RADIOGRAPHY OF THE DOG AND CAT: Guide to Making and Interpreting Radiographs

M.C. Muhlbauer & S.K. Kneller
Radiography of the Dog and Cat

Guide to Making and Interpreting Radiographs
To my father, Dr. Karl C. Muhlbauer, whose uncommon good sense and enduring example continue to inspire me personally and professionally. He was a lifelong teacher, author of several educational textbooks, and a man to whom obstacles were only momentary distractions. We had many great adventures together, and I felt his presence quite often during the creation of this book.

Mike Muhlbauer

To Dr. Robert E. Lewis, who introduced me to this wonderful diagnostic tool we call radiology. Not only did he open the door to the most interesting playground in veterinary medicine, but as a mentor through veterinary school as well as my initial radiology training, he imparted a simple, straightforward method and thinking processes that have had a profound influence on my professional life, teaching philosophy, and general outlook. I owe any meaningful concepts that I have to his guidance.

Steve Kneller
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This book is accompanied by a companion website:
www.wiley.com/go/muhlbauerradiography

The website includes:

• Review questions
• A positioning guide
• Powerpoints of all figures from the book for downloading
• A PDF of the Glossary from the book for downloading
The authors gratefully acknowledge the pioneering work by Drs. Jerry Owens and Darryl Biery in their wonderful book *Radiographic Interpretation for the Small Animal Clinician*. Their use of conceptual illustrations and concise descriptions provided the reader with a practical reference and valuable understanding of radiographic findings in various diseases and disorders. It is upon the foundation laid by such an important work that we are able to build and advance practical understanding in veterinary radiology. Many thanks to Drs. Jerry and Darryl for their inspirational vision.
Introduction

The purpose of radiography is to lessen uncertainty.

When you perform a radiographic examination, you usually have a question that needs to be answered. There was a reason you made the radiographs. To help you and other veterinary personnel, from student to specialist, get the answers to those questions, we have created this guide that we hope will be a valuable reference for you.

The volume of material appropriate for a guide to radiography is extensive and must be organized in a useful and practical format. In some learning or clinical situations, all that is needed is a simple checklist to avoid overlooking radiographic findings. At other times, more in-depth information is required about a particular disease, disorder, or radiographic finding. We determined that presenting the material in a linear fashion would bore some folks and overwhelm others. Therefore, we decided on the following layout:

I. We begin with “Interpretation of Radiographs.” In this section, the reader is encouraged to list all of the abnormalities in size, shape, opacity, margination, position, number, and function as seen on radiographs, without regard to specific etiology.

Many clinicians tend to see what they want on a radiograph, whether it is there or not.

It is well known that preconceived expectations are notorious for inventing or overlooking radiographic abnormalities. Valuable information often is available, if one is willing to deliberately and systematically review the images. This first chapter is divided into musculoskeletal, thoracic, and abdominal sections, each with checklists for evaluating radiographs and descriptions of radiographic findings.

History is not necessary to read radiographs, but it is necessary to interpret radiographs.

Once the radiographic findings have been recognized, the radiographs are reviewed a second time in light of pertinent clinical and laboratory findings and a prioritized list of differential diagnoses is created. In this chapter are listed the most common diseases expected to cause the observed abnormalities. Detailed lists of differential diagnoses are provided in chapters 4 through 6.

Half the magic of a radiologist is having quality radiographs on which we can see things.

II. The second chapter is “Making Quality Radiographs.” (A radiography guide is of little value if you are not working with high-quality images.) In this section, you will find illustrations and detailed descriptions of proper patient positioning in veterinary radiography. There is also a review of basic information regarding the production and use of medical x-rays and the various types of imaging receptors (detectors) currently available. Both analog (film) and digital systems are addressed, and helpful tips are provided regarding use and care of radiography equipment. At the end of that chapter is a detailed outline which addresses complete radiographic interpretation.

III. The third chapter thoroughly describes contrast radiography, including types of contrast agents and more than 25 contrast procedures with indications, contraindications, complications, techniques, dosages, pitfalls, and radiographic findings.

You must know normal to recognize abnormal.

IV–VI. The next three chapters, “Musculoskeletal,” “Thorax,” and “Abdomen,” provide more information and greater detail regarding each major part of the body. Each chapter begins with a section titled “Normal Radiographic Anatomy,” describing basic, unique, and sometimes confusing radiographic appearances of numerous structures.

Many different diseases present with similar radiographic findings.

The next section in each of these three chapters is titled “Diseases and Disorders,” presenting clinical correlations, radiographic findings, and differential diagnoses for many conditions. The final section in each chapter provides exhaustive lists of differential diagnoses for many radiographic findings and diseases.
Introduction

VII. Finally, there is an extensive glossary with a great many definitions and explanations covering a variety of radiographic concepts and terms, including those that are older and not used in this guide.

What is different about this book?

Readers may recognize familiar figures in this guide, many from Radiographic Interpretation for the Small Animal Practitioner by Drs. Jerry Owens and Darryl Biery (the “Purina book,” 1999). The figures in this text are designed to teach concepts and methods of interpretation rather than represent standard radiographs that the reader is expected to memorize. Remember, diseases don’t always present with the classic appearance depicted on many textbook radiographs.

Also, in this guide you will find language that differs from some of the classic radiography terms. We hope this to be a fresh approach using simple correlation with physics, physiology, and pathology. Advances in diagnostic imaging reveal the inaccuracies in some commonly used terms—terms that were pertinent when radiologists were beginning to understand the radiographic appearances of disease, but that are currently inadequate.

It is important to patient care to accurately describe what you see on radiographs.

Radiopacity is relative. ALL materials block x-rays to some degree, even air. To state that a material is radiopaque or radiolucent provides little useful information. For example, cystic calculi that are not visible on survey radiographs are commonly called radiolucent. However, when these same calculi are seen on a pneumocystogram, they are considered radiopaque. Opacity of a material is always relative to the adjacent material. Since this guide is dedicated to radiography and radio- is a given, we will use the term opacity to describe the characteristic of a material to block x-rays. Remember, it’s all about relative opacity and opacity interfaces.

Detail on radiographs, as in photography, has nothing to do with the subject and everything to do with how the image was created (e.g., exposure technique, type of film or detector, method of processing). It is important to determine whether indistinct margins on a radiograph are due to poor detail or a clinical condition. When you describe ill-defined peritoneal serosa as “poor abdominal detail,” you are stating that the radiograph is a poor-quality image. Pathology may or may not be present on a poor-quality image. In the abdomen it’s all about opacity interfaces (between soft tissue, fat, and gas) and it is important to state accurately what you are seeing. When you think about radiography in these correct terms, you will find it easier to understand what you are seeing and why you are seeing it.

Periosteal response is an attempt to heal bone, not a reaction to disease. Understanding the physiology behind a periosteal response aids in understanding the disease process. For example, periosteal new bone never grows outward from the cortex; it is formed perpendicular to the periosseum to fill the space created by separation of the periosseum from the cortex. Recognizing a periosteal response and determining whether the lesion is active or inactive, aggressive or nonaggressive is vital to providing the best patient care. Supportive diagnostic tests are required in most situations to establish the etiology, but accurate reading of radiographs often dictates the need for further diagnostics.

Sunburst pattern, ground-glass appearance, and similar terms rarely are useful by themselves in modern radiography. Classically, a sunburst periosteal response was used to describe a bone tumor. However, we now know that other diseases, such as osteomyelitis, can create a similar radiographic appearance. Ground-glass appearance has been used to describe indistinct or obscured margins, a confusing term at best. Looking for a specific type of lesion or radiographic appearance often interferes with describing what is actually there.

Prominent is not a roentgen sign. If a structure is “prominent” on a radiograph, there is a reason. It may be enlarged or there may be a change in opacity interfaces. For example, pulmonary vessels will appear more “prominent” when enlarged or mineralized or if the lung is well inflated. Abdominal organs will become more “prominent” when there is free gas in the abdominal cavity. It is important to describe what you are seeing to provide the best patient care.

Alveolar lung disease is a misnomer. Alveoli are air spaces. The lining of the alveoli is considered part of the interstitium on radiographs. Essentially, lung disease is either interstitial, vascular, or bronchial. Diseases that produce mostly a cellular response and little fluid result in interstitial thickening. Diseases that produce more fluid (edema, pus, hemorrhage) often result in filling of air spaces. Lung patterns can be summarized as interstitial thickening, altered vascular size, bronchial thickening, and alveolar filling. Recognizing the predominant lung pattern and making follow-up radiographs to monitor progress and response of disease aids in providing the best patient care.

More of these discussions are presented throughout the text. We are not just trying to be different or “buck the system.” We have found during our years of teaching veterinary students, interns, residents, and practitioners that some of the classic terminology frequently causes confusion and laborious memorization. We believe a simpler, more straightforward approach will help you make more accurate radiographic diagnoses with less consternation. Enjoy!!!

M.C. Muhlbauer
S.K. Kneller
Radiography of the Dog and Cat

Guide to Making and Interpreting Radiographs
# Interpretation of Radiographs

## Musculoskeleton
- Evaluation of bone
- Margination
- Opacity
- Geometry
- Lesion distribution
- Evaluation of joints
- Alignment of bones
- Joint space width
- Evaluation of soft tissue
- Evaluation of axial skeleton
  - Spine
  - Head and neck

## Thorax
- Effects related to age, body condition, and conformation
- Thoracic wall
- Diaphragm
- Pleura and pleural space
- Pleural effusion
- Pneumothorax
- Hydropneumothorax
- Pleural masses and nodules
- Mediastinum
- Cardiac silhouette (heart)
- Trachea
- Lungs
  - Patterns of lung disease

## Abdomen
- Effects of age, body condition, and conformation
- Extra-abdominal structures
- Peritoneal and retroperitoneal spaces
  - Peritoneal fluid and gas
  - Retroperitoneal disease
  - Lymph nodes
- Liver
- Gall bladder/biliary system
- Spleen
- Pancreas
- Gastrointestinal tract
  - Stomach
  - Small intestine
  - Large intestine
- Urinary tract
  - Kidneys and ureters
  - Urinary bladder
  - Urethra
- Adrenal glands
- Male genital system (prostate gland)
- Female genital system
1. More detailed information is available in the Musculoskeleton, Thorax, and Abdomen chapters (chapters 4 through 6).
   a. Normal radiographic anatomy is described in chapters 4 through 6.
   b. Possible etiologies for radiographic findings described below are listed in the Differential Diagnoses section in chapters 4 through 6.
   c. Clinical correlations and radiographic findings are more thoroughly discussed in the Diseases and Disorders section in chapters 4 through 6.
2. A glossary is available for definitions and quick information.

Musculoskeleton

“Bone is deposited and removed according to the stresses placed on the frame” (Wolff’s Law).

Evaluation of bone
1. Different bone diseases commonly present with similar radiographic findings.
2. Diagnosis usually requires information in addition to radiographs (e.g., complete blood count, cytology, histopathology).
3. Current disease may be obscured by preexisting conditions (i.e., degenerative joint disease).

Margination
The less distinct the bone margin, the more active and aggressive the disease process.

Sharpness of bone margin is not the same as shape of bone border. An irregular border does not equal an ill-defined margin and a smooth border does not equal a well-defined margin. Assess how easily the bone margin can be traced with a pencil to determine its sharpness.

Opacity

At least 30%–50% of bone must be altered before a change is visible on radiographs.
Active bone destruction may be visible in 5 to 7 days on radiographs.
Active bone production may be visible in 10 to 14 days, possibly sooner in rapidly growing, immature animals.

1. Decreased bone opacity (bone loss):
   a. Osteopenia (radiologic term for “too little bone”).
      1) Bone to soft tissue contrast is poor.
      2) Cortices become thin and faint.
      3) Corticomedullary contrast is poor.
      4) Trabeculae in cancellous bone appear larger and more porous (“coarse trabecular pattern”) due to loss of fine boney structures.
      5) A “double cortical line” may be visible due to intracortical resorption of bone.
      6) May be general (i.e., systemic disease) or regional (i.e., disuse atrophy of a limb).
      7) General osteopenia (e.g., hyperparathyroidism, nutritional deficiency) typically affects vertebrae first, followed by mandible and then long bones.
      8) Regional osteopenia (e.g., limb immobilization) tends to be more severe in distal portion of limb.
   b. Osteolysis
      1) Pattern of osteolysis reflects aggressiveness of disease process.
         a) Geographic pattern (least aggressive).
         b) Moth-eaten pattern (more aggressive).
         c) Permeative pattern (most aggressive).
      2) Osteolytic pattern is assessed by several criteria (Table 1.1):
         a) Size, number, and location of lesions.
         b) Margination (less distinct margin = more aggressive disease process).
         c) Zone of transition between normal and diseased bone (longer and less distinct zone = more aggressive disease).
         d) Rate of change on subsequent radiographs (greater change = more aggressive).

Box 1.1 Checklist for interpreting orthopedic radiographs.

- At least two orthogonal radiographs
- Radiographs are those of the animal being evaluated
- Technique:
  - Exposure
  - Positioning
- Animal’s age, body condition, and conformation
- Bones:
  - Margination
  - Opacity
  - Geometry
  - Lesion distribution
- Joints:
  - Alignment
  - Width of joint space
  - Periarticular findings
  - Lesion distribution
- Soft tissues:
  - Thickness
  - Opacity
- Reassess based on clinical, physical, and laboratory findings
- Prioritize list of differential diagnoses
- Make follow-up radiographs (assess rate of change)
CHAPTER 1 Interpretation of Radiographs

3) Mixed patterns of osteolysis are common, especially with aggressive diseases. As long as disease is active and unchecked, bone destruction will continue and bone margins will remain ill-defined.

a) Aggressive diseases typically begin as a permeative pattern of osteolysis and progress to moth-eaten and a central geographic pattern (Figure 1.1).

4) Some diseases may not present with visible osteolysis on initial radiographs (e.g., rib tumors). Serial radiographs aid in characterization of disease process.

2. Increased bone opacity (bone production):

a. Osteosclerosis (hardening or increased density of bone).

1) May be localized (e.g., degenerative joint disease) or diffuse (e.g., osteopetrosis).

2) Localized osteosclerosis typically appears as a thin rim of increased opacity adjacent to a lesion (as body attempts to wall-off disease) or subchondral near a joint surface.

3) Osteopetrosis results in thickened long bone cortices and a narrowed medullary space.

b. Periosteal response:

1) Whenever periosteum is separated from cortex (and maintains blood supply) it will produce mineral in an attempt to fill the subperiosteal space. Mineral is produced perpendicular to periosteum (Stages of periosteal response are described in the Diseases and Disorders section of chapter 4).

2) Margin of periosteal response reflects activity of disease process (less distinct margin = more active disease process).

3) In addition to margination, periosteal new bone is assessed for:

a) Size and shape.

b) Maturity (more organized bone = more chronic disease process).

c) Rate of change on serial radiographs.

4) If periostium is only mildly elevated, as may occur with a benign process (e.g., bone bruise, stable healing fracture) or in early stages of disease, mineral deposits quickly fill the subperiosteal space.

a) New bone appears smooth-bordered and even in shape (Figure 1.2).

b) Disease process may be active (ill-defined margins) or inactive (well-defined margins; Figure 1.3).

5) With a more aggressive disease process (e.g., neoplasia, severe osteomyelitis), periostium is continuously pushed away from cortex and there is insufficient

Periosteal response is an attempt to heal bone, not a reaction to disease.

### Table 1.1 Patterns of osteolysis

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Geographic</th>
<th>Moth-eaten</th>
<th>Permeative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiographic</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
</tr>
<tr>
<td>appearance</td>
<td><img src="image4" alt="Image" /></td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Size, number of lesions</th>
<th>Large, solitary (over 10 mm)</th>
<th>Small, multiple (3–10 mm)</th>
<th>Tiny, numerous (1–2 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Margination</td>
<td>Well-defined</td>
<td>Poorly-defined</td>
<td>Ill-defined</td>
</tr>
<tr>
<td>Zone of transition</td>
<td>Short, well-defined</td>
<td>Long, poorly-defined</td>
<td>Diffuse, nondefined</td>
</tr>
<tr>
<td>Cortical remodeling</td>
<td>Normal or thinned</td>
<td>Irregular thinning,</td>
<td>Thin, indistinct,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>sometimes disrupted</td>
<td>often disrupted</td>
</tr>
<tr>
<td>Osteosclerosis</td>
<td>May surround lesion</td>
<td>Absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Type of lesion</td>
<td>Benign, nonaggressive</td>
<td>Aggressive</td>
<td>Very aggressive</td>
</tr>
<tr>
<td>Examples</td>
<td>Bone cyst, pressure remodeling</td>
<td>Tumor, osteomyelitis</td>
<td>Malignant tumor, severe osteomyelitis</td>
</tr>
</tbody>
</table>

Figure 1.1 Mixed pattern of osteolysis. An aggressive disease process causing peripheral permeative osteolysis with an inner moth-eaten pattern and central geographic pattern (latter due to coalescence of moth-eaten osteolysis).
time for mineral deposits to fill the subperiosteal space; margins remain irregular, ill-defined, and often are disrupted (Figure 1.4).

6) As long as disease is active, mineral deposits remain ill-defined, forming perpendicular to periosteum.

   a) When disease becomes less active and healing can proceed, mineral deposits become more opaque, better defined and begin to blend with cortex (Table 1.2).

   b) Over next few weeks (if disease remains inactive) mineral deposits continue to mature into organized, woven bone with a trabecular pattern and a well-defined margin.

   c) Normal stresses can then act to gradually remodel new bone to eventually resemble parent bone.

Geometry
1. Alterations in shape, length, angulation, and diameter may result from numerous etiologies (see Differential Diagnoses and Diseases and Disorders in chapter 4).

2. Normal anatomic variations must be differentiated from pathology. Knowledge of normal anatomy, comparison radiographs of contralateral limb (or a known normal limb), and references (books, anatomic models, box of bones) aid in diagnosis.

Lesion distribution
1. Monostotic (all in same bone) or polyostotic (multiple bones affected).

2. Unilateral or bilateral.

3. Symmetrical or asymmetrical.

4. Epiphyseal, physeal, metaphyseal, diaphyseal.

5. Sites and extent of lesions provide clues to underlying etiology (see Differential Diagnoses in chapter 4).

Evaluation of joints
Alignment of bones
1. Subluxation is partial loss of contact between articular surfaces (i.e., partial dislocation).

2. Luxation is complete loss of contact between articular surfaces (i.e., dislocation).

Joint space width
1. On radiographs, joint space width typically represents thickness of articular cartilage as opposed to volume of joint fluid.

2. Widened joint space in non-weight-bearing images may result from joint effusion, intra-articular mass, or loss of subchondral bone.

3. Narrowed joint space most commonly results from loss of articular cartilage.

4. Joint space width is most accurately assessed with animal weight-bearing and x-ray beam directed perpendicular to joint.

   a. Distribution of lesions:

      1) Single joint (monarticular).

      2) Multiple joints (oligoarticular = 2 to 5 joints, poly-articular = 6 or more joints).

      3) Unilateral or bilateral.

      4) Pelvic limbs only.

      5) Tarsi and/or carpi only.

      6) One limb only.

      7) Symmetry (bilateral lesions may be symmetrical or asymmetrical).

b. Periarticular findings:
1) Osteophytes and enthesophytes are common with chronic disease (Figure 1.5):
   a) Appear as well-defined, sharply marginated, bony projections (“bone spurs”).
   b) Osteophytes form at peripheral margins of articular cartilage, in non-weight-bearing areas.
   c) Enthesophytes occur at damaged attachment sites of tendons, ligaments, joint capsules, or fascia, forming in direction of natural pull.
   d) Osteophytes and enthesophytes are slow to change, but will grow over time.
   e) Conditions that may be mistaken for a bone spur:
      1) Normal prominence of bone (especially in chondrodystrophic breeds, usually bilateral).
      2) Normal bony protrusion at attachment site of tendon or ligament.

### Table 1.2 Activity and aggressiveness of bone disease

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Active and Aggressive</th>
<th>Active and Nonaggressive</th>
<th>Active and Chronic</th>
<th>Inactive and Nonaggressive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radiographic Appearance</strong></td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>Margination</td>
<td>Ill-defined</td>
<td>Ill-defined</td>
<td>Ill-defined</td>
<td>Well-defined</td>
</tr>
<tr>
<td>Size and shape of new bone*</td>
<td>Large; irregular</td>
<td>Medium; smooth or irregular</td>
<td>Organized (maturing)</td>
<td>Small; smooth</td>
</tr>
<tr>
<td>Osteolysis</td>
<td>Often severe; ill-defined</td>
<td>Well-defined or absent</td>
<td>Well-defined or absent</td>
<td>Usually absent</td>
</tr>
<tr>
<td>Appearance of cortex</td>
<td>Destructive remodeling</td>
<td>Displaced, thinned, or normal</td>
<td>Normal, displaced, or thinned</td>
<td>Normal</td>
</tr>
<tr>
<td>Soft tissue swelling</td>
<td>Moderate to Severe</td>
<td>Mild</td>
<td>Mild or absent</td>
<td>Absent</td>
</tr>
<tr>
<td>Rate of change</td>
<td>Rapid</td>
<td>Slow</td>
<td>Minimal</td>
<td>None</td>
</tr>
<tr>
<td>Zone of transition</td>
<td>Long and poorly demarcated</td>
<td>Indistinct but visible</td>
<td>Well-defined</td>
<td>Well-defined</td>
</tr>
<tr>
<td>Osteosclerosis</td>
<td>Absent</td>
<td>Ill-defined</td>
<td>Well-defined</td>
<td>Well-defined</td>
</tr>
<tr>
<td>Examples</td>
<td>Malignant neoplasia, severe osteomyelitis</td>
<td>Healing fracture, low grade osteomyelitis</td>
<td>Healing fracture, low grade osteomyelitis</td>
<td>Healed fracture</td>
</tr>
</tbody>
</table>

* NOTE: All lesions start small, but active and aggressive lesions tend to grow quickly, while active and chronic lesions tend to enlarge slowly over a long period of time.

Figure 1.5 Osteophytes and enthesophytes. A. Normal joint. B. Degenerative joint disease with osteophytes (O) forming at periphery of articular cartilage and enthesophytes (E) forming at attachments of joint capsule.
c. Alterations to subchondral bone (e.g., osteosclerosis, osteolysis/erosions, cystic lesions; Figure 1.6).

**Evaluation of soft tissue**

1. Alterations in soft tissues are useful to characterize bone lesions and differentiate normal anatomy from pathology (see Differential Diagnoses in chapter 4).
2. Soft tissue abnormalities usually accompany and often precede bone disease.
3. Musculoskeletal disorders (e.g., pain, lameness) may be limited to soft tissues (e.g., sprain, strain, bruise, inflammation).
4. Comparison radiographs of contralateral limb often aid in recognition of soft tissue anomalies.
5. Increased thickness (swelling):
   a. Swelling accompanies most active bone diseases (due to inflammation, hemorrhage, edema, tumor, etc.) and displaces and obscures fascial planes.

b. Absence of swelling near a suspect bone lesion suggests normal anatomic variation or inactive disease.

c. Localized, well-defined, soft tissue swelling may represent a mass.

   1) Most soft tissue masses cannot be differentiated on survey radiographs.
   2) Fatty masses (e.g., lipoma, liposarcoma) are an exception because they are less opaque than soft tissue.

6. Decreased thickness (deficit):
   a. Disuse atrophy (e.g., pain, immobilization, paralysis) is common with many bone diseases.
   b. Absence of tissue occurs with severe trauma or surgery.

7. Abnormal opacity:
   a. Mineralization may result from chronic inflammation, trauma, tumor, metabolic disease, or presence of foreign material.

---

**Box 1.2 Radiographic signs of joint disease.**

- Malalignment of bones (may be mimicked by poor positioning)
- Joint capsule distension (e.g., joint effusion, synovial thickening)
- Altered width of joint space (widened or narrowed)
- Osteophytes (form at edges of articular margins)
- Enthesophytes (form at attachment sites)
- Subchondral osteosclerosis or osteolysis
- Soft tissue mineralization (periarticular or intra-articular)
- Intra-articular gas (vacuum phenomenon)

**Box 1.3 Neoplasia vs. osteomyelitis*: General tendencies regarding osseous remodeling.**

- Neoplasia tends to be more destructive (osteolytic) than osteomyelitis.
- Osteomyelitis tends to be more productive (larger periosteal response) than neoplasia.
- Neoplastic periosteal response tends to be more irregular and less defined than osteomyelitis.
- Cortical destruction tends to be more severe with neoplasia than with osteomyelitis.
- Codman’s triangle tends to be more common with neoplasia than with osteomyelitis.
- Neoplasia tends to remain local while osteomyelitis often spreads along length of bone.
- Sequestrum formation tends to occur with osteomyelitis but is rare with neoplasia.
- Serial radiographs (10-day intervals) tend to reveal relatively little change with osteomyelitis and more significant change with neoplasia.

* Cytology/histopathology is necessary for definitive diagnosis.
b. Gas (emphysema) may be present at site of a penetrating wound, injection, fistulous tract, or due to infection with gas-producing organism.

**Evaluation of axial skeleton**

**Spine**

**Technique**

1. Proper positioning is essential for accurate interpretation.
   a. Lateral radiograph:
      1) Transverse spinal processes are superimposed.
      2) Intervertebral foramina are superimposed.
      3) Rib heads are superimposed.
      4) Iliac wings are superimposed.
   b. Ventrodorsal (VD) radiograph:
      1) Dorsal spinous processes are centered on vertebral bodies.
      2) Equal distance from dorsal spinous processes to lateral body walls.
      3) Iliac wings are symmetrical.

**Evaluation of spine**

1. See Diseases and Disorders and Differential Diagnoses sections in chapter 4 (“Musculoskeletal”) for specific conditions.
2. Alignment of vertebrae:
   a. Poor positioning may mimic altered alignment.
   b. Scoliosis = lateral curvature (TIP: “Snake like”).
   c. Lordosis = ventral curvature (TIP: rhymes with “low,” “carrying a Load”).
   d. Kyphosis = dorsal curvature (TIP: rhymes with “high,” “mountain peak K2”).
   e. Fracture/subluxation/luxation.
3. Number of vertebrae:
   a. Altered number usually is without clinical significance.
   b. Important to consider when identifying anatomic landmarks used in surgical and advanced imaging procedures.
   c. Altered number of vertebrae may represent a true increase/decrease or an apparent change.
      1) True alterations are not uncommon in some animals (such as cats and Dachshunds with 6 or 8 lumbar vertebrae).
      2) Apparent alterations are common due to presence of congenital vertebral anomalies:
         a) Absence of ribs on T13 appears as 12 thoracic and 8 lumbar vertebrae.
         b) Riblike structures on L1 appears as 14 thoracic and 6 lumbar vertebrae.
   d. Four sacral vertebrae are sometimes present.
4. Shape, margination, and opacity of each vertebra.
   a. Normal variations in shape exist along each spinal region (see Normal Radiographic Anatomy in chapter 4).
   b. Alterations in shape of vertebrae may represent developmental anomalies (e.g., hemivertebrae, transitional vertebrae) or acquired disease (e.g., fracture, tumor).
   c. Altered opacity may be general (e.g., osteoporosis, osteopetrosis) or local (e.g., tumor, infection).
5. Dorsal spinal articulations:
   a. These are synovial joints that are subject to degenerative joint disease.
   b. Dorsal articular facets normally are smooth, well-defined, and similar between vertebrae.
   c. Width of intervertebral joint spaces should be similar between adjacent vertebrae.
6. Spinal canal:
   a. Normal widening occurs at cervical and lumbar intumescence.
   b. Abnormal widening may result from pressure remodeling (e.g., spinal cord tumor).
   c. Abnormal narrowing may represent stenosis (congenital or acquired).
   d. Ventral aspect of spinal canal normally is smooth and continuous (NOTE: vertebrae move slightly to allow bending of spine).
   e. Increased opacity may occur with herniated disc material.
7. Intervertebral disc spaces:
   a. Spaces normally appear similar in width to adjacent spaces (see Normal Radiographic Anatomy in chapter 4). (NOTE: disc spaces at periphery of x-ray beam commonly appear narrowed due to distortion.)
   b. Increased opacity most commonly is caused by mineralized intervertebral disc.
   c. Decreased opacity may result from vacuum phenomenon.
8. Soft tissues are examined dorsal, ventral, and lateral to spine for alterations in thickness and opacity.

**Head and neck**

1. Although CT and MRI are used extensively for skull imaging, radiography is still useful.

**Technique**

1. Radiography of the skull requires high-quality images and careful evaluation.
2. Exposure may need to be adjusted for different thickness of skull or to adequately visualize soft tissues.
3. Symmetry and absence of rotation are important because one side of skull usually is compared with the other. If correct positioning is not possible, take malpositioning into account.

**Evaluation of skull**

1. Considerable variation exists in normal appearance of skull among the many dog and cat breeds.
2. Reference materials such as anatomy and radiology textbooks, bone specimens, and normal radiographs aid in interpretation.
3. Due to superimposition of many bones and extensive compartmentalization, a systematic approach is essential when evaluating skull radiographs:
   a. Region I (Figure 1.7):
      1) Mandibles: horizontal and vertical rami, condyloid process, temporomandibular joints (TMJ), teeth, alveolar bone, symphysis.
      2) Maxillae: hard palate, teeth, alveolar bone.
      3) Zygomatic arch: zygomatic bone, squamous temporal bone, retroglenoid process of TMJ.
   b. Region II (Figure 1.8):
      1) Nasal cavity and turbinates.
      2) Vomer bone (nasal septum).
      3) Ethmoturbinates and cribiform plate.
      4) Frontal sinuses and supraorbital process.
      5) Orbit.
   c. Region III (Figure 1.9):
      1) Cranial vault: frontal, parietal, occipital, temporal bones.
      2) Petrous temporal bone (inner ear).
      3) Osseous bullae (middle ear).
      4) Occipital condyles and foramen magnum.
   d. Region IV
      1) Soft tissues: skin, subcutaneous, muscles of head.
      2) Soft palate.
      3) Nasopharynx, oropharynx, pharynx
      4) Retropharyngeal space.
      5) Larynx: hyoid bones, laryngeal cartilages.
      6) External auditory canals.
      7) Cervical spine.

Nasal cavity and frontal sinuses
1. Evaluated for alterations in opacity and bony structures (Figure 1.10).
   a. Increased opacity may result from presence of foreign material, fluid, or mass, which also tend to obscure normal turbinate patterns.
   b. Decreased opacity usually is caused by osteolysis.
2. Adjacent structures may be involved (e.g., frontal sinuses, frontal and maxillary bones, cranial vault, teeth, soft tissues).
3. Findings often are nonspecific but aid in determining location and extent of lesion(s).
4. Aggressive lesions (e.g., neoplasia, severe osteomyelitis):
   a. Commonly present with increased soft tissue opacity in turbinates and sinuses due to edema, inflammation, tumor cells, or/and accumulation of fluid.
   b. Destruction of nasal turbinates causes loss of fine boney pattern (easiest to see on open mouth ventrodorsal radiograph).
   c. Nasal septum may be deviated due to expanding tumor mass.
   d. May see osteolysis of overlying nasal, maxillary, or frontal bone(s), often with periosteal response.
   e. External soft tissue swelling or mass may be present.
   f. In general, unilateral aggressive lesions are more likely to be neoplastic and bilateral lesions are more likely to represent chronic inflammation, but this is not always the case (cytology/histopathology usually is necessary for definitive diagnosis).
5. Masses or foreign objects may be visible in nasopharynx (Figure 1.11), caudal to last maxillary molar tooth (true lateral radiograph). Exposure may need to be increased for adequate visualization, and opening the mouth aids in detection (rotates vertical mandibular away from area of interest).

**Teeth**
1. Congenital and acquired anomalies of teeth (e.g., size, shape, number) are common in dogs and cats and may or may not be clinically significant.
2. Congenital anomalies are more common in brachycephalic breeds.
3. Abnormal number of teeth may be symmetric or asymmetric.

**Pharynx and larynx**
1. These areas often are included on radiographs of the head.
2. Pharynx and larynx are visible when they contain air.
3. Poor positioning (e.g., flexed neck, rotation) can displace larynx and distort size and opacity of retropharyngeal space. Suspected abnormalities should be confirmed with a well-positioned and properly exposed lateral radiograph.
4. Pharynx and larynx are evaluated for opacity, position, size, and shape.

**Figure 1.10** Nasal cavity lesions (open-mouth VD radiographs).
- **A.** Normal. **B.** Unilateral diffuse increase in opacity in left nasal cavity. **C.** Focal increase in opacity in left nasal cavity. **D.** Osteolysis in left nasal cavity.

**Figure 1.11** Nasopharyngeal mass in a cat (lateral radiograph). Arrow points to increased opacity in nasopharynx, caudal to molar teeth (Adapted from Owens and Biery, Radiographic Interpretation for the Small Animal Clinician, 2nd ed. Baltimore: Williams & Wilkins, 1999.)

**Figure 1.12** Normal width of retropharyngeal space (lateral radiograph). Head is approximately 135° angle to neck. Width of retropharyngeal space (W) is measured from dorsal edge of cricoid cartilage to ventral aspect of C2. Normal width should not exceed the length of C3 (L). (Adapted from O’Brien, Radiographic Diagnosis of Abdominal Disorders in the Dog and Cat. Philadelphia: W.B. Saunders, 1981, p. 124. Special thanks to Dr. T. R. O’Brien.)

- **a.** Increased opacity may be caused by presence of swelling, mass, or foreign material.
- **b.** Retropharyngeal disease may displace larynx ventrally.
- **c.** As a rough estimate, normal distance between dorsal edge of cricoid cartilage and ventral aspect of C2 is approximately equal to length of C3 on a properly positioned lateral radiograph (Figure 1.12).
Thorax

“Radiography does supplement, not supplant, physical examination.”
  – Peter Suter, DVM

Effects related to age, body condition, and conformation
1. Obesity may create the appearance of increased lung opacity, cardiomegaly, and widened mediastinum.
2. Emaciation may mimic overinflated lungs and microcardia.
3. Immature animal hearts are relatively large in relation to size of thoracic cavity.
4. Lungs in immature animals may normally be increased in interstitial opacity.
5. Thymic tissue may be visible in cranial mediastinum of dogs up to 6 months of age and in cats up to 2 years of age.
6. Cardiac silhouettes of deep-chested dogs are more upright and narrow.
7. Cardiac silhouettes of barrel-chested dogs are more rounded and wide, with a more dorsally positioned trachea.
8. Lung opacity in heavily muscled animals may appear increased.
9. Wet or dirty hair coat may mimic intrathoracic lesions.
10. Bronchointerstitial markings commonly are increased in older animals.

Thoracic wall
1. Evaluated for symmetry, width, and opacity.
2. Widening may be general (e.g., obesity, edema) or local (e.g., lipoma, tumor).
3. Alterations in opacity may be due to presence of gas, mineral, metal, or superimposition of adjacent structure (see lists of Differential Diagnoses, chapter 5).
4. Ribs are assessed for number, size, margination, opacity, position, and spacing.
   a. Alteration in number of ribs usually is congenital and incidental; however, lysis caused by infection or tumor must be ruled out.
   b. Expansile remodeling may occur with healing rib fracture, tumor, or infection.
   c. Rib margins may be indistinct due to motion artifact or active remodeling.
   d. Abnormal rib opacity may be caused by fracture, osteolysis, or periosteal response.
   e. Position and spacing of ribs may be altered by trauma, mass effect, expansion of thorax, or muscle contractions.
   f. Costal cartilages begin to mineralize at a few months of age and can present with a variety of patterns, often nonuniform in appearance (Figure 1.13). Normal costochondral junctions can become quite large and may be mistaken for pathology (also see Normal Radiographic Anatomy in chapter 5).

Box 1.4 Checklist for interpreting thoracic radiographs.

- At least two orthogonal radiographs
- Radiographs are those of animal being evaluated
- Technique:
  - Exposure
  - Positioning
  - Inspiration
  - Motion artifact
- Animal’s age, body condition, and conformation
- Extrathoracic structures:
  - Caudal cervical region and thoracic inlet
  - Subcutaneous tissues
  - Cranial abdomen
  - Thoracic limbs
  - Thoracic wall (including spine, sternum, and ribs)
  - Diaphragm
  - Pleura and pleural space
  - Mediastinum
  - Esophagus
  - Cardiovascular structures
  - Trachea and mainstem bronchi
  - Lungs
  - Reassess based on clinical, physical, and laboratory findings
  - Prioritize list of differential diagnoses
  - Serial radiographs to monitor progress and response to therapy

Figure 1.13 Normal costochondral junctions. A. Soft tissue opacity costal cartilage in an immature animal. B. Mineralization of cartilage, which often begins at a few months of age. C. More heterogenous pattern of age-related mineralization. D. Large costochondral junction that may be mistaken for pathology. (Adapted from Owens and Biery 1999.)
CHAPTER 1 Interpretation of Radiographs

g. Detection of rib lesions can be difficult, and altering one's viewing perspective may help:
   1) Oblique/tangential radiographs can be used to image lesions in profile.
   2) Orient radiographs upside down or sideways to draw attention to ribs.
   3) Invert black and white scale on digital images to highlight ribs.
   4) Serial radiographs may document periosteal response that was not evident on initial study.

5. Sternum is assessed for shape, alignment, opacity, and margination.
   a. Abnormal shape may be congenital (e.g., pectus excavatum) or acquired (e.g., fracture, luxation).
   b. Alignment may be altered by trauma, mass effect, or overstretching the animal during positioning for radiography.
   c. Altered opacity and margination typically is caused by tumor or infection (Figure 1.14).
   d. Common aging changes along sternum include bone spurs at edges of sternebrae and mineralization of intersternebral cartilages (more common in large breed dogs).

6. Vertebrae are assessed for alterations in shape, alignment, opacity, and margination (see chapter 4, “Musculoskeletal,” for discussion).

Diaphragm
1. Evaluated for margination, position, and shape.
2. Margin may become indistinct or obscured by hernia, pleural fluid, mediastinal disease, or caudal lung disease.
3. Shape and position of diaphragm are affected by animal’s position during radiography and pathology in abdominal or thoracic cavity (see lists of Differential Diagnoses, chapter 5).

Pleura and pleural space
Pleural effusion
1. Type of pleural fluid cannot be distinguished on radiographs (see Differential Diagnoses in chapter 5).
2. Interlobar fissure lines (pleural fissure lines) are earliest sign of excess fluid in pleural space and appear as thin, curved, soft tissue opacity lines between lung lobes (Figures 1.15 and 1.16).
   a. Fluid creates fissure lines that are wider peripherally and taper toward the hilus (Figure 1.17).
   b. Pleural thickening creates lines that are uniform in thickness and do not taper.
   c. Fat (obese animals) can fill interlobar fissures and create lines that are wider centrally and taper peripherally (“reverse fissure lines”).
   d. Mineralized costal cartilages may be mistaken for pleural fissure lines (especially in cats).
3. Detection of small pleural effusions may be easier on a VD radiograph or on radiographs made during expiration. Horizontal beam radiography can also aid in detection.
4. Radiographic findings with increasing volume of pleural fluid (Figure 1.18):
   a. Lung borders retract from thoracic wall, spine, sternum, and diaphragm (Figure 1.20).
   b. With large effusions, lung lobes will be small and may appear leaflike.
   c. Vascular and bronchial markings do not extend to thoracic wall.

Figure 1.14 Sternal lesion (lateral radiograph). White arrow indicates local soft tissue swelling and osteolysis of 4th sternabra. Intrathoracic soft tissue swelling is evident. Such lesions may result from tumor or infection.

Figure 1.15 Pleural fissure lines (lateral radiograph). White lines indicate interlobar fissures; (1) between cranial and middle lung lobes, (2) between cranial and caudal lobes, (3) between middle and caudal lobes; (MR) indicates cranioventral mediastinal reflection. (Adapted from Owens and Biery 1999.)
Figure 1.16 Pleural fissure lines (DV/VD radiograph). White lines indicate interlobar fissures; (1) between right cranial and middle lung lobes, (2) between right caudal and middle lobes, (3) between cranial and caudal segments of left cranial lobe, (4) between left cranial and caudal lobes. CrV = cranioventral mediastinal reflection; CaV = caudoventral mediastinal reflection. (Adapted from Owens and Biery 1999.)

Figure 1.17 Types of interlobar fissure lines. (1) Fat between lung lobes is wide centrally and tapers peripherally (sometimes called “reverse fissure line”). (2) Fluid in pleural space creates lines that are wide peripherally and taper centrally. (3) Pleural thickening creates lines that are uniform and thin (may be indistinguishable from small pleural effusion). (Adapted from Owens and Biery 1999.)

Figure 1.18 Pleural effusion. A. Lateral radiograph, a large volume of pleural fluid obscures the heart and other intrathoracic soft tissues; air-filled trachea and large bronchi remain visible. B. VD radiograph, bilateral pleural effusion is visible in interlobar fissures and between lung and thoracic wall. (Adapted from Owens and Biery 1999.)

d. Increasing opacity in thoracic cavity.

e. Costophrenic angles become rounded and indistinct.


g. Ventral lung margin becomes scalloped and outlined by fluid (dorsal to sternum).

h. Cardiac silhouette and trachea are dorsally displaced (depending on volume of fluid).

i. Cranial mediastinum may appear widened due to summation with adjacent fluid.

j. Cardiac and diaphragmatic borders become obscured; diaphragm may be caudally displaced.

5. Rounding of lung lobe borders suggests pleural fibrosis, which restricts lung expansion and can lead to lung rupture during rapid re-expansion.