Journals and magazines printed countless “bone shadows” in the earliest years of the X-ray. These hands appeared in the Archives of Clinical Skiagraphy in 1897. (Courtesy of the Center for the American History of Radiology, Reston, Va.)
Skeletal Radiology

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Some subspecialties of radiology mark their history and define their day-to-day practice through the development and use of technologies. The gastrointestinal radiologists have their barium concoctions. The genitourinary radiologists have their excretory urograms. Technology, however, has until recently played a relatively small role in defining skeletal radiology. The radiograph, reputedly of his wife's hand, that Wilhelm Conrad Röntgen obtained in November 1895 (Fig. 6.1) was not quite so refined as some that have been obtained since that time, but it was not inherently different in its informational content. Improvements and changes have certainly been made in a constant juggling of films, plates, screens, and X-ray production. Skeletal radiology shared the benefits of these with other parts of radiology. Arthrography and complex motion tomography were developed. No one technique, however, defined the field the way barium studies defined gastrointestinal radiology. This chapter is, therefore, less a story of technical advancements than a story of developing awareness of the diagnostic significance of the shadows revealed even by the first plain radiographs and fluoroscopic studies of the human skeleton.

1896

Historians of the early years of radiology have been fascinated by the rapidity with which Röntgen's discovery found practical use. Equipment necessary to produce and record X-ray images was readily available, at least in major cities, and physicists, electricians, and physicians lost no time reproducing Röntgen's experiments. Science, on 14 February 1896, carried a translation of Röntgen's On a New Kind of Ray, followed immediately by articles from M. I. Pupin of Columbia University, astronomer Edwin B. Frost of Dartmouth, and A. W. Goodspeed of the University of Pennsylvania, in which they discussed their own X-ray experiments. Each had begun his work by using the new rays to image inanimate objects, producing small still lifes of deliberately arranged keys, coins, pincushions, and similar items. These simple objects produced easily recognizable shadows and immediately confirmed that the method really worked.
Displayed along with the X-ray pictures of inanimate objects in that landmark issue of *Science* were X-ray images of human extremities: a reproduction of the famous radiograph of Bertha Röntgen's hand and some fingers radiographed by Frost. Part of the appeal of the image of Bertha Röntgen's hand is that it is (and was) so easily recognizable and interpretable. It was not recognizable as a specific person's hand, the way a still life could be compared with a specific visible arrangement of objects, but many untrained people and certainly those trained in science or medicine could look at it and immediately discern the outlines of bones and jewelry. Clearly it was someone's hand.

The same issue of *Science* also included the earliest accounts of the diagnostic use of X-rays in the United States. Both Goodspeed and Frost had used X-rays to photograph fractures. Their diagnostic studies had been obtained at nearly the same time. It is impossible to be entirely sure which was first, but the exposure obtained by Frost in the physics laboratory of Dartmouth on 3 February 1896 is often considered to be the first in the United States of a pathologic condition (Fig. 6.2). The well-posed and often-reproduced photograph of the event attests to the fact that the participants were quite aware that they were making history (Fig. 6.3). The radiograph itself is not nearly so dramatic. Indeed, it is fuzzy and underexposed, not only by modern standards but in comparison with Röntgen's example. Nonetheless, as Edwin Frost reported and in later accounts maintained, the ulnar fracture is clearly identifiable.

Frost's account does not mention a radial fracture, yet there is a small discontinuity of the radius that looks very much like a fracture. What the physician, Frost's brother Gilman, told his patient is not recorded. Did he perceive a radial fracture? Could the first American X-ray image of a pathologic condition also be the first American missed radiographic diagnosis? Or did the brothers correctly ignore a deceptive radiographic appearance knowing, perhaps, that their patient was not tender over the radius?

Frost and other early investigators had no textbooks of radiographic images to guide them in diagnoses. To find a fracture they put together what they knew of the patient's history and physical examination with a search for deviations from the imagined radiographic appearance of a normal limb. Astronomers, physicists, and electricians entering the new field did not have the benefit of medical training to guide their imaginations. Nevertheless, sometimes the diagnosis was easy. The technique was simple enough to encourage the rapid proliferation of diagnostic use of X-rays, mostly for fractures and localization of metallic foreign bodies.

Radiographs were soon used not only to diagnose fractures, but also to evaluate the adequacy of reduction. Here again the radiographic appearance was matched with a mental image of what the osseous reduction was expected to look...
like. Sometimes there were surprises. In 1897 Leonard Freeman of Denver reported a case of radial and ulnar fractures in a six-year-old boy. The patient was anesthetized with chloroform, the fractures were splinted, and then a radiograph was obtained that surprised everyone and pleased no one by showing that the alignment of the bones was not nearly so perfect as had been thought clinically and as was deemed necessary. Freeman, among others, was consulted and insisted that better reduction was needed or a very bad result would be obtained. However, nothing more was done, largely because of hesitation to repeat anesthesia, the first episode having gone less smoothly than desired. Nevertheless, the injury healed well.

Faced with a discrepancy between the clinically apparent satisfactory alignment of the flesh-and-blood forearm and the radiographic evidence of misalignment, the physicians and parents unhesitatingly believed the radiograph but applied to it the standards of alignment appropriate for the external appearance of the limb. Freeman concluded that until more was known about their meaning, the shadows revealed by X rays could be a source of "needless anxiety and controversy." Twenty-eight years later the well-known surgeon Rudolph Matas also stressed the need to interpret radiographs in the light of both a thorough understanding of normal and abnormal radiographic appearances and the patient's history, physical examination, and other parts of the total clinical setting. He decried a tendency "to accept the verdict of the roentgen laboratory unconditionally..." and cautioned that "when the roentgen picture allows of diverse interpretations, as is so often the case, the laboratory report must be subordinated to the clinical facts." Where post-reduction examinations were concerned, surgeons needed to develop new standards of acceptable fracture alignment based on radiographic appearance.

Frost's and Freeman's radiographs of wrist fractures were obtained in one view only and imaged as the bones appear when the hand rests flat against a surface. Fractures, however, are notorious for being invisible when seen from certain angles, even when they are glaringly obvious in other projections. This problem was discovered relatively quickly. In his book on fractures published in 1900, to which he appended a lengthy section on the use of X rays in fracture diagnosis and treatment, Carl Beck illustrated an oblique fracture of a child's tibia that was completely inapparent on an anterior view yet easily visible on an oblique view (Fig. 6.4). He cautioned physicians always to obtain at least two radiographs in different positions in cases of suspected fracture.

Many of the early reports of fractures discovered or evaluated radiographically involved common, already well-known
the fracture, of course, was what has since been known as Jones's fracture of the proximal fifth metatarsal, just distal to the intermetatarsal ligaments (Fig. 6.6). Over the next several weeks Jones treated four more patients with this injury. Previously, in similar cases he had suspected a fracture but had been unable to prove his suspicions, as there had been neither externally obvious angulation of the bone nor crepitus, the "crunchy" feeling that often accompanies palpation of a fracture site.12

As Röntgen's On a New Kind of Ray made clear, metal stopped the X rays, while human muscle and other soft tissues did not. This made X rays ideal for finding metal objects, such as bullets, that had become lodged within the human body. During the Spanish-American War of 1898, the United States Army used seventeen radiographic units for diagnosing fractures and localizing bullets.

The army's radiographic units were capable of penetrating relatively thick extremities such as the thigh and shoulder. They were not, however, able to penetrate the trunk from the side. Therefore, although orthogonal views (views obtained from different directions at right angles to one

Fig. 6.4a Frontal radiograph of both lower legs of a two-year-old child, with no fracture apparent.

Fig. 6.4b Oblique, nearly lateral projection of the left leg of the same child. The fracture is now obvious. (Reproduced with permission from Carl Beck, Fractures)

Fig. 6.4c Lateral radiograph of a two-year-old child obtained ca. 1965 with no evident fracture.

Fig. 6.4d Frontal radiograph of the same child with an obvious fracture. (Authors' collection)

The principle noted by Carl Beck as early as 1900, that even very displaced fractures could be hidden on radiographs unless more than one projection was obtained, is as true now as then.

Fig. 6.5 Eugene Rollin Corson (1856-1946). Corson began his radiographic investigations in 1896 and published not only on fractures but also on normal radiographic anatomy. (Reproduced with permission from E. H. Skinner's biography of Corson, A.J.R. 1931)
FIG. 6.6 Jonas's fracture. This is a modern example of the fracture described by Robert Jones in 1901. (Authors' collection)

FIG. 6.7 Bullet. This Spanish-American War soldier had a bullet lodged in the sole of his foot. By getting two views like this, the bullet's position could be determined both side-to-side and top-to-bottom at the same time. Simple geometric principles like this were already well known by the late nineteenth century. (Reproduced from W. C. Borden's analysis of the army's use of radiography in the Spanish-American War)

Another) were used to locate bullet fragments in thin body parts like the foot (Fig. 6.7), more complicated methods were needed to locate bullets within the trunk or about the hip. These methods involved analysis of the sharpness or blurriness of the object (sharply projected objects being closer to the photographic plate than blurry objects) and observation of the direction of motion of the object when the X-ray tube was moved in relation to the patient (Fig. 6.8). The fact that such principles were well understood by 1896 is one of the reasons why X rays began to be used so promptly for diagnostic purposes. W. C. Borden, who analyzed the army's roentgenologic experience during the war, suggested that radiographs were preferable to fluoroscopy, particularly for use in thick parts, because of the greater detail portrayed. In the early military use, as in civilian medicine, X rays were useful for little other than skeletal injuries.

ANATOMY

A potential pitfall in fracture diagnosis was proper evaluation of the normal physeal lines seen near the ends of bones in children as well as normal variants of bone that may persist into adulthood. The existence and cartilage composition of human growth centers was already well known from gross anatomic and histologic studies, but the order of appearance and disappearance of ossification centers in complex anatomic sites such as the elbow was known less perfectly than would be ideal for radiographic evaluation. In addition, the knowledge that was available was probably not used frequently in daily practice before radiographs began displaying these ossification centers for evaluation. Indeed, the very words usually chosen to describe the mineralization and later fusion of ossification centers, "appearance" and "disappearance," imply tran-
ANATOMICAL RESEARCH

Methods used by investigators of radiographic anatomy have changed over the years due to recognition of the dangers associated with radiation exposure together with increasing sensitivity to the rights of patients and others to be protected from unnecessary exposure. Early investigators often experimented with abandon on themselves or anyone else who was willing to serve as a model, for while the danger of radiation burns was soon recognized, these could be avoided with reasonable care, and it was not until 1902 that radiation-induced cancers were tentatively recognized. Eugene Corson, after his article on the Colles fracture, next turned his attention to anatomy. He studied the motion of the wrist, using his own wrist as a model. The mistake eventually cost him three fingers of his left hand and ended his career as a surgeon.

Other investigators also radiographed normal children and adults. In 1924 when Isadore Cohn, an orthopedist in New Orleans, published Normal Bones & Joints Roentgenologically Considered, he was able to summarize, compare, and contrast the findings of several studies of the radiography of the epiphyses of each joint (Fig. 6.9). Even more were available to Paul Hodges, D.B. Pheister, and Alexander Brunswig in 1938 for use in their textbook on skeletal radiology. They commented that for most part routine comparison views of the extremity opposite the affected side could be abandoned in favor of comparison with published charts and pictures. John Caffey, a pioneer in pediatric radiology, was among those who stressed the need for a thorough understanding of normal anatomy.

By the 1980s radiography of normal individuals to investigate anatomy was uncommon, and researchers more often resorted to work with anatomic specimens or cadavers as well as drawing inferences from the frequency of certain findings in examinations obtained of patients for apparently unrelated reasons (Fig. 6.10). Meanwhile computed tomography and magnetic resonance (MR) imaging increased skeletal radiologists' needs for knowledge of soft-tissue cross-sectional anatomy. Donald Resnick and his associates, working at the Veterans' Administration Hospital in La Jolla, California, have conducted many useful studies of cross-sectional anatomy using cadaver specimens. The apparent harmlessness of MR imaging, however, has also encouraged a resurgence of anatomic investigation involving living, normal volunteers.
Fig. 6.11 Bipartite patella. This configuration of the patella (the knee-cap) in which the bone is divided into two pieces with a small separate piece (arrows) above and lateral to the main part is quite common. It has generally been considered a normal variant, and Theodore Keats classified it as such in his compendium of normal variants. It may, however, be not a normal variant but the aftermath of chronic trauma. Furthermore, a bipartite patella may cause its owner pain. Jack Lawson, who cited several earlier publications, including one by John A. Ogden and other colleagues at Yale University, popularized this view in the radiologic literature in the 1930s and 1950s. Mysteries like this keep anatomy interesting and may never be resolved to complete satisfaction. (Authors' collection)

The recent emphasis on radiographic visibility of the patella. Although the bone is divided into two pieces with a small separate piece (arrows) above and lateral to the main part, it is quite common. It has generally been considered a normal variant, and Theodore Keats classified it as such in his compendium of normal variants. It may, however, be not a normal variant but the aftermath of chronic trauma. Furthermore, a bipartite patella may cause its owner pain. Jack Lawson, who cited several earlier publications, including one by John A. Ogden and other colleagues at Yale University, popularized this view in the radiologic literature in the 1930s and 1950s. Mysteries like this keep anatomy interesting and may never be resolved to complete satisfaction. (Authors' collection)

Fig. 6.12 William Stell Newcomet (1872–1950). Newcomet was a prominent figure in radiographic private practice in Philadelphia for many years. (Reproduced with permission from his obituary in A.J.R., 1961)

Besides Fractures

Besides fractures and foreign bodies, many other bone disorders were imaged in the first year or two after Röntgen's discovery. Most likely the majority of these studies were of patients with known diagnoses who were radiographed out of scientific curiosity. As radiology matured as a discipline, investigators worked to increase understanding of the radiographic appearance of specific diseases and to develop the ability to tell one disease from another, both in terms of distinguishing the radiographic appearances of two separate, known diseases and in terms of cooperating with physicians in other specialties to split large categories of diseases with similar radiographic or clinical features into separate diseases, much as a botanist divides oaks into different species. Rather than discussing each disorder or group of differential diagnoses separately, in the interests of space three representative topics, osteoarthritis, tuberculosis, and bone tumors, will be discussed.

Osteoarthritis

Not long after Röntgen's discovery, German physicians Alfred Stieda and Heinrich Ernst Albers-Schönberg (1865–1921), and French physicians R. Leclercq, Chabaneix, and Dessane all noticed peculiar spots in the bones of some patients.22,23,24 William Stell Newcomet of Philadelphia (Fig. 6.12)
introduced American radiologists to the phenomenon of "spotted bones," also known as osteopoikilosis, in 1929. The patients described in these first reports were normal otherwise, and their spots would never have been found at all had they not been radiographed for unrelated reasons. Radiologists and radiologic journals evinced, particularly in the decade following Newcomer's report, marked enthusiasm for this elucidation. Reports concentrated on describing the characteristic radiographic appearance of the disorder, and soon it was known with great detail and accuracy (Fig. 6.13).

Radiologists' fascination with osteopoikilosis may seem odd given that patients with this disorder are usually perfectly well. It is important to distinguish osteopoikilosis readily from more serious disorders that may also cause spots of increased mineral content in the bones, but still the amount of interest generated by this obscure disorder was greater than its medical importance would seem to warrant. The explanation may be that osteopoikilosis is almost exclusively a radiographic diagnosis. At a time when many radiographs were taken to document improvement or progression of a known disease, it was refreshing and exciting to know about an unusual, harmless disorder that the radiologist could diagnose alone in seconds.

Tuberculosis

Unlike osteopoikilosis, tuberculosis was well known long before the discovery of X-rays. In the late nineteenth and early twentieth centuries, tuberculous arthritis was a relatively common disease, for tuberculosis itself was common. In the United States and other developed countries, tuberculosis incidence declined slowly throughout the nineteenth century and into the twentieth century, yet remained the leading cause of disease-related death among young American men and women as late as the 1940s. Although only 1 to 10 percent of all patients with tuberculosis developed skeletal involvement, this proportion was sufficient to make tuberculosis an important part of the practice of many orthopedic surgeons. Identification of the tubercle bacillus by Robert Koch in 1882 had made it possible to distinguish tubercular disease from other forms of arthritis or osteomyelitis with certainty. Histologic or bacteriologic diagnosis of skeletal disease, however, often required an open synovial biopsy, which created a path for secondary infection with pyogenic bacteria or for possible sinus tract formation. When possible, therefore, many surgeons preferred to make the diagnosis on other grounds and to obtain a biopsy only at the time of surgical treatment. The advent of radiography provided hope for a noninvasive aid to diagnosis and follow-up of cases.

Despite the prevalence of skeletal tuberculosis in the years after Röntgen's discovery, relatively little attention was paid to its radiographic diagnosis, particularly in the American literature. James Young in 1909, John Fraser in 1914, and Evard Collin in 1922 wrote about radiography of skeletal tuberculosis. From those publications it is possible to identify most of the signs of skeletal (particularly articular) tuberculosis. Despite the avowed intentions of the authors to display typical findings, however, there was little distinction made between the common and the uncommon, nor were the findings of tuberculous arthritis distinguished from other similar diseases. Part of the reason for this may be that the authors' anticipated use of radiography was not so much in diagnosing the disease as in dis-
covering the extent of local disease and documenting responses to therapy, the diagnosis having already been made on clinical grounds. Another limiting factor was that these authors apparently had relatively little opportunity to compare radiologic and pathologic abnormalities. Fraser attempted to correlate radiographic and pathologic changes, but the final result was confusing. The lack of radiographic illustrations in his work (he used drawings instead) contributed to this confusion, as did a possible lack of understanding of the contribution of various structures to the final radiographic picture. For example, he suggested incorrectly that periosteal elevation may be visible before it has ossified. Exactly when radiologists realized that calcification is necessary before the periosteum becomes visible is uncertain, but it was stated as incontrovertible truth in Bactier’s and Waters’s classic textbook on skeletal radiology in 1921.

When Dallas Burton Phenister became interested in the radiography of tuberculosis, he found that the best sources of information predated X rays. Phenister, a surgeon at the University of Chicago Medical School, primarily wrote about and treated orthopedic diseases, though like most surgeons of the time, he did not limit his practice entirely to one area and also practiced general surgery (Fig. 6.14).\textsuperscript{33} He was interested in the correlation between the radiographic appearance of a condition and its gross and histologic pathology as discussed by earlier writers and as identified at subsequent surgery. Radiologic and pathologic examination of joints resected for infectious arthritis revealed to him two basic differences in the pathologic processes occurring in bacterial and tuberculous arthritis. In bacterial arthritis there is extensive and rapid cartilaginous destruction, which is most marked in areas of pressure between opposing cartilaginous surfaces. In tuberculous arthritis cartilage destruction occurs more slowly and takes place first on the noncontacted parts of cartilage.\textsuperscript{34}

Phenister also described four findings typical of adult articular tuberculosis: (1) periarthritic atrophy, (2) preservation of the articular cartilage and joint space until late in the disease, (3) loss of the line demarcating the articular cortex, and (4) marginal erosions.\textsuperscript{35} Of these, the first, second, and fourth are often grouped together as Phenister’s triad (Fig. 6.15). Phenister’s work has been expanded on by many later writers. It remains frequently cited, however, because it was a distinct improvement over what was previously available. Phenister’s advantages were, first, that he learned from all aspects of a case including the patient’s history and physical examination, the radiographic appearance of the disease, and the gross and histologic pathology; and second, that he perceived that careful examination of
radiographs could allow a physician not merely to document progression or improvement in a known disease but also to distinguish with some accuracy between two similar diseases.

**Bone Tumors**

For osteopoikilosis, the radiograph revealed the truth without need for pathologic corroboration. For articulat tuberculosis, the radiograph and clinical history made the diagnosis, and bacteriological or histological study produced definitive confirmation. In the case of osseous tumors, neither the radiographic appearance nor the pathology represented the complete truth about a lesion. Pathologists differed among themselves not only about the identity of a particular bone tumor but about the best way to categorize tumors in general. Even those physicians who in the 1920s and 1930s spoke with the most recognized authority, James Ewing (1866–1948), Ernest Amory Codman (1869–1940), and Joseph Colt Bloodgood (1867–1935), realized that their categorizations of tumors were confusing other physicians.36

This confusion may be sampled by reading a few of the papers included in the February 1931 issue of *Radiology*. These papers emanated from Johns Hopkins, but despite their uniform source, the papers are not consistent in their categorization of tumors. One author used the terms chondrosarcoma and chondroid form of osteosarcoma, as though both were mere subsets of osteosarcoma.37 Another, like Phemister in Chicago, wanted to separate chondrosarcomas from other tumors and include in that group all malignant tumors with primarily chondroid composition.38,39 All of these authors agreed that Ewing’s sarcoma was a distinct entity, but no one was sure what it was. Ewing thought it was of vascular endothelial origin, and wanted to call it an endothelioma, but that opinion was.

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**Skeletal Radiology**

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**Fig. 6.16 Registry of Bone Sarcoma.** The registry was begun in 1928 through the American College of Surgeons. To Codman it had both political and scientific merit. Its political mission was to further his End Result Idea. The idea (invariably capitalized by Codman) held that physicians and hospitals should collect statistics on the ultimate outcome of all the cases they treated to allow analysis of the merits of specific types of treatment and also (a most touchy subject in Boston in the 1910s) the skills of individual practitioners. The registry’s scientific purpose, of course, was to collect in one place histologic, radiographic, and clinical information on many victims of bone sarcoma to allow systematic study of the classification and treatment of these rare tumors. The figure is a reproduction of one of the envelopes designed to hold material from a registered case which appeared in Codman, *The Shoulder*, p. 419; see pp. 401-402 on the End Result Idea. (Reproduced with permission from Robert E. Kreiger Pub. Co.)
not generally accepted. In fact, the eponymous name was a polite way to reject his explanation while accepting the tumor as a distinct entity. “As a matter of classification,” Codman wrote in 1925, “we carry this tumor under Ewing’s name, rather against his will and more or less to his mortification.”

This issue of Radiology was dedicated to Joseph Colt Bloodgood who worked at Johns Hopkins for many years, becoming famous for his insistence on the close cooperation of the surgeon, radiologist, and pathologist in diagnosing and treating tumors of all types. Bloodgood was not alone in regarding radiographic input as essential in the study of bone tumors. When Codman proposed a new type of tumor occurring in the greater tuberosity of the proximal humerus of children and young adults (now called chondroblastoma), he did so on the basis of a distinct radiographic appearance as well as distinct pathology and clinical outcome. Thus the task of radiologists studying bone tumors was to interact with pathologists and surgeons to diagnose individual patients and to refine the categorization of tumors.

This was what Codman called on radiologists to do as he introduced them to the Registry of Bone Sarcoma in 1925 (Fig. 6.16). “It is clear...that neither microscopist nor roentgenologist nor the clinician can alone classify bone tumors. Classification must be done by a cooperative effort on the part of these groups.”

Radiologic identification alone was not sufficient for a successful diagnosis, because Codman and others realized that bone tumors lacked a specific, pathognomonic radiographic appearance, and that an appearance usually associated with one entity could be seen at other times in association with another. Thus, while spiculated periosteal new-bone formation was often seen in osteogenic sarcoma, it could occasionally be seen in Ewing’s tumor as well. At the same time, the lamellated, onion-skin periosteal reaction often associated with Ewing’s tumor frequently caused confusion with the similar appearance of periosteal new bone in osteomyelitis. The most useful keys to a tumor’s identity were its location and the age of the patient. Of the radiologic clues, the form of periosteal reaction and the balance between bone production and bone destruction were considered the most important to diagnosis. Relatively little attention was paid to the margin of the tumor.

In 1930 Gwilym Lodwick (Fig. 6.18) emerged from pathology and radiology residencies at the University of Iowa with a board certificate in radiology and a job that was not to start until late 1951. To use the intervening time to advantage, he was sent to the Armed Forces Institute of Pathology (AFIP), where he studied bone tumors with Lent Johnson, chief of the Registry of Orthopedic Pathology at the AFIP, and created a display on the radiographic patterns of common tumors for the 1951 meeting of the American Roentgen Ray Society (ARRS). He then returned to Iowa to join the faculty in Iowa City. In 1954 Lent Johnson called to say that Codman’s beloved Registry of Bone Sarcoma had left Chicago to join the collections of the AFIP.

Lodwick broke free of ordinary work and family to spend three months with Johnson feverishly studying both the pathology and the radiology of bone tumors. Soon finding that there was not an adequate vocabulary to describe the radiographic findings, particularly the borders of the lesions, Lodwick began sketching the tumors. Finally he reached the end of his allotted time and went back to Iowa with a large trunk stuffed with hundreds of drawings of tumor radiographs. His dream was to categorize the radiographic findings with sufficient precision that a computer could, when the characteristics of an individual lesion were entered, construct an accurate, short differential diagnosis that would reliably include the actual entity. The attempt was predicated on the supposition that bone tumors behave, for the most part, in what Johnson described as “an orderly and predictable manner.” The dream succeeded, but not quite in the way Lodwick had hoped. The computer program actually did work and earned him a place of honor among the founders of
PERIOSTEAL REACTION

Some roentgen signs are considered classical or occasionally even pathognomonic of specific conditions. Active periosteal new bone formation (lamellated or "onion skin" reaction) is classically seen in aggressive bone tumors such as Ewing’s sarcoma. However, this periosteal response can also be seen with acute osteomyelitis. There have been only a few attempts to codify the different appearances of periosteal new bone with specific diseases. This is probably because the reactions correlate best with the rapidity, intensity, and duration of the periosteal elevation rather than with individual diseases. Any such listing of diseases would inevitably omit some. In special settings one must enlarge the differential diagnosis. For example, in a population where sickle cell disease is present, an aseptic acute bone infarct can be the etiology of an acute periosteal reaction. Soft tissue cellulitis in a young patient may also produce such a reaction, and correlation with physical findings and clinical history may be important in ordering the differential diagnoses.

Roentgenographically, as Lodwick and others have suggested, other descriptive findings such as the location of a lesion can help to alter the probabilities of the differential considerations. For example, a metadiaphyseal location weakens primary osteomyelitis as the most likely diagnosis in a child, as this condition classically occurs at the metaphysis in the young. Acute long bone infarcts in sickle cell anemia often occur at this specific site (Fig. 6.17). Much of the accumulated knowledge available to bone radiologists has come from isolated discoveries and case reports that slowly expand the differential diagnosis of a certain radiographic finding, balanced with in-depth examinations of a disease or a finding. The latter provides a balanced perspective of how often a particular radiographic appearance may be expected in association with a particular disease.

the field of medical informatics. Of more importance to skeletal radiology, however, was the fact that ordinary radiologists, using Lodwick’s analysis together with previously known information about bone tumors, could do in their heads in seconds what a very bulky and expensive computer did in minutes.

Though words like “moth-eaten” had previously been employed to describe the margins of tumors, Lodwick developed a well-defined system to correlate the
1983. Lodwick pioneered the use of computers in diagnosis and systematized the radiographic diagnosis of bone tumors based on analysis of the X-ray characteristics of hundreds of proven cases. (Photograph courtesy of Dr. Lodwick)

Fig. 6.19a Example of Grade Ia margin in a bone cyst. This type of lesion, with a well-defined border demarcated by a white line, indicates slow growth and a high likelihood that the lesion is benign. (Authors’ collection)

Fig. 6.19b This patient does not have a tumor at all but osteomyelitis, an infection of the bone. Like the lesion in Fig. 6.19a, this lesion has a well-defined border rimmed in white, but it wiggles or twists through the bone. The “serpiginous tract” sign of osteomyelitis was described in 1973 by Vijay Kohel, Murray Dalinka, and Jack Edeiken. (Reproduced with permission from the Journal of the Canadian Association of Radiologists)

Fig. 6.19c Clearly there are very few characteristics of bone lesions that identify particular types of disease with certainty. One of those is the “fallen fragment” sign described by Jack Reynolds in 1969. A fragment of bone (arrows) falls to the bottom of a fluid-filled bone lesion, thus identifying the lesion as a simple bone cyst. (Reproduced with permission from Radiology)

lesion’s margin with its growth rate (Fig. 6.19). This contribution took an unusually long time to appear in print. Lent Johnson had played a large enough role in the project that Lodwick did not wish to publish without him, but Johnson was in no hurry and did not want to put anything into print that fell short of perfection. Finally, in the 1980s Lodwick, John Madewell, and other subsequent workers at the AFIP, encouraged by Lee Theros, who became the registrar of radiologic pathology at the AFIP in 1967, disseminated this information and summarized knowledge concerning other important characteristics of tumors—periosteal reaction and matrix calcification.50

SKELETAL RADIOLOGY: A SUBSPECIALTY

There are still many general diagnostic radiologists in this country, particularly in private practice, and there are few, if any, radiologists who are so specialized that they never read a film outside their subspecialty. Nonetheless, we have reached a stage at which it seems natural to divide radiology into small areas of knowledge or practice—as has been done in organizing this book, as was done when the American Board of Radiology organized the oral board examination, and as has been done in multiple academic settings and many larger private practices. It was not always this way. By World War I radiology was definitely a recognized specialty, but within a radiologic practice it was generally assumed that radiologists were interchangeable. Naturally people had distinct individual talents and limitations, but most could be considered generalists.

This model began to change in the late 1960s and early 1970s. One by one, academic radiology departments reorganized along subspecialties lines, first for teaching purposes and then for day-to-day practice. Faculty members had to choose areas of specialization or had subspecialties thrust upon them by their departments. Many senior skeletal radiologists were content in general diagnostic radiology until departmental needs turned them into subspecialists. Robert Freiberger, for example, became a skeletal radiologist primarily because he was hired by an orthopedic hospital. Murray Dalinka was thrust into skeletal radiology by his superiors at an air force teaching hospital who assumed that he must know a lot about bone radiology since he had done his residency in
Jack Edeiken of Philadelphia (later Houston), and Ronald Murray of Britain began conspiring in 1970 to create a society for the study of skeletal disease, analogous to the Fleischner Society for chest radiology. The result, the International Skeletal Society (ISS), was founded on 4 October 1972 at an organizing meeting in Washington, D.C., during the meeting of the ARRS. In March 1974 the ISS held its first general meeting along with a refresher course. Skeletal Radiology, the official journal of the ISS, was first issued in early 1976. Both the existence and the success of the journal owe much to Heinz Götzte of Springer-Verlag, who was willing to publish the journal with no promise of financial reward. In 1983 the ISS expressed its gratitude by electing him to honorary membership.

The ISS has been of great importance in promoting skeletal radiology as an intellectual discipline and providing to its members the professional contacts necessary to create group identity and aid members in building careers (Figs. 6.20 and 6.21).

For skeletal radiology to become a viable subspecialty that radiologists (particularly those in academics) might actively choose to pursue and in which they could construct a career, there was a need for subspecialty professional societies. Harold Jacobson of New York, Harold Jacobson's department. In some cases skeletal radiology was not a first choice. Air-contrast techniques were adding an exciting new dimension to barium studies, and several respected skeletal radiologists had to be bribed away from gastrointestinal radiology (Figs. 6.20 and 6.21).

Fig. 6.20 William Martel was lured away from a primary interest in gastrointestinal radiology by the intimate connection between inflammatory bowel disease and arthritis. This photograph illustrates his discovery of the common subluxation of the first cervical vertebra in patients with rheumatoid arthritis. Research into arthritis has followed a pattern similar to that of tumor research. Radiologists have worked with rheumatologists to divide a large category of disease into multiple separate entities.


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The ISS has been of great importance in promoting skeletal radiology as an intellectual discipline and providing to its members the professional contacts necessary to create group identity and aid members in building careers (Fig. 6.23). The ISS tries to attract members with the potential to provide professional and intellectual leadership in the field. To accomplish this the organization has adopted moderately exclusive rules governing membership. In general, a radiologist becomes eligible for membership six years after residency and then must demonstrate expertise in skeletal radiology as evidenced by being the first author on at least six articles on skeletal radiology in peer-reviewed jour-
nals and must demonstrate interest in the ISS and its journal. The potential member must also practice skeletal radiology at least 50 percent of the time. Though it is primarily a radiological society, as the name of its journal suggests, the ISS also invites membership to a small number of prominent skeletal pathologists, orthopedic surgeons, and other clinicians with special interest in the musculoskeletal system.

The development and twenty-year dominance of arthrography was also important to the new subspecialty of skeletal radiology. Arthrography involves injection of air and/or positive contrast material into joints to allow visualization of the outlines of the internal soft tissues. It was the first important technique in bone radiology to convey inherently different information than Wilhelm Röntgen's first radiograph. To the degree that musculoskeletal radiology has ever had a defining technology, that quintessentially skeletal technique was arthrography. From the late 1960s through the late 1980s, when it began to be replaced by magnetic resonance (MR) imaging, arthrography filled the afternoon fluoroscopy schedule of hospitals just as barium gastrointestinal procedures filled the mornings.

While it has largely replaced arthrography, MR imaging has also greatly increased interest in musculoskeletal imaging. It allows better visualization of the soft tissues than any prior imaging technique and has elevated the imaging of sports injuries to a higher plane than was possible with arthrography (Fig. 6.26). When Lee Rogers began writing about skeletal trauma, he felt that so little had been done on it that the field was wide open. With MR widely available, the pages of radiologic journals are filled with articles on trauma.

Muscloskeletal imaging fellowships, one-year training programs following residency, have also contributed to the development of musculoskeletal radiology as a recognized subspecialty. As skeletal MR imaging has become more common, private practices have begun to attract people with advanced training in skeletal radiology. This, in turn, has led to a proliferation of fellowship positions.

Subspecialty Organizations

Not uncommonly, as a specialty or subspecialty develops, several organizations will arise to serve the needs of the new community. Each fills a slightly different need. In 1978 the Southeastern Society for Skeletal Radiology (SSSR) was founded by a group of young skeletal radiologists including W. Bonner Guilford of Charlotte, North Carolina; Terry Hudson of Atlanta, Georgia; and Anne Brower of Norfolk, Virginia (Fig. 6.24). They wanted the SSSR to be more
Fig. 6.23 Professional societies provide opportunities for members to become acquainted both during the meeting and at less formal social functions which are often attended by family members. Caught in relaxed moments at ISS meetings are:

Fig. 6.23a Alkar Bonakdarpour;
Fig. 6.23b Harry Genant and Henri Schutte;
Fig. 6.23c John Kirkpatrick, Lorraine Shapero, and Andrew Poznanski;
Fig. 6.23d Richard Gold at the piano;
Fig. 6.23e Louis and Debbie Gilula;
Fig. 6.23f Rubem Pochaczewsky and Frieda Feldman and
Fig. 6.23g Jeremy Kaye. (Photographs courtesy of B.G. Brogdon)

Fig. 6.24 Society of Skeletal Radiology. Four founding members of the society pose at the 17th annual meeting, Scottsdale, Arizona, February 1994. Left to right: Jeno Sebes, Anne Brower, Bonner Guilford, and Terry Hudson.
ARTHROGRAPHY

When Robert Freiberger first came to the Hospital for Special Surgery, he wanted to make a niche for himself by trying something that was not done regularly. Arthrography had been in occasional use since the early twentieth century (Fig. 6.25), but before development of safe water-based positive contrast media, the benefits of the procedure seldom outweighed the risks. In 1963 Freiberger had a visitor from Sweden, Dr. Lars Andren, who said that he and his colleagues had been having good luck with arthrography. Freiberger went to Sweden to study the technique, and on his return persuaded two orthopedic surgeons at the Hospital of Special Surgery to refer patients for arthrography.

One of these surgeons was James Nicholas, who cared for the champion New York Jets football team. When quarterback Joe Namath injured his knee, Nicholas referred him for an arthrogram. The event received widespread media attention, and other patients began demanding arthograms. The number of arthograms requested by referring physicians skyrocketed. Even after other hospitals in New York began doing them, the Hospital for Special Surgery was performing more than a thousand arthograms per year. The case load at other hospitals may have been similar. Asked about arthrography at the Hospital of the University of Pennsylvania in the early 1970s, Melvin Turner replied, "Murray [Dalinka] used to say, 'Four a day forever'—sometimes we did six." The seemingly endless dominance of arthrography lasted approximately twenty years. Books on arthrography by Freiberger and Jeremy Kaye and by Dalinka helped popularize arthrography in America.

Fig. 6.25a World War II arthrogram. It is often important to know the location of a bullet in relationship to nearby anatomic structures. This arthrogram, performed during World War II by injection of air into the knee, determined that the bullet fragment was inside the joint. (Reproduced from K.O.A. Allen, "Diagnostic Considerations," in Radiology in World War II, p. 471)

Fig. 6.25b Double-contrast knee arthrogram. Air-contrast arthrography of the internal structures of the knee was dependent on development of image intensifiers that allowed visualization of low contrast fluoroscopy. In this study, performed in 1984, intrusion of white contrast material into the black triangle (arrow) indicates a meniscal tear. (From the collection of Allen Klein)

open than the ISS to young members and those in private practice, yet they, too, were exclusive in some ways. Members had to practice primarily skeletal radiology and live in the southeastern United States. The geographic requirement, never precisely defined, was intended to keep membership small enough to be manageable and did not last long. First, new members squeezed in from border states (Maryland, Texas, Oklahoma); then a few deliberate excep-
tions were made, and in 1990 geographic restrictions were dropped altogether and the group became the Society for Skeletal Radiology (SSR). Still smaller and less formal than the ISS, the SSR neither offers a review course nor publishes a journal. (Personal communications, W. Bonner Guilford, Terry Hudson, Wanda Bernreuter.)

Another important group is so informal that it lacks a distinct name. In 1979 a group of "young bone radiologists" gathered together to offer a refresher course in Sun Valley, Idaho. The first meeting was organized by Jay Mall and Harry K. Genant, and the course became a yearly event. Seven of the original faculty members, Murray K. Dalinka, Deborah M. Forrester, Genant, Jeremy Kaye, Morris Kricun, Michael Pitt, and Donald Resnick remained on the faculty. Over the years all have become well known in skeletal radiology and, through their involvement with this yearly course and with the ISS, have become close friends. (Personal communications, Murray K. Dalinka, Jeremy J. Kaye.)

Groups like the ISS and the two discussed above are important because they provide forums for education, for development of practice standards, and for the development of friendships between members of a subspecialty. Individuals associating with such groups gain a comfortable sense of belonging as well as the more practical connection to employment and research opportunities.

**Conclusion**

Skeletal radiology, like any medical discipline, is both a collection of technical abilities and accumulated wisdom and a community of practitioners. To evaluate the history and future of the field effectively, both aspects must be considered.

Until the late 1960s, when arthrography gained popularity, skeletal radiology's techniques were limited to conventional radiographs and tomography. Research centered on discovering the anatomic and pathologic meaning of the shadows revealed by these techniques and finding the proper emphasis to be placed on them in the overall care of the patient. In some diseases, like fractures or osteoporosis, the diagnosis could be made entirely from the radiograph. In others, like tuberculosis, radiographs provided a noninvasive clue to an essentially nonradiographic diagnosis. In the case of bone tumors and rheumatologic diseases, radiology played an integral part in establishing diagnoses and defining the limits of disease entities. These gains in knowledge have come through the accumulation of countless small discoveries rather than through a few isolated, important ideas. MR imaging and arthrography were important gains in technical ability...

Fig. 6.25 Magnetic resonance imaging. Images obtained in both (a) coronal oblique and (b) sagittal oblique projections show a tear of the rotator cuff of the shoulder. MR imaging is based on completely different properties than radiographs and conveys different types of information concerning the extremities. It has come into widespread use, especially in joint imaging, largely because of its exquisite contrast between different types of soft tissues.

Ultrasound, like MR imaging, also carries different information than conventional radiographs but is not used as commonly in imaging of the skeletal system. Laurence A. Mack was particularly instrumental in demonstrating the usefulness of ultrasound in skeletal disease.

(Authors' collection)
Storage Phosphor Imaging

All digital imaging modalities, whether computed axial tomography, MR imaging, or computed radiography (CR), offer three major advantages over conventional radiography: (1) decreased space requirements for archiving, (2) the ability to manipulate (postprocess) the image electronically, and (3) the ability to transmit one or more copies of the image electronically over unlimited distances. The major problems with digital radiographs have been high cost and inability to compete with the convenience and spatial resolution of conventional film/screen radiographs. There are two basic methods for creating computed radiographs: (1) make a digital copy of an existing film/screen radiograph and (2) replace the film/screen system with a digital detector. The latter allows one to collect data that may not be collectable with a film/screen system. As a direct replacement for film/screen detectors, photostimulable (storage) phosphor plates have offered the greatest promise of several methods tried to date.

Storage phosphor plates can be placed in cassettes the same size and shape as conventional film/screen cassettes. This allows the plates to be used in any situation that film/screen radiography is utilized. For example, a storage phosphor cassette can be placed on the table top for extremity imaging or taken to the ICU for a bedside (portable) chest exam.

The greatest advantage of storage phosphor images over conventional film/screen radiographs is the dynamic range of the system. The increase in dynamic range allows the operator an exposure latitude about a thousand times greater than that of a film/screen system. This increased latitude, combined with the ability to manipulate the window level and width, almost completely eliminates the need for repeat examinations secondary to exposure errors (Fig. 6.27).

As with other digital imaging methods, cost and spatial resolution remain a problem. For the majority of extremity imaging, however, the small spatial resolution loss of CR may not present a major problem in diagnosis, and the advantages of the system may well outweigh this disadvantage. Therefore, CR is likely to become increasingly important in skeletal radiology in the future.

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but each prompted the same flurry of small contributions to medical knowledge.

In the future, it is impossible to predict what new technical developments may come along. One technique that is available now and that may become more important and more widely used in the future is digital acquisition of conventional radiographs through techniques such as storage phosphor imaging. The biggest challenge facing medicine in the future is likely to be the need to control escalating medical costs. Cost analyses and studies of the contribution of various imaging techniques to patient outcome will help to guide the use of skeletal imaging technologies.

As a community of practitioners, skeletal radiology has slowly evolved over the years in tandem with the remainder of radiology. As radiology became a specialty, responsibility for interpretation of skeletal radiologic procedures shifted to radiologists, particularly within hospitals. Other physicians, particularly orthopedic surgeons, however, continue to use radiographic studies in their daily practice. Especially in outpatient settings, they often have sole responsibility for interpretation of studies. In research as in daily practice proportionately more contributions were made by radiologists as the century progressed. Orthopedists, however, continue to include skeletal radiology among their research interests and make useful observations. How much skeletal radiology is practiced in the future by what group of physicians will probably be a political and economic question arrived at by weighing the quality of care provided by competing groups and the price for that care.

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