned pulmonary radiologist, and his co-workers described and performed arterial portography by injecting the celiac axis and superior mesenteric artery, obtaining delayed films to visualize the portal venous system. In 1958 P. Odman refined arterial portography; the technique is now a commonplace procedure.

**Venous Disease—Venography**

In 1923 J. Berberich and S. Hirsch, using strontium bromide, were the first to perform venous studies using X rays. Their work was then improved upon by H. O. McPheeters and C. O. Rice with Lipiodol injections and finally by dos Santos, who, in 1938, introduced direct phlebography.

 Contributions to venography of the lower extremities and abdominal venography were made by such individuals as R. May from Austria and Jurgen Weber from Germany. In 1969 Ernest J. Ferris, Ervin Philipp, Paul C. Kahn, Jerome H. Shapiro, and Florencio A. Hipona published the first text on inferior vena caviography with anatomic pathologic correlation. Selective venographic studies were also used and pioneered for endocrine disorders by S. R. Reuter and Joseph Bookstein, Paul C. Kahn, Rheingard Sorenson, J. L. Doppman, and others. Reminiscing in 1950, Bookstein commented, "I well remember how the clinicians thought angiographers were next to God in the early '60s because we could catheterize the renal veins for renin sampling."

**Lymphography**

The lymphatics, extraordinarily important in the lymphoproliferative disorders and the evaluation of metastatic disease from neoplastic involvement of many organs, were difficult to evaluate except by direct visualization and excision or biopsy. In 1950 S. Funakawa of Japan and in 1931 R. de Carvalho of Portugal had essentially the same idea. They injected Thorotrast into the lymph nodes and subcutaneous tissues of experimental animals. This agent was taken up by the lymphatics. In 1932 George Pfahler was the first to introduce the so-called indirect method of lymphography in patients. He injected Lipiodol into the maxillary sinuses and then visualized some seven days later that the lymphatics leading from the region were opacified. Similarly, many other investigators injected Lipiodol into subcutaneous tissues and examined the lymph nodes in the region for uptake of the agent, which was opaque on radiography. This technique proved to be quite unsatisfactory because the contrast agent was diluted by the time it reached the lymph nodes. In 1936 S. Tenefet and F.
Stoppani and in 1945 M. Servelle visualized the lymphatic channels by injecting Thorotrace into the inguinal nodes and taking delayed films.\textsuperscript{79,80} J. B. Kinmonth, who in 1952 developed the methodology for directly injecting the lymphatic vessels, is considered by many to be the "father of lymphography."\textsuperscript{81,82} Kinmonth’s technique proved technically difficult, but he did note that a blue dye solution injected into the tissues between the toes was taken up by the lymphatics. This was of assistance in visualizing the lymphatics once the incision to the appropriate area (the dorsum of the foot) was made.

The use of oil-based contrast material for lymphography became commonplace following the work of Sidney Wallace and his co-workers, who conceived of lymphography as both a diagnostic and therapeutic aid.\textsuperscript{83} The architecture of the lymph nodes was a clue to the particular pathologic process present. Since the lymph nodes remained opacified for months, a response to various therapies could be judged by simply evaluating the arteries periodically on plain roentgenograms of the abdomen. Another radiologist, Manuel Viamonte, wrote extensively on lymphography and was one of the founders of the International Society of Lymphography.\textsuperscript{84} Other contributors to this interesting area are described in the work by M. E. Clouse.\textsuperscript{85}

**EMBOLOTHERAPY**

Embolootherapy was practiced just after the turn of the century, when Dawbain in 1904, using an open technique, injected melted paraffin into the external carotid arteries of patients suffering from neoplasms involving the head and neck area.\textsuperscript{86} In 1980 Brooks ingeniously injected a small piece of muscle marked by a silver clip into the internal carotid artery to obstruct a carotid cavernous fistula.\textsuperscript{87} In 1960 A. J. Luessenhop and W. T. Spence injected methylmethacrylate, in the form of small spheres, into the common carotid artery of a patient who had an arteriovenous malformation (AVM) being fed by the middle cerebral artery.\textsuperscript{88} By injecting these spheres and anticipating that the flow would direct these objects to the AVM, they were proved theoretically and practically correct, as the AVM was clinically improved. Before embolizing the AVM, these surgeons reviewed each case in detail, considering especially the size of the vessels they wanted to obstruct.

Other developments occurred primarily in the area of neuroradiology, with the successful embolization of a spinal cord angioma by T. H. Newton and J. E. Adams in 1968.\textsuperscript{89} This was followed by a similar percutaneous approach by H. Krıcheff, M. Madayag, and P. Braunstein in the embolization of an arteriovenous malformation of the brain.\textsuperscript{90} Embolootherapy in peripheral vascular angiography was perhaps precipitated by M. Nusbaum and Stanley Baum who, with both experimental studies and clinical studies, demonstrated the ability of angiography to detect extravasation of contrast material from bleeding vessels during serial angiography.\textsuperscript{91} By 1971 the same two investigators had introduced intra-arterial vasoconstrictors for the control of bleeding in the gastrointestinal tract.\textsuperscript{92}

The following year J. Rosch, Charles T. Dotter, and M. J. Brown, using autologous clot, were able to control acute hemorrhage from the stomach by embolizing the gastroduodenal artery.\textsuperscript{93} Subsequently various agents were introduced for embolization, including isobutyl-2-cyanoacrylate (Bucrylate) by P. H. Zanciti and E. E. Sherman, Gelfoam particles by L. S. Carey and D. M. Grace, detachable balloons by F. A. Serbinenko (popularized by G. Debrun, N. E. White, and others), the Gianturco coil, and variations of the Gianturco coil.\textsuperscript{94,95,96,97,98,99} This field is still developing internationally.

Because of the less invasive nature of the technique, some angiographers-turned-interventionalists realized that many areas of bleeding or hypervascularity could be altered by selective arterial injections. Once Manuel Viamonte had described the technique of selective bronchial arteriography, physicians such as J. Remy and F. Pinet began
embolization for pulmonary hemorrhage secondary to bronchial artery hemorrhage.\textsuperscript{100,101,102} Virtually any hemorrhage could be treated by catheter embolization if angiographically accessible.

**Thrombolysis**

The vascular use of thrombolytic agents dates from 1933, with W. S. Tillett and R. L. Garner's discovery of streptokinase, a bacterial protein.\textsuperscript{103} R. G. MacFarlane and J. Pilling noted in 1947 that there was thrombolytic activity in human urine.\textsuperscript{104} This material was called urokinase. Although urokinase was initially gathered from human urine, the material is now prepared commercially using human red cell cultures. Probably the first investigators to use the thrombolytic effect of streptokinase were A. J. Johnson and W. R. McCarty, who used the substance intravenously in a clinical trial to determine whether it lysed thrombi.\textsuperscript{105} Thrombolytic agents came into common use in 1979, when K. P. Rentrop started using them for infusions into the coronary arterial system.\textsuperscript{106} In 1981 B. T. Katzen reported the use of low-dose infusions in the peripheral vasculature.\textsuperscript{107} Other agents, including tissue plasminogen activators (TPAs), have become available since then. Consequently, the use of thrombolytic agents has secured a firm place in the lysis of thrombi in the arterial—and indeed the venous—circulation. Investigators such as Tom McNamara, Joe Bookstein, and Laslo Horvath have contributed enormously to the methodology of thrombolysis with the development of infusion, pulse spray, and lacing techniques.\textsuperscript{108,109,110}

**Inferior Vena Caval Filters**

In 1969 the Moin-Uddin "umbrella"—a silastic filter with eighteen small apertures of 3 millimeters each, straddled with aluminum legs—was introduced.\textsuperscript{111} This was inserted in the internal jugular vein via a cut-down in the neck. Under normal circumstances, the filter was placed in a retrograde fashion. In 1972 Lasur J. Greenfield's filter, also inserted by a cut-down of the neck, was introduced; it proved to be much more acceptable because of the low incidence of thrombogenesis associated with it.\textsuperscript{112} In 1982, however, Gianturco developed the first percutaneous filter, called the "bird's nest." It was placed in clinical trial in 1985.\textsuperscript{113} Since that time, other filters have been developed, including the Amplatz, the Simon Palestrant Nitinol, the Vena-Tech, and the Titanium-Greenfield—all in the United States.\textsuperscript{114,115,116,117} In Europe a host of filters have been developed, including one developed by Rolf Gunther in Aachen. Ease of insertion and placement of the filter became important; so did the follow-up, as studies by many investigators including C. J. Grassi, G. S. Dorfman, Ernest J. Ferris, and Timothy C. McCowan, as well as Christos A. Athanassoulis, indicate.\textsuperscript{118,119,120,121} The indications for filter usage became broader, probably secondary to the ease of filter insertion.

**Superselective Angiography**

In the field of vascular and interventional radiology, superselective angiography is important not only for diagnosis but for the delivery of embolic material to a selected location. Advancements in catheter design permitted the selective study of vessels that were difficult to catheterize selectively. Manuel Viamonte was able to selectively inject bronchial arteries not only for diagnosis but also for therapy. Subselective or superselective pancreatic angiography was first performed by R. E. Paul and P. C. Kahn and later refined by S. R. Rutter.\textsuperscript{122,123} Angiography of the adrenal arteries, with particular attention to the inferior phrenic arteries, from which come the superior group of arteries, was pioneered by Kahn.\textsuperscript{124}

**Stents**

In 1964 Charles T. Dotter and M. P. Judkins suggested the concept of intravascular stenting.\textsuperscript{125} Within five years Dotter had successfully developed a spring-coil stent, which he tested in animals.\textsuperscript{126} In 1983 a report by A. Cragg and another by Dotter stirred enormous interest in the principle of stent-
Various designs were then produced and tested for vascular as well as biliary stenting by J. C. Palmaz, S. R. Reuter, E. P. Strecker, R. W. Gunther, and others.\textsuperscript{129,130,131,132,133,134}

**Transjugular Internal Portasystemic Shunts**

Transjugular liver biopsies, developed by Dotter in 1964, served as the impetus to seek access to the biliary tree and the hepatic vascular system.\textsuperscript{135,136,137} In 1969 J. Rosch (Fig. 11.7), in collaboration with W. Hanafee and H. Snow, performed the first transjugular internal portasystemic shunt (TIPS) in animals. R. F. Colapinto in 1982 modified Rosch’s technique and made TIPS a practical possibility in humans.\textsuperscript{138,139}

G. M. Richter conducted a pilot clinical study of the TIPS procedure, completed in 1990.\textsuperscript{140} Subsequent investigators, including G. Zemel and N. Chalmers refined the technique.\textsuperscript{141,142,143,144}

**Angiographic Societies**

During the late 1950s and 1960s much of the development of angiography was being done in Sweden by such angiographers as Olle Olsen and E. Bojsen. A mass exodus from the United States to Sweden occurred about that time because young angiographers wanted to learn the selective techniques of the Swedes. Some of these people, when they returned to the United States, as well as many others, were trained by such eminent leaders in angiography as Herbert Abrams (Fig. 11.8). Local angiographic societies were formed and demonstrated interesting cases to one another. Eventually, the societies in the United States, such as the Boston, New Haven, New York, and Philadelphia societies, united with the rest of the angiographic societies nationally to form, in 1972, the Society of Cardiovascular and Interventional Radiology. At first the members num-
bered in the dozens, but at the twentieth anniversary in 1992, there were almost three thousand society members. In the 1980s the Cardiovascular and Interventional Radiological Society of Europe was formed, with the same enthusiasm as the society formed in the United States. Such well-known radiologists as Rheingard Sorensen, Plinio Rossi, David Allison, and Rolf Gunther were instrumental in the formation of the European society.

The first president was Stanley Baum, an eminent pioneer in angiography (Fig. 11.9). He and M. Nusbaum had described the methodology of detecting bleeding in the gastrointestinal tract and alluded to therapy as well, which they subsequently verified by using vasoconstrictors. Opportunities in angiography existed not only for men but also for women. Some of the first women angiographers to be trained were Barbara Carter, Renate Soulen, and Helen Redman. Redman later became president of the Radiological Society of North America. Other young women also found new opportunities in this exciting field.

In conclusion, from the time of prehistoric humans to the end of the twentieth century a rapidly progressing revolution in medicine has been reinforced by the technological advances which began with Röntgen’s discovery in 1895. Investigators worldwide have applied their skills to develop angiography, a field with an expanding role not only for diagnosis but for therapeutic intervention as well. The assembly of all the parts of what was once a puzzle is still unclear. The future course of vascular interventional radiology is still not complete. The field seems unlimited and will continue to have an impact on health care.

This chapter has covered many of the significant contributions to the field of vascular and interventional radiology. New developments are on the horizon. The fact that most texts in this field are outdated by the time they are published speaks well for progress in radiology.

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