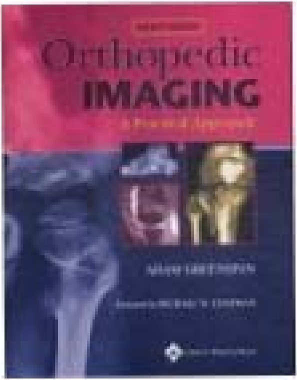
Orthopedic
IMAGING

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Preface

Five years have elapsed since the third edition of this text was released by the publishers. This is a long time when we consider the rapid progress in radiologic imaging and the continued technological advances in this field. These facts prompted a new edition that, in part, reflects the above-mentioned progress, being a very much “overhauled” and improved copy of the previous editions. Because radiologists are now using imaging technologies not connected with an X-ray beam, such as magnetic resonance imaging, ultrasound, and scintigraphy, the older terms “radiography” and “radiology” are often being substituted with a new term, “imaging.” Hence, the new title of the book, *Orthopedic Imaging: A Practical Approach*. However, despite the frequent use of these “high-technology” advanced techniques in orthopedic imaging, in this as in the previous editions of this text, the emphasis is placed on conventional radiography which, at least in the eyes of the author, remains a cost-effective modality and plays a fundamental role in the care of patients rendered by orthopedic surgeons and other physicians, and should always be performed first before more sophisticated and advanced imaging techniques are employed. Nevertheless, as in the previous editions, the main objective of this book is to demonstrate the availability of various imaging modalities for evaluation of traumatic, arthritic, neoplastic, infectious, metabolic, and congenital disorders of the musculoskeletal system, and to indicate the effectiveness of specific techniques for specific abnormalities.

There are, however, many changes, additions, and improvements in this edition. The book has received a new design, and color was introduced to better depict the titles and subtitles. As suggested by one of the reviewers of the previous edition, the captions for the illustrations have been improved, with the diagnosis placed at the beginning of the legend in boldface type. Technically suboptimal illustrations have been either deleted or substituted with better-quality images. Outdated text and references have been deleted and replaced with current ones. New tables summarizing the salient features of various disorders have been added. In addition, the text has been revised to include many MRIs, thin-section CTs, and 3-D CT studies.

Several new sections have been added to almost every chapter. For example, in the chapter on imaging techniques the newest information about diagnostic use of positron emission tomography (^{18}FDG PET) was added. In the chapters dealing with trauma, injury to the glenoid and to the glenohumeral ligaments, MRI classification of acromioclavicular joint injury, suprascapular nerve syndrome, injury to the soft tissues of the elbow (including tears of the ligaments), Essex-Lopresti fracture-dislocation, ulnar impingement and ulnar impaction syndromes, and scaphoid dislocations, have been included. New material also consists of injuries to the acetabular labrum, newest advances in MRI of meniscal injuries, navicular bone fractures, sinus tarsi and tarsal tunnel syndromes, Scheuermann disease, and annular tears of the intervertebral disk. In the section dealing with arthritides, recent advances in total joint replacement, updated information on Postel coxarthropathy, newest information on erosive osteoarthritis, and amyloid arthropathy complicating long-term hemodialysis and chronic renal failure have been added. The section on tumors contains new information about the latest advances in imaging of osteoid osteoma and CT-guided radiofrequency thermal ablation of this lesion. Previously omitted facts on intracortical chondroma, Jaffe-Campanacci syndrome, fibrocartilaginous dysplasia of long bones, Mazabraud syndrome, the solid variant of aneurysmal bone cyst (giant cell reparative granuloma), multifocal giant cell tumors, staging of giant cell tumor, epithelioid hemangioma, soft tissue (extraskeletal) osteosarcoma and its differential diagnosis, revised classification of lymphomas, primary leiomyosarcoma of bone, hemangioendothelioma and angiosarcoma of bone, and on lipoma arborescens are now incorporated. In the section on musculoskeletal infections, the role of MRI in diagnosing musculoskeletal infections has been expanded. The section on metabolic disorders incorporates the newest information on imaging techniques for measurement of bone mineral density. In the section on congenital and developmental anomalies, information on Madelung deformity, treatment of congenital hip dysplasia, and material on some of the sclerosing bone dysplasias have been augmented with new material. Again, as in the previous editions, to keep up with the latest developments in musculoskeletal imaging, up-to-date references and suggested readings appear at the end of each chapter.

Despite the increased number of illustrations and the additional text, the single-volume format has been retained. This should facilitate the use of this text by radiologists, orthopedic surgeons, and other physicians interested in application of imaging techniques to musculoskeletal disorders, and should serve as a convenient addition to the multivolume editions of similar books now on the market.

Adam Greenspan M.D., F.A.C.R.

Chapter 1

The Role of the Orthopedic Radiologist

Spectacular progress has been made and continues to be made in the field of radiologic imaging. The introduction and constant improvements of new imaging modalities—computed tomography (CT) and its spiral (helical) and tridimensional (3-D) variants, digital (computed) radiography (DR, CR) and its variants, digital subtraction radiography (DSR) and digital subtraction angiography (DSA), three-dimensional ultrasound (US), radionuclide angiography and perfusion scintigraphy, positron emission tomography (PET), single-photon emission computerized tomography (SPECT), magnetic resonance imaging (MRI), among others—have expanded the armamentarium of the radiologist, facilitating the sometimes difficult process of diagnosis. These new technologic developments have also brought disadvantages. They have contributed to a dramatic increase in the cost of medical care and have often led clinicians, trying to keep up with new imaging modalities, to order too many frequently unnecessary radiologic examinations.

This situation has served to emphasize the crucial importance of the role of the orthopedic radiologist and the place of conventional radiography. The radiologist must not only comply with prerequisites for various examinations but also, more importantly, screen them to choose only those procedures that will lead to the correct diagnosis and evaluation of a given disorder. To this end, radiologists should bear in mind the following objectives in the performance of their role:

- To *diagnose an unknown disorder*, preferably by using standard projections along with the special views and techniques obtainable in conventional radiography before using the more sophisticated modalities now available.
- To perform examinations in the *proper sequence* and to know what should be performed *next* in the radiologic investigation.
- To demonstrate the determining *radiologic features of a known disorder*, the *distribution* of a lesion in the skeleton, and its *location* in the bone.
- To monitor the *progress of therapy* and possible *complications.*
- To be aware of what *specific information* is important to the orthopedic surgeon.
- To recognize the *limits of noninvasive radiologic investigation* and to know when to *proceed with invasive techniques.*
- To recognize lesions that require biopsy and those that do not (the “don't touch” lesions).
- To assume a more active role in therapeutic management, such as performing an embolization procedure, delivering chemotherapeutic material by means of selective catheterization, or performing (usually CT-guided) radiofrequency thermal ablation of osseous lesions (such as osteoid osteoma).

The radiologic diagnosis of many bone and joint disorders cannot be made solely on the basis of particular recognizable radiographic patterns. Clinical data, such as the patient's age, gender, symptoms, history, and laboratory findings, are also important to the radiologist in correctly interpreting an imaging study. Occasionally, clinical information is so typical of a certain disorder that it alone may suffice as the basis for diagnosis. Bone pain in a young person that is characteristically most severe at night and is promptly relieved by salicylates, for example, is so highly suggestive of osteoid osteoma that often the radiologist's only task is finding the lesion. However, in many cases clinical data do not suffice and may even be misleading.

When presented with a patient, the cause of whose symptom is *unknown* (Fig. 1.1) or *suspected* on the basis of clinical data (Fig. 1.2), the radiologist should avoid, as a point of departure in the examination, the more technologically sophisticated imaging modalities in favor of making a diagnosis, whenever possible, on the basis of simple conventional radiographs. This approach is essential not only to maintain cost-effectiveness but also to decrease the amount of radiation to which a patient is exposed. Proceeding first with conventional technique also has a firm basis in the chemistry and physiology of bone. The calcium apatite crystal, one of the mineral constituents of bone, is an intrinsic contrast agent that gives skeletal radiology a great advantage over other radiologic subspecialties and makes information on bone production and destruction readily available through conventional radiography. Simple observation of changes in the shape or density of normal bone, for example in the vertebrae, can be a deciding factor in arriving at a specific diagnosis (Figs. 1.3 and 1.4).

To aid the radiologist in the analysis of radiographic patterns and signs, some of which may be pathognomonic and others nonspecific, a number of options within the confines of conventional radiography are available. Certain *ways of positioning the patient* when radiographs are obtained allow the radiologist the opportunity to evaluate otherwise hidden anatomic sites and to more suitably demonstrate a particular abnormality. The frog-lateral projection of the hip, for example, is better than the anteroposterior view for imaging the signs of suspected osteonecrosis of the femoral head by more readily demonstrating the crescent sign, the early radiographic feature of this condition (see Figs. 4.58 and 4.59B). The frog-lateral view is also extremely helpful in early diagnosis of slipped femoral capital epiphysis (see Fig. 32.30B). Likewise, the application of *special techniques* can help to identify a lesion that is difficult to detect on routine radiographs. Fractures of complex structures such as the elbow, wrist, ankle, and foot are not always demonstrated on the standard projections. Because of the overlap of bones on the lateral view of the elbow, for example, detecting a nondisplaced or minimally displaced fracture of the radial head occasionally requires a special 45-degree angle view (called the radial head–capitellum view) that projects the radial head free of adjacent structures, making an otherwise obscure lesion evident (see Figs. 6.12 and 6.28). Stress radiographic views are similarly useful, particularly in evaluating tears of various ligaments of the knee and ankle joints (see Figs. 9.16, 9.71B, 10.10, 10.11).

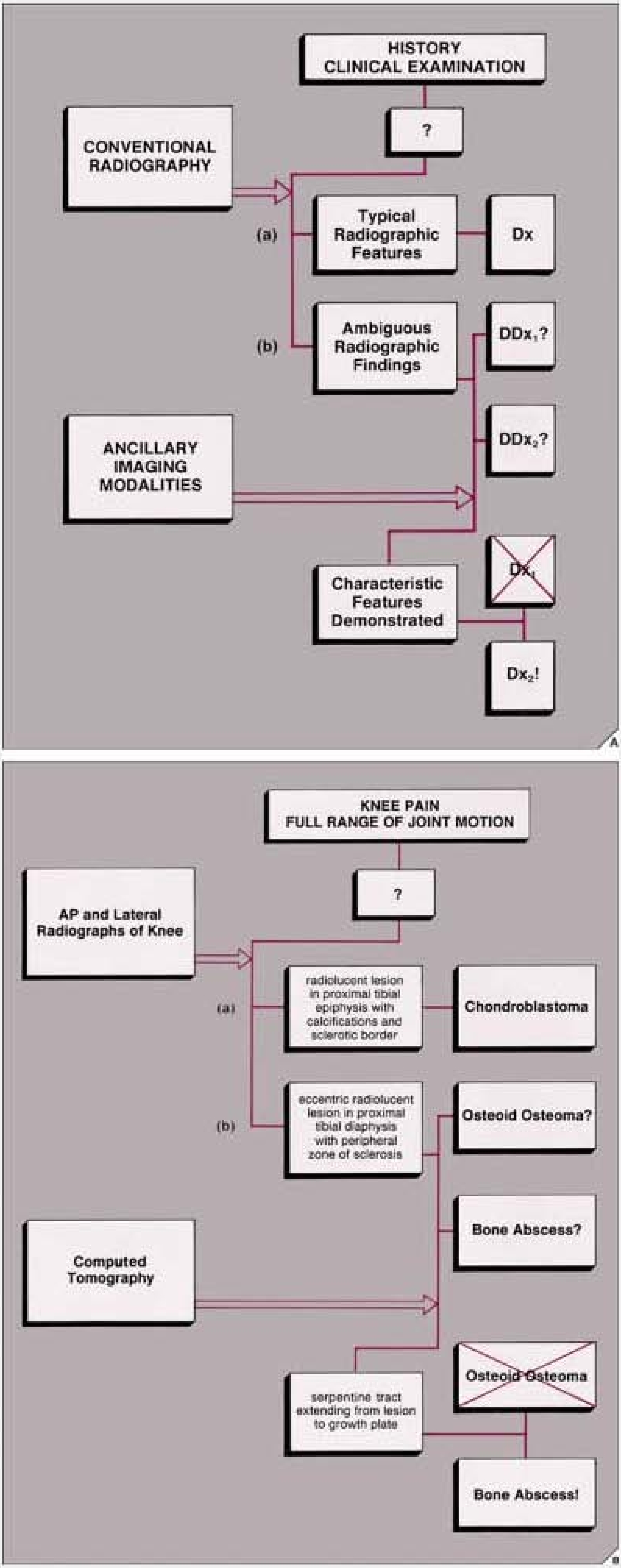
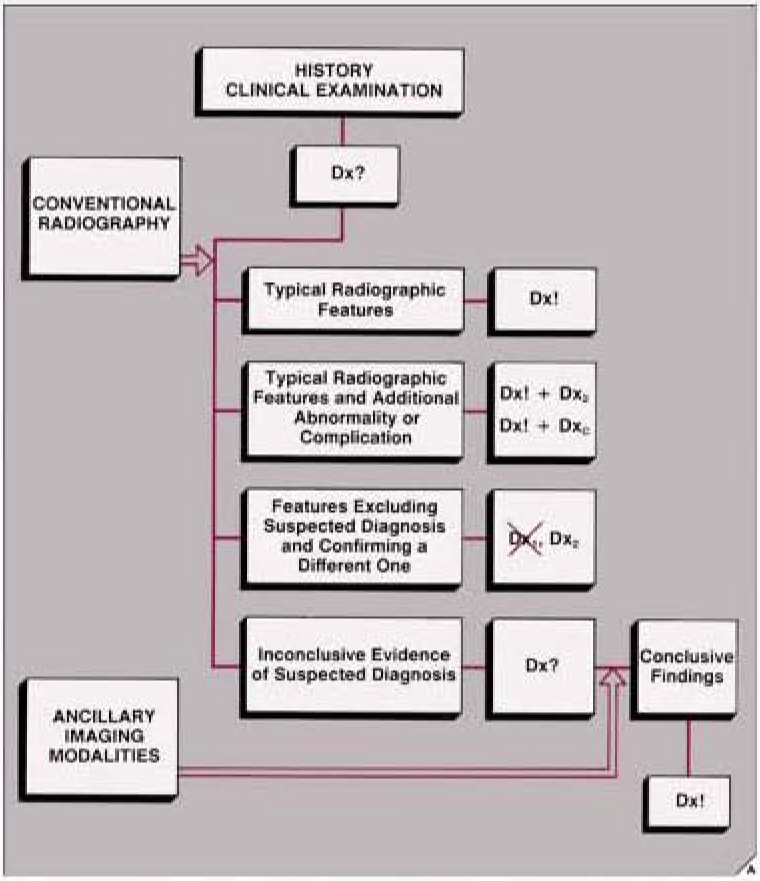

HISTORY
CLINICAL EXAMINATION
?
CONVENTIONAL RADIOGRAPHY
(a)
Typical Radiographic Features
Dx
(b)
Ambiguous Radiographic Findings
DDx1?
DDx2?
ANCILLARY IMAGING MODALITIES
Characteristic Features Demonstrated
Dx1
Dx2!
A
KNEE PAIN
FULL RANGE OF JOINT MOTION
?
AP and Lateral Radiographs of Knee
(a)
radiolucent lesion in proximal tibial epiphysis with calcifications and sclerotic border
Chondroblastoma
(b)
eccentric radiolucent lesion in proximal tibial diaphysis with peripheral zone of sclerosis
Osteoid Osteoma?
Bone Abscess?
Computed Tomography
serpentine tract extending from lesion to growth plate
Osteoid Osteoma
Bone Abscess!
B

Figure 1.1 Cause of symptoms unknown. (A) and **(B)** The patient's history and the results of the clinical examination, supplied to the radiologist by the referring physician, are not sufficient to form a diagnosis (*?*). On the basis of conventional radiographic studies, (a) the diagnosis is established (*Dx*), or (b) the studies may suggest the differential possibilities (*DDx*). In the latter case, ancillary imaging techniques, such as tomography, arthrography, scintigraphy, computed tomography, or magnetic resonance imaging, among others, are called on to confirm or exclude one of the options.

An accurate diagnosis depends on the radiologist's acute observations and careful analysis, in light of clinical information, of the radiographic findings regarding the size, shape, configuration, and density of a lesion, its location within the bone, and its distribution in the skeletal system. Until the conventional approach with its range of options fails to provide the radiographic findings necessary for correct diagnosis and precise evaluation of an abnormality, the radiologist need not turn to more costly procedures.


HISTORY
CLINICAL EXAMINATION
Dx?
CONVENTIONAL RADIOGRAPHY
Typical Radiographic Features
Dx!
Typical Radiographic Features and Additional Abnormality or Complication
Dx! + Dx_2
Dx! + Dx_c
Features Excluding Suspected Diagnosis and Confirming a Different One
Dx_1, Dx_2
Inconclusive Evidence of Suspected Diagnosis
Dx?
Conclusive Findings
ANCILLARY IMAGING MODALITIES
Dx!
A

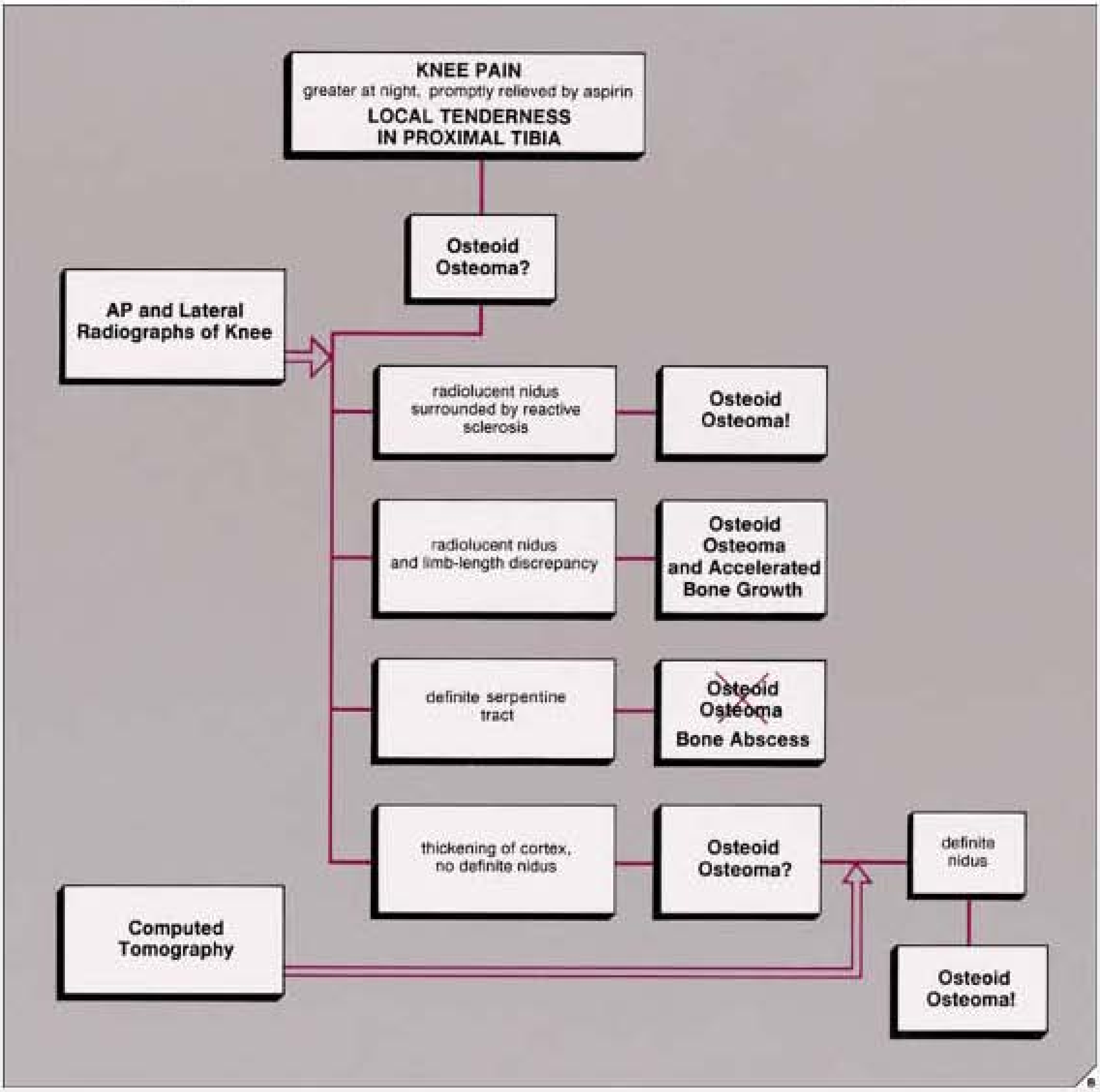

KNEE PAIN
greater at night, promptly relieved by aspirin
LOCAL TENDERNESS IN PROXIMAL TIBIA
Osteoid Osteoma?
AP and Lateral Radiographs of Knee
radiolucent nidus surrounded by reactive sclerosis
Osteoid Osteoma!
radiolucent nidus and limb-length discrepancy
Osteoid Osteoma and Accelerated Bone Growth
definite serpentine tract
Osteoid Osteoma
Bone Abscess
thickening of cortex, no definite nidus
Osteoid Osteoma?
definite nidus
Computed Tomography
Osteoid Osteoma!
B

Figure 1.2 Cause of symptoms suspected. (A) and **(B)** From the information supplied by the referring physician, the radiologist may suspect the diagnosis (*Dx?*) and proceed with conventional radiographic studies. The results of the examination may confirm the suspected diagnosis (*Dx!*), reveal an additional abnormality ($Dx! + Dx_2$) *or an unsuspected complication* ($Dx! + Dx_c$), *or exclude the suspected diagnosis and confirm a different one* (symbol Dx_2). The studies may also show inconclusive evidence of the original suspected diagnosis, in which case ancillary imaging modalities, such as scintigraphy, conventional tomography, computed tomography, or magnetic resonance imaging, among others, are used.

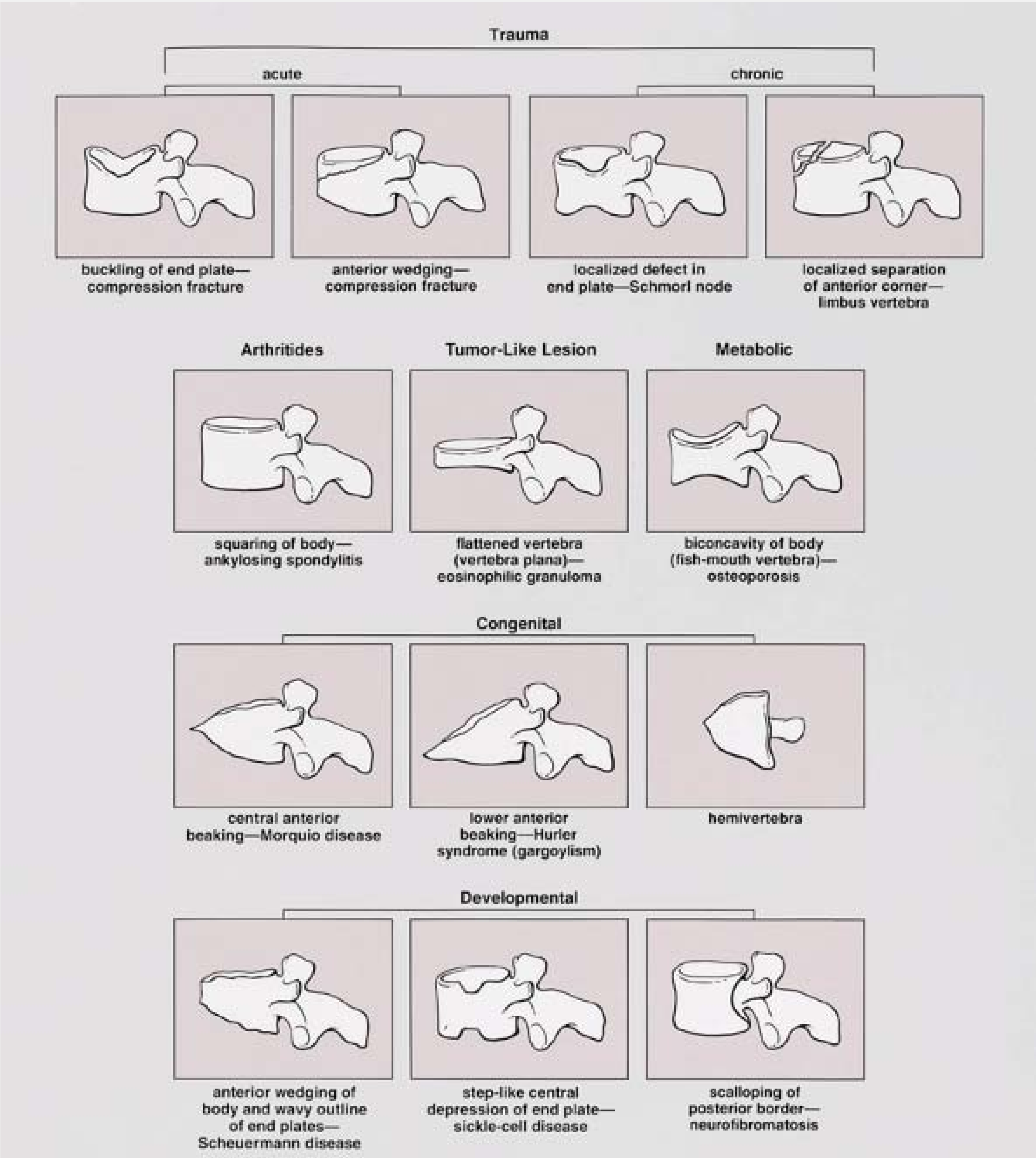


Figure 1.3 Shape and contour of bone. Observation of changes in the shape and contour of a vertebral body on conventional radiographs may disclose critical information leading to a correct diagnosis.

Knowing the *proper sequence* of procedures in radiologic investigation depends, to a great extent, on the pertinent clinical information provided by the referring physician. The choice of modality or modalities for imaging a lesion or investigating a pathologic process is dictated by the clinical presentation as well as by the equipment, availability, physician expertise, cost, and individual patient restrictions. Knowing *where to begin* and *what to do next*, as rudimentary as it may sound, is of paramount importance in reaching a precise diagnosis by the shortest possible route, with the least expense and detriment to the patient. Redundant studies should be avoided. For example, if a patient presents with arthritis and if clinician is interested in demonstrating the distribution of "silent" sites of the disorder, the radiologist should not begin by obtaining radiographs of every joint (a so-called joint survey). It is instead more sensible to perform a scintigraphy and, afterward, to order radiographs of only those areas that show increased uptake of radiopharmaceutical. A simple radionuclide bone scan rather than a broad-ranging bone survey is also a reasonable starting point for investigating other possible sites of involvement when a lesion is detected in a single bone and is suspected of representing part of a multifocal or systemic disorder, such as polyostotic fibrous dysplasia or metastatic disease. Similarly, if a patient is suspected of having osteoid osteoma around the hip joint and standard radiography has not demonstrated the nidus, a radionuclide bone scan should be performed next to determine the site of the lesion. This should be followed-up by conventional tomography or CT for more precise localization of a nidus in the bone. However, if the routine examination demonstrates the nidus, scintigraphy and conventional tomography can be omitted from the sequence of examination. At this point, only CT scan is required to determine the lesion's exact location in the bone and to obtain specific measurements of the nidus (Fig. 1.5; see also Fig. 17.11). If osteonecrosis (ON) of the femoral head is suspected and the radiographs are normal, MRI should be ordered as the next diagnostic procedure, because it is a more sensitive modality than conventional tomography, CT, or scintigraphy. The text that follows presents many similar situations in which the proper sequence of imaging modalities may dramatically shorten the diagnostic investigation.

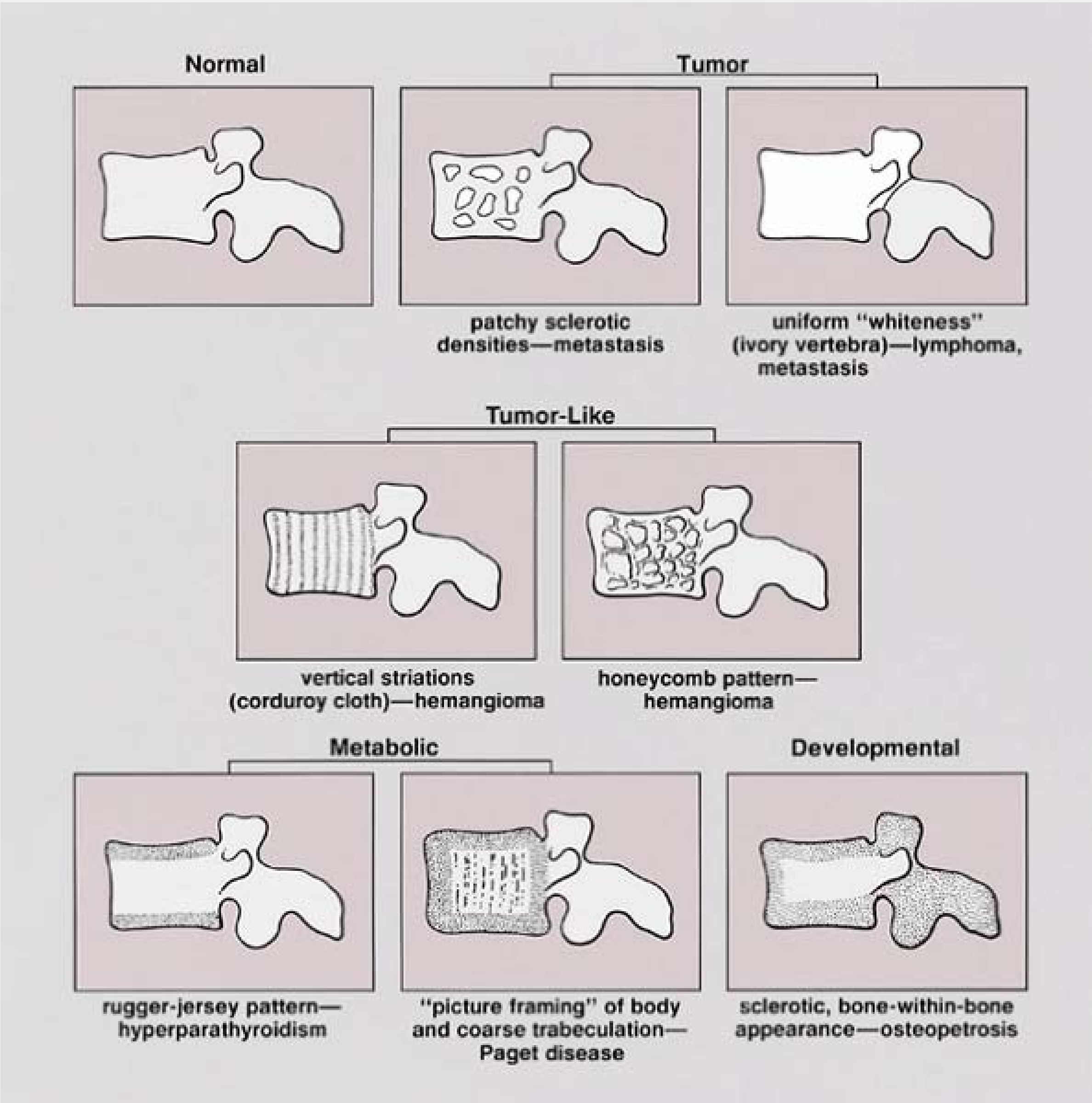
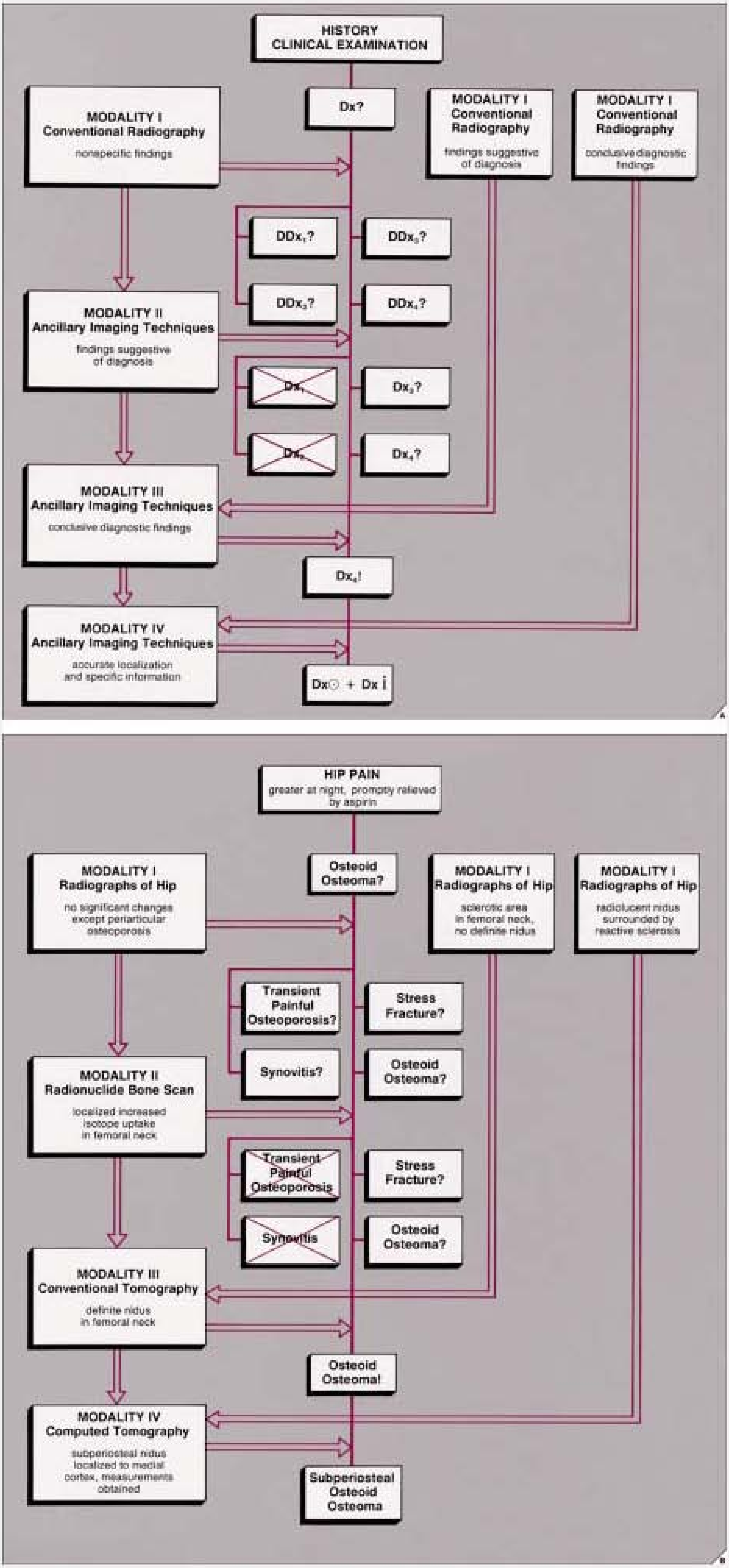


Figure 1.4 Density and texture of bone. Changes in the

density and texture of a vertebral body on conventional radiographs may offer useful data for arriving at a diagnosis.

Reaching a correct diagnosis does not end the process of radiologic investigation, because the course of treatment often depends on the *identification of distinguishing features of a particular disorder* (Fig. 1.6). For example, the diagnosis of Ewing sarcoma by conventional radiography is only the beginning of a radiologic workup of the patient. The *crucial features* of this tumor must be identified, such as intraosseous and soft-tissue extension (by CT or MRI) and the vascularity of the lesion (by conventional arteriography or magnetic resonance arteriography [MRA]). Similarly, a diagnosis of osteosarcoma must be followed by determination of the exact extent of the lesion in the bone and the status of bone marrow in the vicinity of the tumor. This can be accomplished by precise measurement of bone marrow density using Hounsfield numbers during CT examination (see Fig. 2.10) or by using MR images with or without contrast enhancement. Diagnosing Paget disease may be an important achievement in the investigation of an unknown disorder, but even more important is the further search for an answer to a crucial question: Is there any sign of malignant transformation? (see Fig. 29.18).

Localization of a lesion in the skeleton or in a particular bone can frequently be more important than diagnosis itself. The best example of this is, again, the precise localization of the nidus of osteoid osteoma, because incomplete resection of this lesion invariably results in recurrence. Determining the *distribution of a lesion* in the skeleton is helpful in planning the treatment of various arthritides and the management of a patient with metastatic disease. Scintigraphy is an invaluable technique in this respect.



HISTORY
CLINICAL EXAMINATION
Dx?
MODALITY I
Conventional Radiography
nonspecific findings
MODALITY I
Conventional Radiography
findings suggestive of diagnosis
MODALITY I
Conventional Radiography
conclusive diagnostic findings
DDx_1?
DDx_3?
DDx_2?
DDx_4?
MODALITY II
Ancillary Imaging Techniques
findings suggestive of diagnosis
Dx_1
Dx_3?
Dx_2
Dx_4?
MODALITY III
Ancillary Imaging Techniques
conclusive diagnostic findings
Dx_4!
MODALITY IV
Ancillary Imaging Techniques
accurate localization and specific information
Dx⊙ + Dx i
A
HIP PAIN
greater at night, promptly relieved by aspirin
Osteoid Osteoma?
MODALITY I
Radiographs of Hip
no significant changes except periarticular osteoporosis
MODALITY I
Radiographs of Hip
sclerotic area in femoral neck, no definite nidus
MODALITY I
Radiographs of Hip
radiolucent nidus surrounded by reactive sclerosis
Transient Painful Osteoporosis?
Stress Fracture?
Synovitis?
Osteoid Osteoma?
MODALITY II
Radionuclide Bone Scan
localized increased isotope uptake in femoral neck
Transient Painful Osteoporosis
Stress Fracture?
Synovitis
Osteoid Osteoma?
MODALITY III
Conventional Tomography
definite nidus in femoral neck
Osteoid Osteoma!
MODALITY IV
Computed Tomography
subperiosteal nidus localized to medial cortex, measurements obtained
Subperiosteal Osteoid Osteoma
B

Figure 1.5 Sequence of imaging modalities. (A) and **(B)** A diagnosis is suspected (*Dx?*) on the basis of a patient's history and the results of the clinical examination. The radiologist suggests the proper sequence of imaging modalities, eliminating various disorders in the process and narrowing the differential possibilities to arrive at one correct diagnosis (*Dx!*). An accurate localization (*Dx*symbol) and specific information pertinent to the correct diagnosis (*Dx*symbol) are also provided.

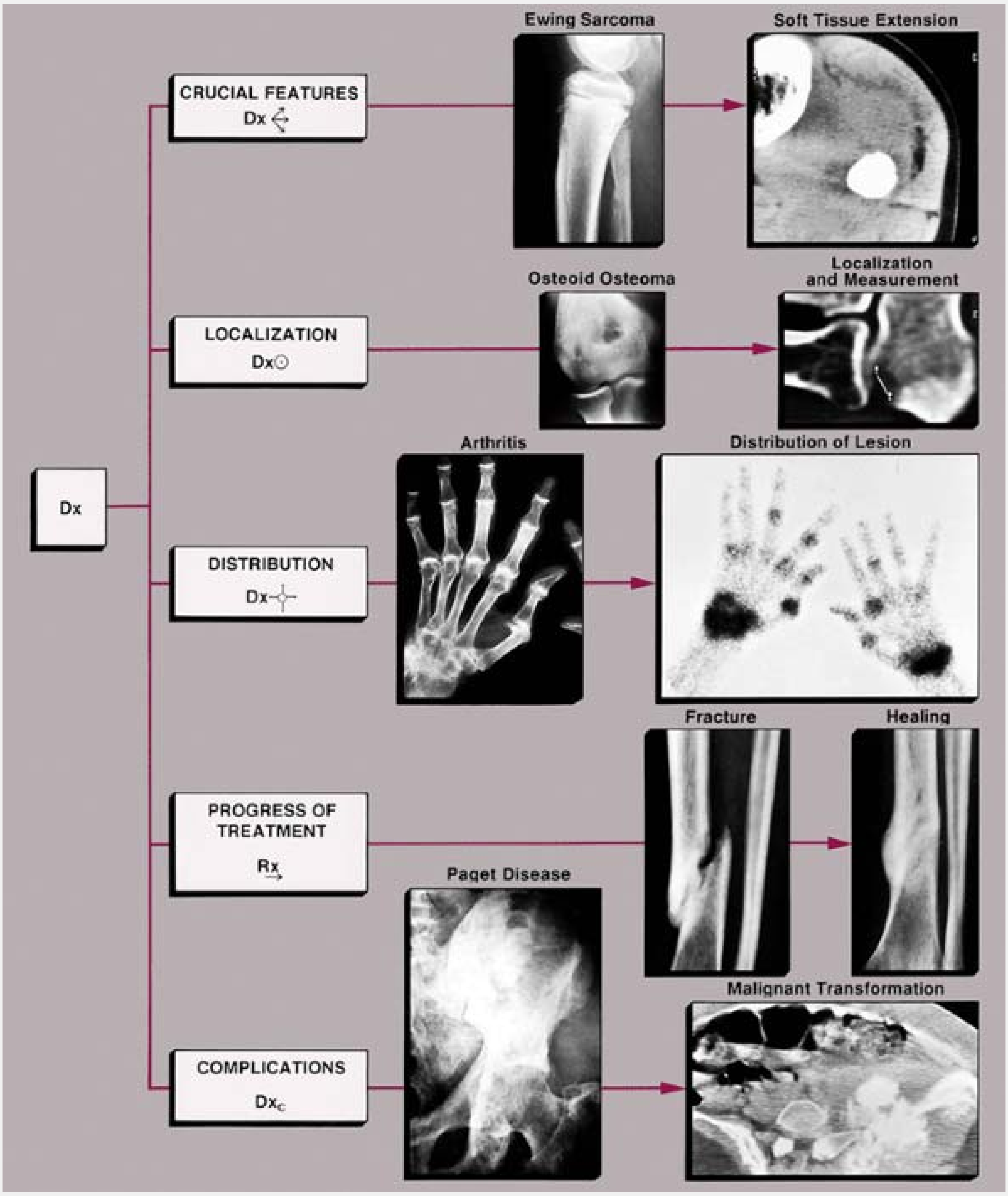


Figure 1.6 Distinguishing features of lesion, progress of treatment, and complications. The diagnosis is known (*Dx*). The clinician is interested in demonstrating: (1) the crucial features of the lesion (*Dx*symbol), i.e., its character, extent, stage, and other pertinent data; (2) the location of the lesion in

the bone (*Dx*symbol); (3) the distribution of the lesion in the skeleton (*Dx*symbol); (4) the progress of treatment (symbol); and (5) the emergence of any complications (Dx_c).

Many of the most important questions put to the radiologist by the orthopedic surgeon concern monitoring the *progress of treatment* and the appearance of possible *complications.* At the stage when the diagnosis is already established, the fate of the lesion, and consequently the patient, must be established. Comparison of earlier radiographic examinations with present findings plays a crucial role at this stage, because it may disclose the dynamics of specific conditions (see Fig. 16.21). Likewise, in monitoring the progress of healing fractures, study of the diagnostic sequence of radiographs complemented by conventional tomography or CT should decide questionable cases. Ancillary imaging techniques such as scintigraphy, CT, and MRI play an essential role in evaluating one of the most serious complications of benign tumors and tumor-like lesions—malignant transformation that may occur in enchondroma, osteochondroma, fibrous dysplasia, or Paget disease.

Providing the orthopedic surgeon with *specific information* is also an important function of the radiologist at the time when a diagnosis is being established. If, for example, osteochondritis dissecans is diagnosed, the decision on the choice of therapy requires information on the status of the articular cartilage covering the lesion. This information is obtainable by contrast arthrography, alone or combined with CT, or by MRI (see Figs. 6.39, 6.40 and 6.41). If the cartilage is intact, conservative treatment should be contemplated; if it is damaged, surgical intervention is the more likely course of treatment. Similarly, in contributing to the plan of treatment of anterior dislocation in the shoulder joint, the radiologist should be aware of the importance to the surgeon of information about the status of the cartilaginous labrum of the glenoid (see Fig. 5.47) and the possible presence of osteochondral bodies in the joint. These features must be confirmed or excluded by arthrography combined with tomography (arthrotomography), CT (computed arthrotomography), or MRI (Fig. 1.7).

Recognizing *the limits of noninvasive radiologic investigation* and knowing when to proceed with *invasive techniques* are as important to arriving at a diagnosis and precise evaluation of a condition as any of the points already mentioned. This situation is best illustrated in the case of tumors and tumor-like bone lesions. Many tumor-like lesions have distinctive radiographic presentations that lead to unquestionable diagnoses on conventional studies. In such cases, invasive procedures such as biopsy are not indicated. This is particularly true of a group of definitely benign conditions commonly called “don't touch” lesions (see Fig. 16.48 and Table 16.10). The name “don't touch” speaks for itself. Conditions such as a bone island (enostosis), posttraumatic juxtacortical myositis ossificans, and a periosteal desmoid are unquestionably benign lesions whose determining features can, with certainty, be demonstrated with the appropriate noninvasive techniques without the need for histopathologic confirmation. Obtaining a biopsy of such lesions may in fact lead to mistakes in diagnosis and treatment. The histologic appearance of a periosteal desmoid, for example, may exhibit aggressive features resembling a malignant tumor; in inexperienced hands, this can lead to inappropriate treatment. However, there are times when the radiologist faces the situation in which a battery of conventional and sophisticated noninvasive techniques has yielded equivocal information. At this point, there is no shame in saying, “I don't know what it is, but I know a biopsy should be performed” (Fig. 1.8). Fluoroscopy-guided or CT-guided percutaneous biopsy can be performed by the radiologist in the radiology suite, eliminating the use of costly operating-room time and personnel.

Occasionally, the radiologist may also assume a more active role in therapeutic management by performing an embolization procedure under image intensification or with CT guidance, or performing radiofrequency thermal ablation of bone lesion. This more interventional role for the radiologist may shorten the length of a patient's hospitalization and be more cost-effective.

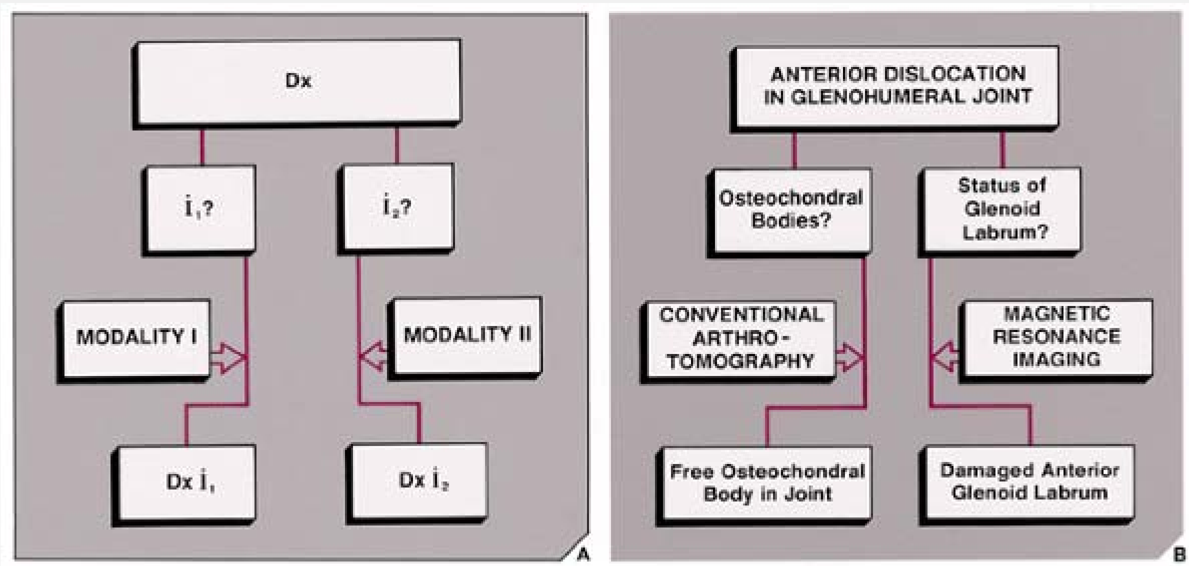


Figure 1.7 Specific information. (A) and **(B)** The diagnosis is known (*Dx*). The radiologist should be aware of the specific information (*i*), for example, regarding the features (i_1?) or extent (i_2?) of a lesion, which is required by the orthopedic surgeon in planning treatment. The information may also concern the distribution of a lesion and its localization, the

progress of treatment, or the emergence of complications. Application of the best radiologic modality for demonstrating the required information is one of the radiologist's primary functions. The modalities may vary depending on the specific information needed.

In summary, to sufficiently manage the diagnosis and treatment of patients with conditions affecting the musculoskeletal system, the radiologist and the referring physician should be aware of the range of radiologic modalities and their proper uses. This will increase the precision of diagnostic radiologic investigation and reduce the amount of radiation to which a patient is exposed and the cost of hospitalization. The obligation of the radiologist is to:

- Use the conventional radiographic methods, with knowledge of the capabilities and effectiveness of the various techniques, before resorting to more sophisticated modalities.
- Follow a logical sequence of imaging modalities in diagnostic investigation.
- Be as noninvasive as possible at the start, but use invasive techniques if they will shorten the diagnostic pathway.
- Improve communication between the radiologist and the orthopedic surgeon by using the same language and by knowing what the surgeon needs to know about the lesion.
- Provide knowledge to referring physicians about indications, advantages, disadvantages, risks, contraindications, and limitations of the various imaging techniques.

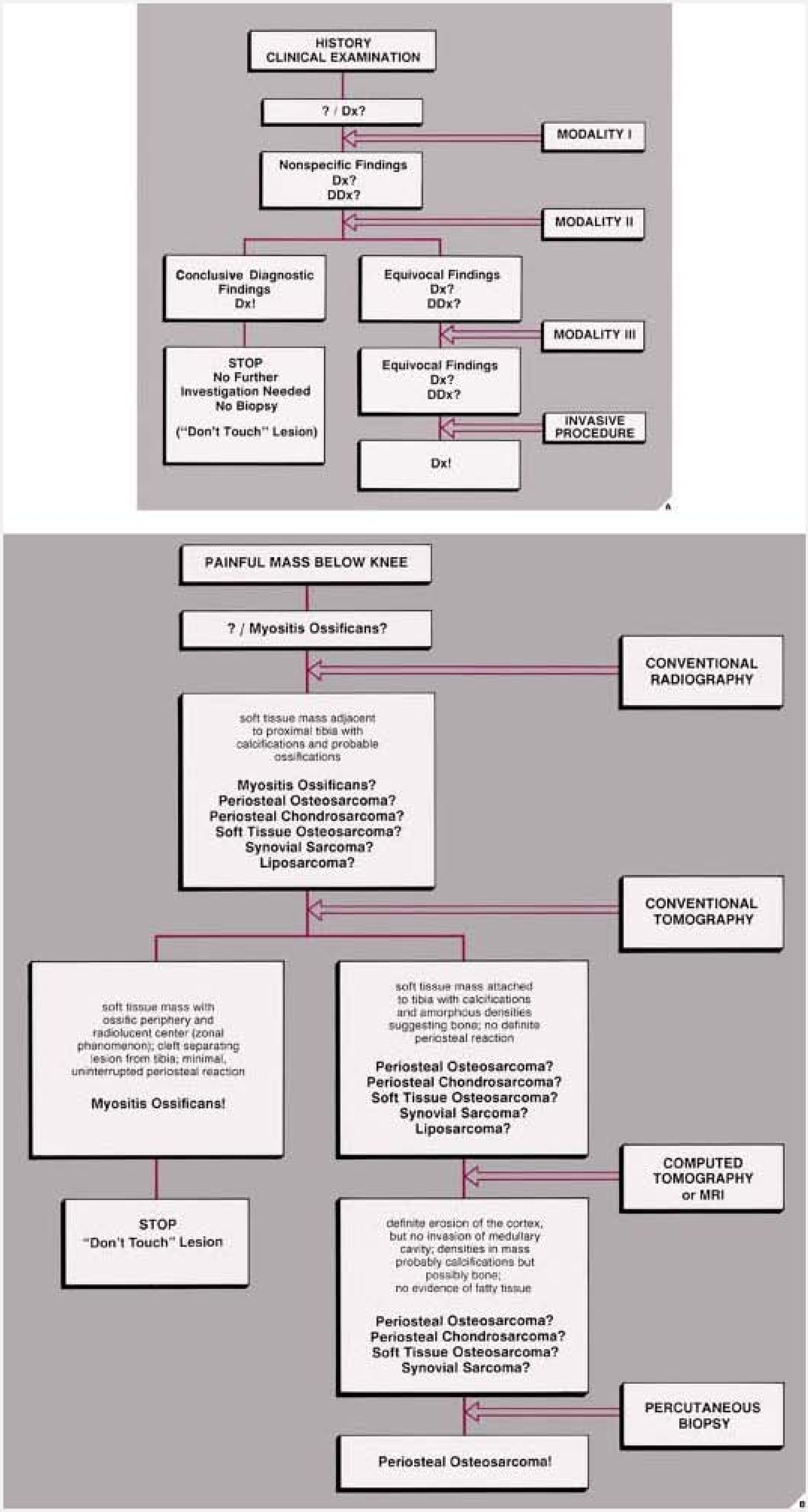

HISTORY
CLINICAL EXAMINATION
? / Dx?
MODALITY I
Nonspecific Findings
Dx?
DDx?
MODALITY II
Conclusive Diagnostic Findings
Dx!
Equivocal Findings
Dx?
DDx?
MODALITY III
STOP
No Further Investigation Needed
No Biopsy
("Don't Touch" Lesion)
Equivocal Findings
Dx?
DDx?
INVASIVE PROCEDURE
Dx!
A
PAINFUL MASS BELOW KNEE
? / Myositis Ossificans?
CONVENTIONAL RADIOGRAPHY
soft tissue mass adjacent to proximal tibia with calcifications and probable ossifications
Myositis Ossificans?
Periosteal Osteosarcoma?
Periosteal Chondrosarcoma?
Soft Tissue Osteosarcoma?
Synovial Sarcoma?
Liposarcoma?
CONVENTIONAL TOMOGRAPHY
soft tissue mass with ossific periphery and radiolucent center (zonal phenomenon); cleft separating lesion from tibia; minimal, uninterrupted periosteal reaction
Myositis Ossificans!
soft tissue mass attached to tibia with calcifications and amorphous densities suggesting bone; no definite periosteal reaction
Periosteal Osteosarcoma?
Periosteal Chondrosarcoma?
Soft Tissue Osteosarcoma?
Synovial Sarcoma?
Liposarcoma?
COMPUTED TOMOGRAPHY or MRI
STOP
"Don't Touch" Lesion
definite erosion of the cortex, but no invasion of medullary cavity; densities in mass probably calcifications but possibly bone; no evidence of fatty tissue
Periosteal Osteosarcoma?
Periosteal Chondrosarcoma?
Soft Tissue Osteosarcoma?
Synovial Sarcoma?
PERCUTANEOUS BIOPSY
Periosteal Osteosarcoma!
B

Figure 1.8 Noninvasive versus invasive procedures. (A) and **(B)** The diagnosis is unknown (*?*) or suspected (*Dx?*). Noninvasive radiologic procedures may yield sufficient data to make an unquestionable diagnosis. No further investigation is required, nor is biopsy indicated, particularly if the diagnosis is that of a definitely benign condition commonly called a “don't touch” lesion. However, noninvasive procedures may yield equivocal information at each step in the examination. At this point, proceeding to an invasive procedure such as biopsy is indicated.

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Chapter 2

Imaging Techniques in Orthopedics

Choice of Imaging Modality

In this chapter, the principles and limitations of current imaging techniques are described. Understanding the basis of the imaging modalities available to diagnose many commonly encountered disorders of the bones and joints is of utmost importance. It may help determine the most effective radiologic technique, minimizing the cost of examination and the exposure of patients to radiation. To this end, it is important to choose the modality appropriate for specific types of orthopedic abnormalities and, when using conventional techniques (namely, “plain” radiography), to be familiar with the views and the techniques that best demonstrate the abnormality. It is important to reemphasize that conventional radiography remains the most effective means of demonstrating a bone and joint abnormality.

Use of radiologic techniques differs in evaluating the presence, type, and extent of various bone, joint, and soft-tissue abnormalities. Therefore, the radiologist and orthopedic surgeon must know the indications for use of each technique, the limitations of a particular modality, and the appropriate imaging approaches for abnormalities at specific sites. The question, “What modality should I use for this particular problem?” is frequently asked by radiologists and orthopedic surgeons alike, and although numerous algorithms are available to evaluate various problems at different anatomic sites, the answer cannot always be clearly stated. The choice of techniques for imaging bone and soft-tissue abnormalities is dictated not only by clinical presentation but also by equipment availability, expertise, and cost. Restrictions may also be imposed by the needs of individual patients. For example, allergy to ionic or nonionic iodinated contrast agents may preclude the use of arthrography; the presence of a pacemaker would preclude the use of magnetic resonance imaging (MRI); physiologic states, such as pregnancy, preclude the use of ionized radiation, favoring, for instance, ultrasound. Time and cost consideration should discourage redundant studies.

No matter what ancillary technique is used, conventional radiograph should be available for comparison. Most of the time, the choice of imaging technique is dictated by the type of suspected abnormality. For instance, if osteonecrosis is suspected after obtaining conventional radiographs, the next examination should be MRI, which detects necrotic changes in bone long before radiographs, tomography, computed tomography (CT), or scintigraphy become positive. In evaluation of internal derangement of the knee, conventional radiographs should be obtained first and, if the abnormality is not obvious, should again be followed-up by MRI, because this modality provides exquisite contrast resolution of the bone marrow, articular cartilage, ligaments, menisci, and soft tissues. MRI and arthrography are currently the most effective procedures for evaluation of rotator cuff abnormalities, particularly when a partial or complete tear is suspected. Although ultrasonography can also detect a rotator cuff tear, its low sensitivity (68%) and low specificity (75% to 84%) make it a less definitive diagnostic procedure. In evaluating a painful wrist, conventional radiographs and trispiral tomography should precede use of more sophisticated techniques, such as arthrotomography or CT–arthrography. MRI may also be performed; however, its sensitivity and specificity in detecting abnormalities of triangular fibrocartilage and various intercarpal ligaments is slightly lower than that of CT–arthrotomography, particularly if a three-compartment injection is used. If carpal tunnel syndrome is suspected, MRI is preferred because it provides a high-contrast difference among muscles, tendons, ligaments, and nerves. Similarly, if osteonecrosis of carpal bones is suspected and the conventional radiographs are normal, MRI would be the method of choice to demonstrate this abnormality. In evaluation of fractures and fracture healing of carpal bones, trispiral tomography and CT are the procedures of choice, preferred over MRI, because of the high degree of spatial resolution. In diagnosing bone tumors, conventional radiography and tomography are still the gold standard for diagnostic purposes. However, to evaluate the intraosseous and soft-tissue extension of tumor, they should be followed by either CT scan or MRI, with the latter modality being more accurate. To evaluate the results of radiotherapy and chemotherapy of malignant tumors, dynamic MRI using gadopentetate dimeglumine (Gd-DTPA) as a contrast enhancement is far superior to scintigraphy, CT, or even plain MRI.

Imaging Techniques

Conventional Radiography

The most frequently used modality for the evaluation of bone and joint disorders, and particularly traumatic conditions, is conventional radiography. The radiologist should obtain at least two views of the bone involved, at 90-degree angles to each other, with each view including two adjacent joints. This decreases the risk of missing an associated fracture, subluxation, and/or dislocation at a site remote from the apparent primary injury. In children, it is frequently necessary to obtain a radiograph of the normal unaffected limb for comparison. Usually the standard radiography comprises the anteroposterior and lateral views; occasionally, oblique and special views are necessary, particularly in evaluating complex structures, such as the elbow, wrist, ankle, and pelvis. A weight-bearing view may be of value for a dynamic evaluation of the joint space under the weight of the body. Special projections, such as those described in the next chapters, may at times be required to demonstrate an abnormality of the bone or joint to further advantage.

Magnification Radiography

Magnification radiography is occasionally used to enhance bony details not well-appreciated on the standard radiographic projections and to maximize the diagnostic information obtainable from a radiographic image. This technique involves a small focal-spot radiographic tube, a special screen–film system, and increased object-to-film distance, resulting in a geometric enlargement that yields magnified images of the bones and joints with greater sharpness and greater bony detail. This technique is particularly effective in demonstrating early changes in some arthritides (see Fig. 12.7) as well as in various metabolic disorders (see Fig. 26.9B). Occasionally, it may be useful in demonstrating subtle fracture lines otherwise not seen on routine projections.

Stress Views

Stress views are important in evaluating ligamentous tears and joint stability. In the hand, abduction–stress film of the thumb may be obtained when gamekeeper's thumb, resulting from disruption of the ulnar collateral ligament of the first metacarpophalangeal joint, is suspected. In the lower extremity, stress views of the knee and ankle joints are occasionally obtained. Evaluation of knee instability caused by ligament injuries may require use of this technique in cases of a suspected tear of the medial collateral ligament, and less frequently in evaluating an insufficiency of the anterior and posterior cruciate ligaments. Evaluation of ankle ligaments also may require stress radiography. Inversion (adduction) and anterior–draw stress films are the most frequently obtained stress views (see Figs. 4.4, 10.10, 10.11).

Scanogram

The scanogram is the most widely used method for limb-length measurement. This technique requires a slit-beam diaphragm with a 1/16-inch opening attached to the radiographic tube and a long film cassette. The radiographic tube moves in the long axis of the radiographic table. During exposure, the tube traverses the whole length of the film, scanning the entire extremity. This technique allows the x-ray beam to intersect the bone ends perpendicularly; therefore, comparative limb lengths can be measured. When a motorized radiographic tube is not available, a modified technique may be used with three separate exposures over the hip joints, knees, and ankles. In this technique, an opaque tape measure is placed longitudinally down the center of the radiographic table. Occasionally, an orthoroentgenogram is obtained. For this technique, the patient is positioned supine with the lower limbs on a 3-foot–long cassette and a long ruler at one side. A single exposure is made, centered at the knees to include the entire length of both limbs and the ruler.

Fluoroscopy and Video Taping

Fluoroscopy is a fundamental diagnostic tool for many radiologic procedures including arthrography, tenography, bursography, arteriography, and percutaneous bone or soft-tissue biopsy. Fluoroscopy combined with videotaping is useful in evaluating the kinematics of joints. Because of the high dose of radiation, however, it is only occasionally used, such as in evaluating the movement of various joints or to detect transient subluxation (i.e., carpal instability). Occasionally, it is used after fractures in follow-up examination of the healing process to evaluate the solidity of the bony union. Fluoroscopy is still used in conjunction with myelography, where it is important to observe the movement of the contrast column in the subarachnoid space; in arthrography, to check proper placement of the needle and to monitor the flow of contrast agent; and intraoperatively, to assess reduction of a fracture or placement of hardware.

Digital Radiography

Digital (computed) radiography is the name given to the process of digital image acquisition using an x-ray detector comprising a photostimulable phosphor imaging plate and an image reader–writer that processes the latent image information for subsequent brightness scaling and laser printing on film (Fig. 2.1). The system works on the principle of photostimulated luminescence. When the screen absorbs x-rays, the x-ray energy is converted to light energy by the process of fluorescence, with the intensity of light being proportional to the energy absorbed by the phosphor. The stimulated light is used to create a digital image (a computed radiograph).

A major advantage of computed radiography over conventional film/screen radiography is that once acquired, the digital image data are readily manipulated to produce alternative renderings. Potential advantages of digitization include contrast and brightness optimization by manipulation of window width and level settings, as well as a variety of image-processing capabilities, quantitation of image information, and facilitation of examination storage and retrieval. In addition, energy subtraction imaging (also called dual-energy subtraction) may be acquired. Two images, acquired either sequentially or simultaneously with different filtration, are used to reconstruct a soft-tissue–only image or a bone-only image.

In digital subtraction radiography, a video processor and a digital disk are added to a fluoroscopy imaging complex to provide online viewing of subtraction images. This technique is most widely used in evaluation of the vascular system, but it may also be used in conjunction with arthrography to evaluate various joints. Use of high-performance video cameras with low noise characteristics allows single video frames of precontrast and postcontrast images to be used for subtraction. Spatial resolution can be maximized using a combination of geometric magnification, electric magnification, and a small anode–target distance. The subtraction technique removes surrounding anatomic structures and thus isolates the opacified vessel or joint, making it more conspicuous.

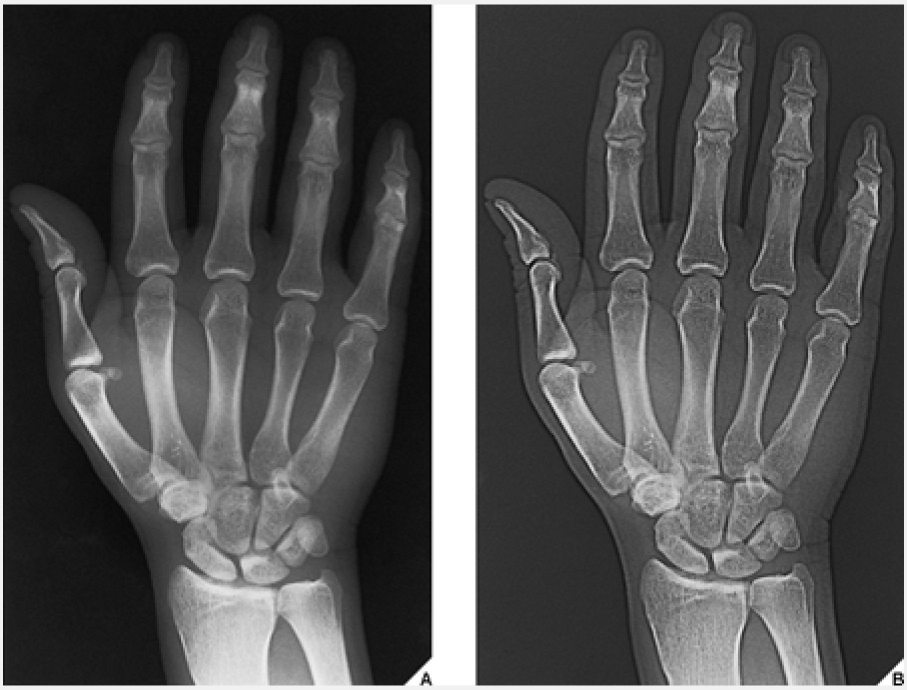

Figure 2.1 Digital radiography. Digital radiograph of the hand without **(A)** and with **(B)** edge enhancement. The bone details and the soft tissues are better appreciated than on the standard radiographs.

Nonvascular digital radiography may be used to evaluate various bone abnormalities and, in conjunction with contrast injection, a procedure called digital subtraction arthrography (Fig. 2.2), to evaluate subtle abnormalities of the joints, such as tears of the triangular fibrocartilage or intercarpal ligaments in the wrist, or to evaluate the stability of prosthesis replacement. Digital radiography offers the potential advantages of improved image quality, contrast sensitivity, and exposure latitude, and it provides efficient storage, retrieval, and transmission of radiographic image data. Digital images may be displayed on the film or on a video monitor. A significant advantage of image digitization is the ability to produce data with low noise and a wide dynamic range suitable for window-level analysis in a manner comparable to that used in a CT scanner.

Digital subtraction angiography (DSA), the most frequently used variant of digital radiography, can be used in the evaluation of trauma, bone and soft-tissue tumors, and in general evaluation of the vascular system. In trauma to the extremity, DSA is effectively used to evaluate arterial occlusion, pseudoaneurysms, arteriovenous fistulas, and transection of the arteries (Fig. 2.3). Some advantages of DSA over conventional film techniques are that its images can be studied rapidly and multiple repeated projections can be obtained. Bone subtraction is useful in clearly delineating the vascular structures. In evaluation of bone and soft-tissue tumors, DSA is an effective tool for mapping tumor vascularity.

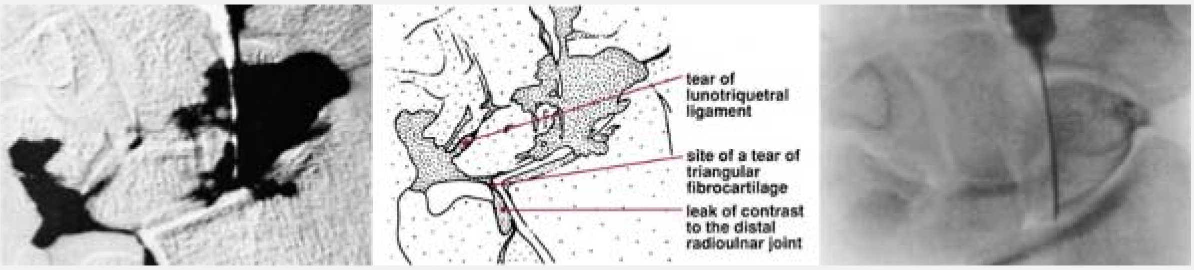

Figure 2.2 Digital subtraction arthrography. Digital subtraction arthrogram demonstrates tears of the lunotriquetral ligament and the triangular fibrocartilage complex. **(A)** This image was obtained by subtracting the digitally acquired preinjection image **(B)** from postinjection film. (Courtesy of Dr.

B. J. Manaster, Denver, Colorado.)

Figure 2.3 Digital subtraction angiography. Digital radiograph **(A)** and digital subtraction angiogram **(B)** of a 23-year-old man who sustained fractures of the proximal tibia and fibula show disruption of the distal segment of the popliteal artery.

Tomography

Tomography is a body section radiography that permits more accurate visualization of lesions too small to be noted on conventional radiographs or demonstrates anatomic detail obscured by overlying structures. It uses continuous motion of the radiographic tube and film cassette in opposite directions throughout exposure, with the fulcrum of the motion located in the plane of interest. By blurring structures above and below the area being examined, the object to be studied is sharply outlined on a single plane of focus. The focal plane may vary in thickness according to the distance the x-ray tube travels; the longer the distance (or arc) traveled by the tube, the thinner the section in focus. Newly developed tomographic units can localize the image more precisely and have aided greatly in the ability to detect lesions as small as approximately 1 mm.

The simplest tomographic movement is linear, with the radiographic tube and film cassette moving on a straight line in opposite directions. This linear movement has little application in the study of bones because it creates streaks that often interfere with radiologic interpretation. Resolution of the plane of focus is much clearer when there is more uniform blurring of undesired structures. This requires a multidirectional movement, such as in zonography or in circular tomography, in which the radiographic tube makes one circular motion at a preset angle of inclination. More complex multidirectional hypocycloidal or trispiral movements increase the distance of excursion of the tube and create a varying angle of projection of the x-ray beam during the exposure. These complex movements are more advantageous because they produce even greater blurring and yield the sharpest images. Trispiral tomography is an important radiographic technique in the diagnosis and management of a variety of bone and joint problems. It continues to be one of the tools for examining patients who have sustained trauma to the skeletal system. Its advantages over conventional radiographs include the visualization of subtle fractures (see Figs. 4.5B and 4.6B). It is not only helpful in delineating the fracture line and demonstrating its extent but also helpful in evaluating the healing process (see Fig. 4.43B), posttraumatic complications (see Figs. 4.50B and 4.59C), and bone grafts in the treatment of nonunions. It is also invaluable in evaluating various tumor and tumor-like lesions (for instance, to demonstrate a nidus of osteoid osteoma or to delineate calcific matrix in enchondroma or chondrosarcoma). Small cystic and sclerotic lesions and subtle erosions can also be better demonstrated. As a rule, the tomograms should be interpreted together with a radiograph for comparison.

Computed Tomography

CT is a radiologic modality containing an x-ray source, detectors, and a computer data-processing system. The essential components of a CT system include a circular scanning gantry, which houses the x-ray tube and image sensors, a table for the patient, an x-ray generator, and a computerized data-processing unit. The patient lies on the table and is placed inside the gantry. The x-ray tube is rotated 360 degrees around the patient while the computer collects the data and formulates an axial image, or “slice.” Each cross-sectional slice represents a thickness between 0.1 and 1.5 cm of body tissue.

The newest CT scanners use a rotating fan of x-ray beams, a fixed ring of detectors, and predetector collimator. A highly collimated x-ray beam is transmitted through the area being imaged. The tissues absorb the x-ray beam to various degrees depending on the atomic number and density of the specific tissue. The remaining, unabsorbed (unattenuated) beam passes through the tissues and is detected and processed by the computer. The CT computer software converts the x-ray beam attenuations of the tissue into a CT number (Hounsfield units) by comparing it with the attenuation of water. The attenuation of water is designated as 0 (zero) H, the attenuation of air is designated as -1,000 H, and the attenuation of normal cortical bone is +1,000 H. Routinely, axial sections are obtained; however, computer reconstruction (reformation) in multiple planes may be obtained if desired.

The introduction of spiral (helical) scanning was a further improvement of CT. This technique, referred to as volume-acquisition CT, has made possible a data-gathering system using a continuous rotation of the x-ray source and the detectors. It allows the rapid acquisition of volumes of CT data and rendering ability to reformat the images at any predetermined intervals ranging from 0.5 to 10.0 mm. Unlike standard CT, in which up to a maximum of 12 scans could be obtained per minute, helical CT acquires all data in 24 or 32 seconds, generating up to 92 sections. This technology has markedly reduced scan times and has eliminated interscan delay, and hence interscan motion. It also has decreased motion artifacts, improved definition of scanned structures, and markedly facilitated the ability to obtain three-dimensional reconstructions generated from multiple overlapping transaxial images acquired in a single breath hold. Spiral CT allows data to be acquired during the phase of maximum contrast enhancement, thus optimizing detection of a lesion. The data volume may be viewed either as conventional transaxial images or as multiplanar and three-dimensional reformation.

CT is indispensable in the evaluation of many traumatic conditions and various bone and soft-tissue tumors because of its cross-sectional imaging capability. In trauma, CT is extremely useful to define the presence and extent of fracture or dislocation; to evaluate various intraarticular abnormalities, such as damage to the articular cartilage or the presence of noncalcified and calcified osteocartilaginous bodies; and to evaluate adjacent soft tissues. CT is of particular importance in the detection of small bony fragments displaced into the joints after-trauma; in the detection of small displaced fragments of the fractured vertebral body; and in the assessment of concomitant injury to the cord or thecal sac. The advantage of CT over conventional radiography is its ability to provide excellent contrast resolution, accurately measure the tissue attenuation coefficient, and obtain direct transaxial images (see Figs. 11.23C, 11.31, 11.33B and 11.57C). A further advantage is its ability—through data obtained from thin, contiguous sections—to image the bone in the coronal, sagittal, and oblique planes using reformation technique. This multiplanar reconstruction is particularly helpful in evaluating vertebral alignment (Fig. 2.4), demonstrating horizontally oriented fractures of the vertebral body, or evaluating complex fractures of the pelvis, hip (Fig. 2.5), or calcaneus, abnormalities of the sacrum and sacroiliac joints, sternum and sternoclavicular joints, temporomandibular joints, and wrist. Modern CT scanners use collimated fan beams directed only at the tissue layer undergoing investigation. The newest advances in sophisticated software enable three-dimensional reconstruction, which is helpful in analyzing regions with complex anatomy, such as the face, pelvis, vertebral column, foot, ankle, and wrist (Figs. 2.6, 2.7, 2.8 and 2.9). New computer systems now permit the creation of plastic models of the area of interest based on three-dimensional images. These models facilitate operative planning and allow rehearsal surgery of complex reconstructive procedures.

Figure 2.4 CT reconstruction imaging. Sagittal CT reformatted image demonstrates the flexion tear-drop fracture of C-5. It also effectively shows malalignment of the vertebral body and narrowing of the spinal canal. (From Greenspan A, 1992, with permission.)

CT plays a significant role in the evaluation of bone and soft-tissue tumors because of its superior contrast resolution and its ability to measure the tissue attenuation coefficient accurately. Although CT by itself is rarely helpful in making a specific diagnosis, it can precisely evaluate the extent of the bone lesion and may demonstrate a break through the cortex and the involvement of surrounding soft tissues. Moreover, CT is very helpful in delineating a tumor in bones having complex anatomic structures, such as the scapula, pelvis, and sacrum, which may be difficult to image fully with conventional radiographic techniques or even conventional tomography. CT examination is crucial to determine the extent and spread of a tumor in the bone if limb salvage is contemplated, so that a safe margin of resection can be planned (Fig. 2.10). It can effectively demonstrate the intraosseous extension of a tumor and its extraosseous involvement of soft tissues such as muscles and neurovascular bundles. It is also useful for monitoring the results of treatment, evaluating for recurrence of resected tumor, and demonstrating the effect of nonsurgical treatment such as radiation therapy and chemotherapy.

Occasionally, iodinated contrast agents may be used intravenously to enhance the CT images. Contrast medium directly alters image contrast by increasing the x-ray attenuation, thus displaying increased brightness in the CT images. It can aid in identifying a suspected soft-tissue mass when initial CT results are unremarkable, or it can assess the vascularity of the soft-tissue or bone tumor.

CT has a crucial role in bone mineral analysis. The ability of CT to measure the attenuation coefficients of each pixel provides a basis for accurate quantitative bone mineral analysis in cancellous and cortical bone. Quantitative computed tomography (QCT) is a method for measuring the lumbar spine mineral content in which the average density values of a region of interest are referenced to that of calibration material scanned at the same time as the patient. Measurements are performed on a CT scanner using a mineral standard for simultaneous calibration and a computed radiograph (scout view) for localization. The evaluation of bone mass measurement provides valuable insight into improving the evaluation and treatment of osteoporosis and other metabolic bone disorders.

CT is also a very important modality for successful aspiration or biopsy of bone or soft-tissue lesions, because it provides visible guidance for precise placement of the instrument within the lesion (Fig. 2.11).

Some disadvantages of CT include the so-called average volume effect, which results from lack of homogeneity in the composition of the small volume of tissue. In particular, the measurement of Hounsfield units results in average values for the different components of the tissue. This partial volume effect becomes particularly important when normal and pathologic processes interface within a section under investigation. The other disadvantage of CT is poor tissue characterization. Despite the ability of CT to discriminate among some differences in density, a simple analysis of attenuation values does not permit precise histologic characterization. Moreover, any movement of the patient will produce artifacts that degrade the image quality. Similarly, an area that contains metal (for instance, prosthesis or various rods and screws) will produce significant artifacts. Finally, the radiation dose may occasionally be high, particularly when contiguous and overlapping sections are obtained during examination.

Arthrography

Arthrography is introduction of a contrast agent (“positive” contrast—iodide solution, “negative” contrast—air, or a combination of both) into the joint space. Despite the evolution of newer diagnostic imaging modalities, such as CT and MRI, arthrography has retained its importance in daily radiologic practice. The growing popularity of arthrography has been partially caused by advances in its techniques and interpretation. The fact that it is not a technically difficult procedure and is much simpler to interpret than ultrasound, CT, or MRI makes it very desirable for evaluating various articulations. Although virtually every joint can be injected with contrast, the examination, at the present time, is most frequently performed in the shoulder, wrist, and ankle. It is important to obtain preliminary films prior to any arthrographic procedure, because contrast may obscure some joint abnormalities (i.e., osteochondral body) that can be easily detected on conventional radiographs. Arthrography is particularly effective in demonstrating rotator cuff tear (Fig. 2.12; see Figs. 5.53 and 5.54) and adhesive capsulitis in the shoulder (see Fig. 5.63), and osteochondritis dissecans, osteochondral bodies, and subtle abnormalities of the articular cartilage in the elbow joint (see Fig. 6.38). In the wrist, arthrography retains its value in diagnosing triangular fibrocartilage complex abnormalities (see Fig. 7.23). Recent introduction of the three-compartment injection technique and the combination of arthrographic wrist examination with digital subtraction arthrography (see Fig. 2.2) and postarthrographic CT examination have made this modality very effective when evaluating a painful wrist.

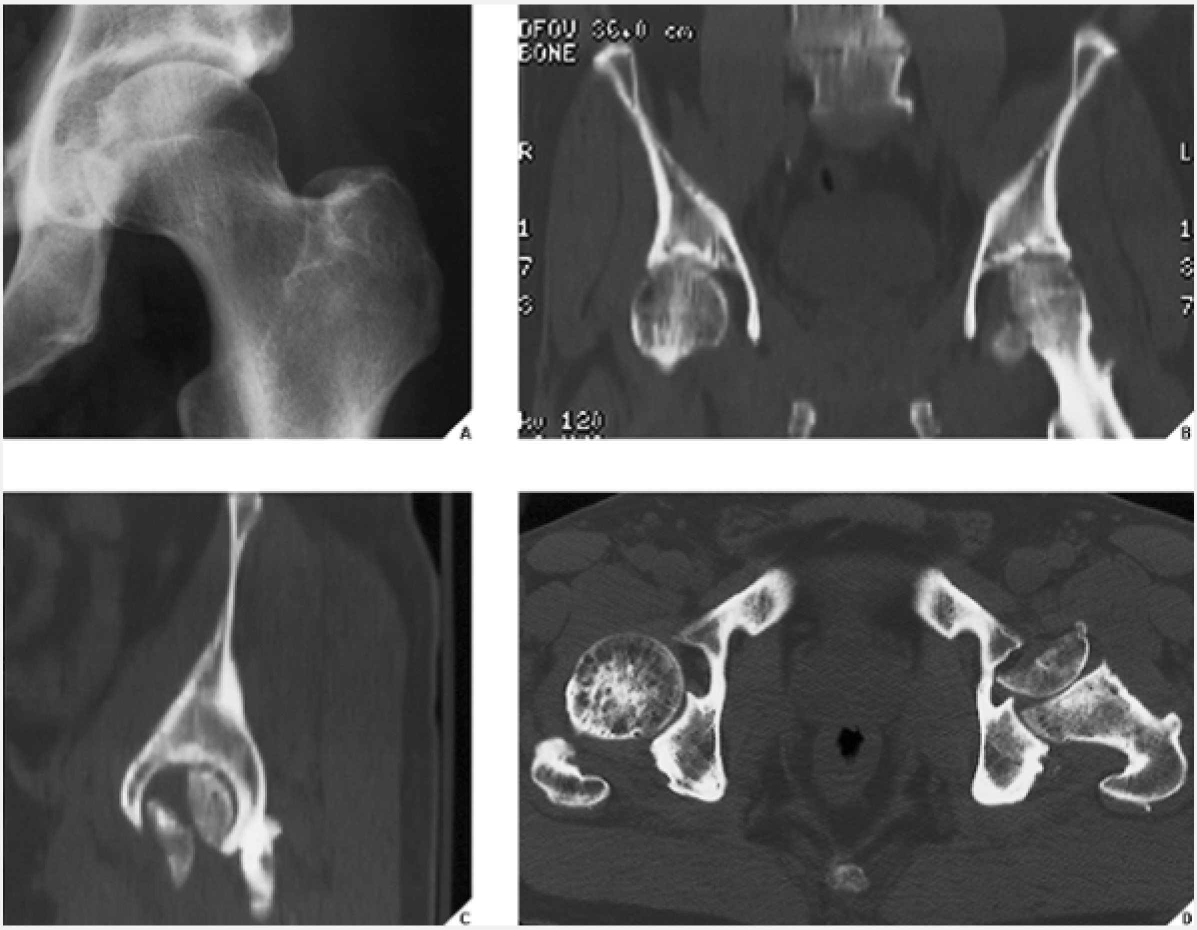

Figure 2.5 CT multiplanar imaging. A 62-year-old man sustained a posterior dislocation of the left femoral head. After reduction of dislocation, the anteroposterior radiograph of the left hip showed increased medial joint space and distortion of the medial aspect of the femoral head **(A)**. To evaluate the hip joint further, CT was performed. Coronal **(B)** and sagittal **(C)** reformatted images showed unsuspected fracture of the femoral head, and axial image **(D)** demonstrated a 180-degree rotation of the fractured fragment.

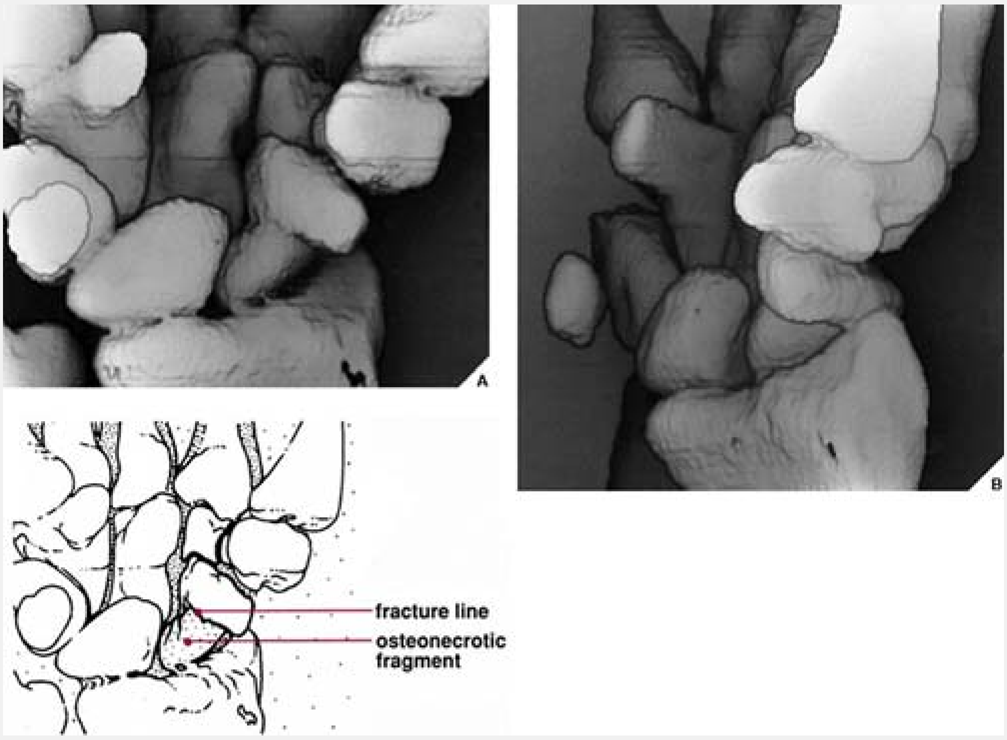

Figure 2.6 CT three-dimensional imaging. Anteroposterior **(A)** and oblique **(B)** three-dimensional CT reformation of the wrist demonstrates a fracture through the waist of the scaphoid bone, complicated by osteonecrosis of the proximal fragment.

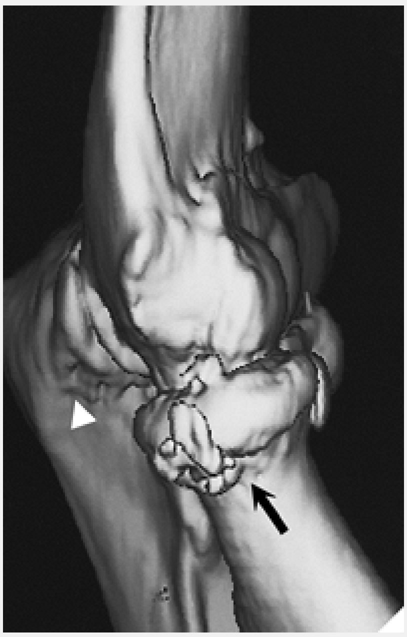

Figure 2.7 CT three-dimensional imaging. Three-dimensional CT reformation of the elbow shows a fracture of the neck of the radius (*arrow*) and fracture of the olecranon process (*arrowhead*).

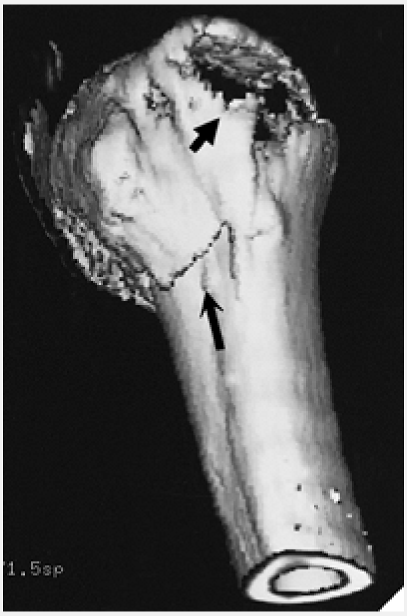

Figure 2.8 CT three-dimensional imaging. Fracture of the surgical neck of the humerus (*arrow*) and a displaced fracture of the greater tubercle (*short arrow*) are well demonstrated.

Figure 2.9 CT three-dimensional imaging. Three-dimensional CT reformation of the thoracic spine shows sagittal cleft with an anterior defect of T11, a typical appearance of congenital butterfly vertebra.

Although arthrography of the knee has been almost completely replaced by MRI, it still may be used to demonstrate injuries to the soft-tissue structures, such as the joint capsule, menisci, and various ligaments (see Fig. 9.61). It also provides important information on the status of the articular cartilage, particularly when subtle chondral or osteochondral fracture is suspected, or when the presence or absence of osteochondral bodies (i.e., in osteochondritis dissecans) must be confirmed (see Figs. 9.46D, 9.50C).

In the examination of any of the joints, arthrography can be combined with tomography (so-called arthrotomography), with CT (CT–arthrography) (Fig. 2.13), or with digitization of image (digital subtraction arthrography) (see Fig. 2.2), thus providing additional information.

There are relatively few absolute contraindications to arthrography. Even hypersensitivity to iodine is a relative contraindication because, in this case, a single contrast study using only air can be performed.

Tenography and Bursography

Occasionally, to evaluate the integrity of a tendon, contrast material is injected into the tendon sheath. This procedure is known as a tenogram (see Figs. 10.13 and 10.71). Since introduction of newer diagnostic modalities, such as CT and MRI, this procedure is seldom performed. It has relatively limited clinical application, mainly being used to evaluate traumatic or inflammatory conditions of the tendons (such as peroneus longus and brevis, tibialis anterior and posterior, and flexor digitorum longus) of the lower extremity and in the upper extremity to outline the synovial sheaths within the carpal tunnel.

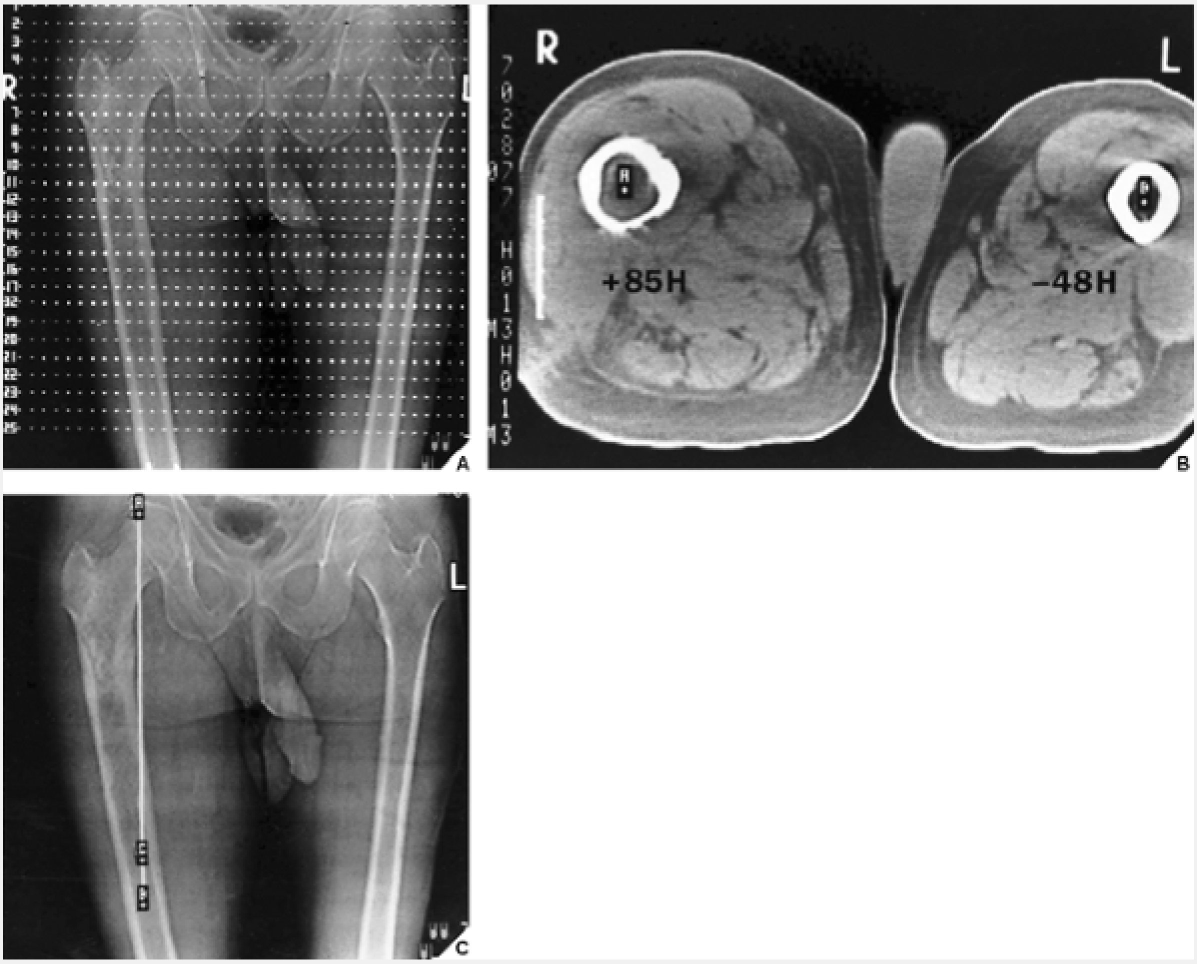

Figure 2.10 CT measurement of Hounsfield values. CT evaluation of intraosseous extension of chondrosarcoma is an important part of the radiologic workup of a patient if limb salvage is contemplated. **(A)** Several contiguous axial sections, preferably 1 cm in thickness, of affected and nonaffected limbs are obtained. **(B)** Hounsfield values of the bone marrow are measured to determine the distal extent of tumor in the

medullary cavity. A value of +85 indicates the presence of tumor; a value of -48 is normal for fatty marrow. **(C)** The linear measurement is obtained from the proximal articular end of the bone *A* to the point located 5 cm distally to the tumor margin *B*. Point *C* corresponds to the most distal axial section that still shows tumor in the marrow. (From Greenspan A, 1989, with permission.)

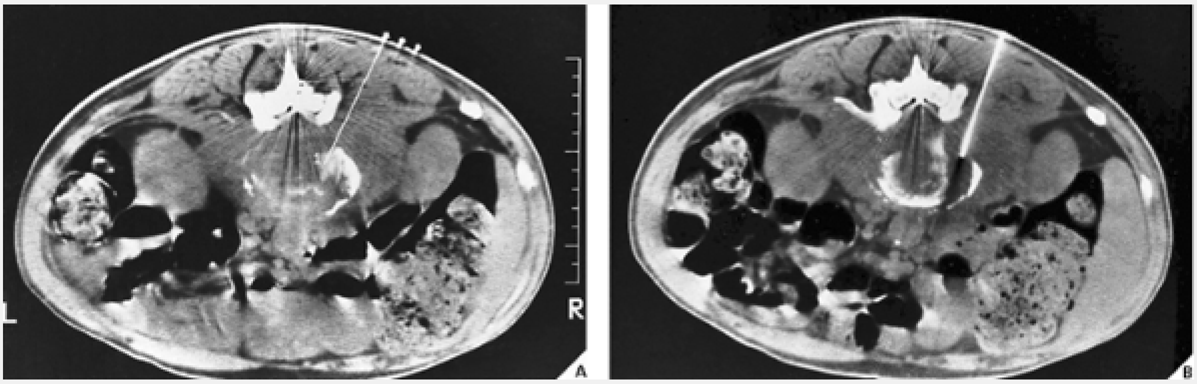

Figure 2.11 CT-guided aspiration biopsy. Aspiration biopsy of an infected intervertebral disk is performed under CT guidance. **(A)** Measurement is obtained from the skin surface to the area of interest (intervertebral disk). **(B)** The needle is advanced under CT guidance and placed at the site of the partially destroyed disk.

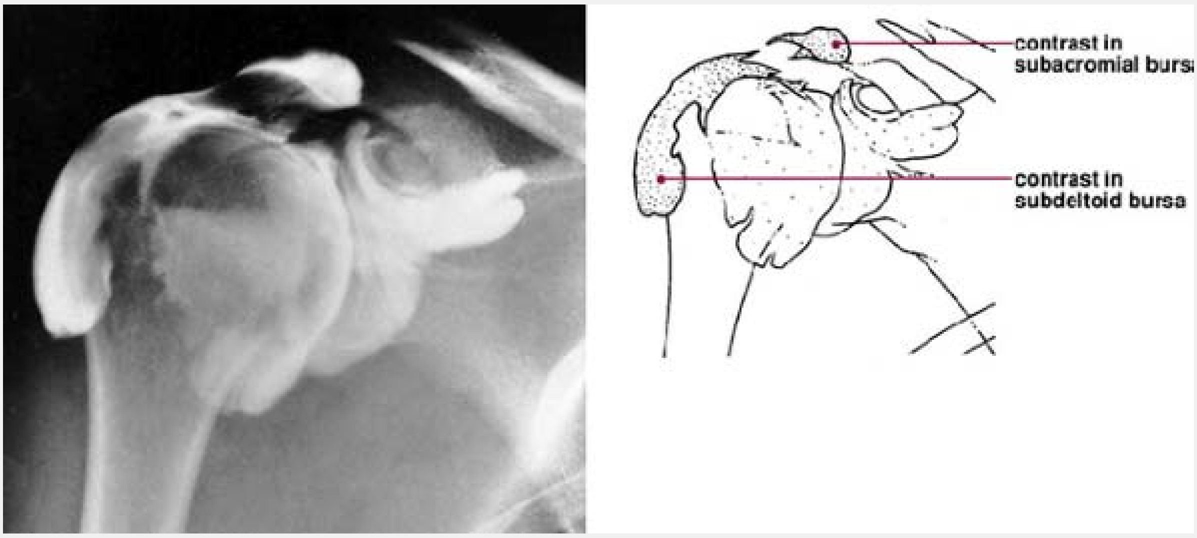

Figure 2.12 Shoulder arthrogram. After injection of contrast into the glenohumeral joint there is filling of subacromial–subdeltoid bursae complex, indicating rotator cuff tear.

Bursography involves the injection of contrast agent into various bursae. This procedure in general has been abandoned, and only occasionally is the subacromial–subdeltoid bursae complex directly injected with contrast agent to demonstrate partial tears of the rotator cuff.

Angiography

The use of contrast material injected directly into selective branches of the arterial and venous circulation has aided greatly in assessing the involvement of the circulatory system in various conditions and has provided a precise method for defining local pathology. With arteriography, a contrast agent is injected into the arteries and films are made, usually in rapid sequence. With venography, contrast material is injected into the veins. Both procedures are frequently used in evaluation of trauma, particularly if concomitant injury to the vascular system is suspected (see Figs. 2.3 and 4.13).

In evaluation of tumors, arteriography is used mainly to map out bone lesions, demonstrate the vascularity of the lesion, and assess the extent of disease. It is also used to demonstrate the vascular supply of a tumor and to locate vessels suitable for preoperative intraarterial chemotherapy. It is very useful in demonstrating the area suitable for open biopsy, because the most vascular parts of a tumor contain the most aggressive component of the lesion. Occasionally, arteriography can be used to demonstrate abnormal tumor vessels, corroborating findings with radiography and tomography (see Fig. 16.11B). Arteriography is often extremely helpful in planning for limb-salvage procedures, because it demonstrates the regional vascular anatomy and thus permits a plan to be made for the tumor resection. It is also sometimes used to outline the major vessels before resection of a benign lesion (see Fig. 16.12). It can also be combined with an interventional procedure, such as embolization of hypervascular tumors, before further treatment (see Fig. 16.13).

Myelography

During this procedure, water-soluble contrast agents are injected into the subarachnoid space, mixing freely with the cerebrospinal fluid to produce a column of opacified fluid with a higher specific gravity than the nonopacified fluid. Tilting the patient will allow the opacified fluid to run up or down the thecal sac under the influence of gravity (see Figs. 11.16 and 11.48). The puncture usually is performed in the lumbar area at the L2-3 or L3-4 levels. For examination of the cervical segment, a C1-2 puncture is performed (see Fig. 11.16A). Myelographic examination has been almost completely replaced by high-resolution CT and high-quality MRI.

Diskography

Diskography is an injection of contrast material into the nucleus pulposus. Although this is a controversial procedure that has been abandoned by many investigators, under tightly restricted indications and immaculate technique a diskogram can yield valuable information. Diskography is a valuable aid to determine the source of a patient's low back pain. It is not purely an imaging technique, because the symptoms produced during the test (pain during the injection or pain provocation) are considered to have even greater diagnostic value than the obtained radiographs. It should always be combined with CT examination (so-called CT–diskogram) (see Figs. 11.49 and 11.50). According to the official position statement on diskography by the Executive Committee of the North American Spine Society in 1988, this procedure “is indicated in the evaluation of patients with unremitting spinal pain, with or without extremity pain, of greater than four months duration, when the pain has been unresponsive to all appropriate methods of conservative therapy.” According to the same statement, before a diskogram is performed, the patient should have undergone investigation with other modalities (such as CT, MRI, and myelography) and the surgical correction of the patient's problem should be anticipated.

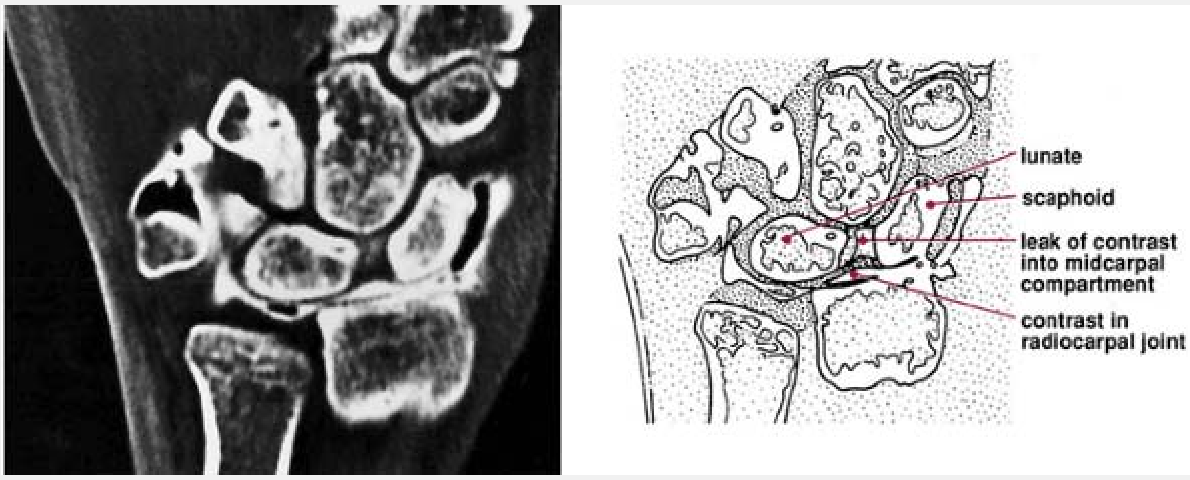

Figure 2.13 CT–arthrography. Coronal CT arthrogram of the wrist demonstrates a subtle leak of contrast from the radiocarpal joint through a tear in the scapholunate ligament, a finding not detected on routine arthrographic examination of the wrist.

Ultrasound

Over the past several years, ultrasound has made an enormous impact in the field of radiology and became a useful tool in skeletal imaging. It has several inherent advantages. It is relatively inexpensive, allows comparisons with the opposite normal side, uses no ionizing radiation, and can be performed at bedside or in the operating room. It is a noninvasive modality, relying on the interaction of propagated sound waves with tissue interfaces in the body. Whenever the directed pulsing of sound waves encounters an interface between tissues of different acoustic impedance, reflection or refraction occurs. The sound waves reflected back to the ultrasound transducer are recorded and converted into images.

Various types of ultrasound scanning are available. Most modern ultrasound equipment displays dynamic information in “real time,” similar to information that is provided by fluoroscopy. With real-time sonography, the images may be obtained in any scan plane by simply moving the transducer. Thus, imaging may include transverse or longitudinal images and any obliquity can also be produced. Modern probe technology has extended usefulness of ultrasound in orthopedic radiology (Fig. 2.14). Higher-frequency transducers of 7.5 and 10 MHz have excellent spatial resolution and are ideal for imaging the appendicular skeleton.

Applications of ultrasound in orthopedics include evaluation of the rotator cuff, injuries to various tendons (for instance, the Achilles tendon), and, occasionally, soft-tissue tumors (such as hemangioma).

The most effective application, however, is in evaluation of the infant hip, for which ultrasound has become the imaging modality of choice. Contributing factors are the cartilaginous composition of the hip, ultrasound's real-time capability for studying motion and stress, absence of ionizing radiation, and relative cost effectiveness. The newest development in this area is the introduction of three-dimensional ultrasound for evaluation of developmental dysplasia of the hip. Three-dimensional sonography provides functional utility in the evaluation of the joint in the added sagittal plane (section image) and craniocaudal projection (revolving spatial image). This technique permits excellent demonstration of the femoral head–acetabulum relationship and femoral head containment (see Figs. 32.16, 32.17). The important advantage of this technique is not only acquisition of images in real time but also subsequent reconstruction and viewing at a workstation, allowing further manipulation of the volume image. This permits extraction of usable measurements and enhancement of the anatomic information obtained from the images.

Ultrasound has recently been applied to certain areas in rheumatic disorders, particularly to detect intraarticular and periarticular fluid collection, and to the differentiation of popliteal fossa masses (e.g., aneurysm versus Baker cyst versus hypertrophied synovium).

More recent ultrasound techniques such as Doppler ultrasound or color-flow imaging, which expresses motion from moving red blood cells in color, have found limited applications in orthopedic radiology. This modality is used mainly to detect arterial narrowing and venous thrombosis. However, there have been a limited number of reports regarding the use of this technology in detecting tumor vascularity within soft-tissue masses.