PULMONARY IMAGING:
GETTING THE MOST INFORMATION FROM THORACIC RADIOGRAPHS
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Outline

• Pulmonary anatomy
  • Selecting the imaging examination
  • Principles of radiographic interpretation
  • The incompletely expanded lung
    • The fully expanded lung
  • Summary

Pulmonary Anatomy

• 2 lungs
  – Left
  – Right
• 2 “lung fields”
  – Cranioventral
  – Caudodorsal

Dog: Left lung

Pulmonary Imaging

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Pulmonary Anatomy

• 6 lung lobes
  – Right cranial
  – Right middle
  – Right caudal
  – Accessory
  – Left caudal
  – Left cranial
    • Cranial part
    • Caudal part
• Bronchopulmonary segments

Gross Anatomy

Gross Anatomy

• Trachea
  – Principal bronchi
    • Lobar bronchi
      – Segmental bronchi
        • Bronchi
      • Bronchioles

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L LAT R LAT
Radiographic Localization of Lung Disease

- Bronchovascular bundle (conducting zone)
- Pulmonary parenchyma (respiratory zone)
- Pulmonary blood vessels

Gross & Histologic Anatomy

- Lung
  - Lobe
    - Bronchopulmonary segment
      - Secondary pulmonary lobule
        » Pulmonary acinus
          - Primary pulmonary lobe
            - Alveolus
              - Wall (interstitial pattern)
              - Space (alveolar pattern)
Gross & Histologic Anatomy

- Lung
  - Lobe
    - Bronchopulmonary segment
      - Secondary pulmonary lobule
        » Pulmonary acinus
          - Imaging limit
    - Primary pulmonary lobule
      - Alveolus
        - Wall (interstitial pattern)
        - Space (alveolar pattern)

Anatomic Organization of the Lung

Computed tomography of the lung, A pattern approach, 2007, Springer

Pulmonary Interstitium

Connective Tissue

Computed tomography of the lung, A pattern approach, 2007, Springer
Pulmonary Interstitium

Connective Tissue

1. Subpleural space, bronchopulmonary segments, secondary pulmonary lobules, & pulmonary acini
2. Originate at hilum, surrounds bronchovascular structures & alveoli
3. Between the alveoli and capillaries (alveolar wall)

Computed tomography of the lung, A pattern approach, 2007, Springer

Bovine & Canine Lungs

Selecting the Examination

• Orthogonal-view thoracic radiography
  – RLAT and DV Cardiac cases
  – LLAT and VD Respiratory cases
  – Other combinations
• 1-view thoracic radiography
• 3-view thoracic radiography
• Thoracic CT

In small-animals, see lung lesions best in the “up” lung
Other lesions best when placed close to the detector

“Up” lung

195681
Principles of Radiographic Interpretation

- Assuming proper
  - Examination
  - Positioning
  - Exposure
  - No superimposition
  - of collar, wet hair, etc.
Age-related Changes & Body Condition

Principles of Radiographic Interpretation

- Classic pattern approach
  - Interstitial pattern
  - Alveolar pattern
  - Bronchial pattern
  - Vascular pattern
  - Mixed pattern

- Pulmonary patterns are a combination of signs
  - Degree of lung expansion
    - Reduced, normal, or increased
  - The opacity of the lung
    - Increased or decreased
  - Appearance of increased opacity
    - Alveolar, interstitial, bronchial, vascular
  - Macroscopic distribution of altered opacity
    - Cranioventral, diffuse, lobar, focal, etc
  - Additional signs

Incomplete Lung Expansion
Incomplete Lung Expansion

- Often considered as only a technical complication
  - Obscure pathology
  - Spurious pathology
    - Cardiomegaly
    - Increased lung opacity

Inhalation

Exhalation

- Commonly due to normal exhalation
- Can be a component of the disease process
  - Reduced or absent gas exchange
  - Clue to the underlying pathology

Textbook of Veterinary Diagnostic Radiology, 3rd Ed.

Signs of Incomplete Lung Expansion

- Decreased lung size
- Increased opacity
- Lobar sign
- Crowding of ribs
- Air bronchogram sign
- Positive silhouette sign
- Poorly defined margins of vessels
- Mediastinal shift (toward collapse)
- Crowding and reorientation of pulmonary blood vessels

- Compensatory hyperinflation
- Bronchial rearrangement
- Cardiac rotation
- Displacement of diaphragm
- Rounded pulmonary margins
- Displacement of pleural fissures
- Changed location of abnormal structures

Anectasis
- Lungs never expanded

Atelectasis
- Lungs previously expanded then collapsed

Collapse
- Same as atelectasis, but often used when more severe
- Less severity may be indicated by “partial collapse”
Atelectasis or Collapse

- Related to physiology of lung expansion
  - Elasticity
  - Compliance
  - Airway patency
  - Surface tension

Relaxation Atelectasis

- Lung does not expand due to the unopposed tendency for lung to collapse due to elasticity
  - Exhalation
  - Pleural fluid
  - 100% oxygen
  - Pneumothorax
  - Shallow breathing
  - Gravity dependent
  - Space-occupying lesion

Relaxation Atelectasis

0.6-year-old, M, Siberian husky

5-year-old, FS, mixed-breed dog

Obstructive Atelectasis

- Lung not expanded due to absorption of alveolar gas without replacement due to airway obstruction
  - Infectious bronchitis or pneumonia
  - Mucous plugging (eg, asthma)
  - Ciliary dyskinesia
  - Foreign body
  - Neoplasm

Obstructive Atelectasis

186808 13-year-old, FS, DSH Cat
Obstructive Atelectasis

Basal cell carcinoma

186808 13-year-old, FS, DSH Cat

Obstructive Atelectasis

11-year-old, MC, DLH Cat

5-year-old, M, Labrador Retriever
with Chronic Coughing

Compare lung expansion on both laterals

5-year-old, M, Labrador Retriever
with Chronic Coughing

Compare lung expansion on both laterals

Bronchial Foreign Bodies

- Visible foreign body
- No radiographic sign
- Obstructive atelectasis
  - Chronic
  - Complete obstruction
- Obstructive emphysema
  - Acute
  - Partial obstruction

Cat found dead in cage
Tracheal foreign body (kibble)

Feline Asthma

194119 Collapsed & hyperinflated lung lobes
Cicatrizing Atelectasis

- Lungs do not increase in volume under normal respiration due to reduced compliance
  - Chronic immune-mediated lung disease
  - Chronic idiopathic fibrosis
  - Radiation pneumonitis
  - Chronic pneumonia

Compliance

- Relationship between volume & pressure

Cicatrizing Atelectasis

14-year-old, MC, West Highland White terrier with chronic idiopathic pulmonary fibrosis

Pulmonary Fibrosis

140648 Unspecified age, FS, mixed-breed dog

Restrictive Pleuritis

Adhesive Atelectasis

- Lungs do not expand due to lumen surfaces of alveoli sticking from surfactant abnormality
  - Neonatal respiratory distress syndrome
  - Acute respiratory distress syndrome
  - Pulmonary thrombosis

Surfactants (surface active agents) are compounds that lower the surface tension between two liquids or between a liquid and solid. Surfactants may act as detergents, wetting agents, emulsifiers, foaming agents, and dispersants.
Adhesive Atelectasis

Pre-mature, F, Thoroughbred horse

Ventilation and Perfusion

- Goal is to match ventilation of air (V) with the perfusion of blood flow (Q) to the lung
  - Ventilation perfusion quotient (V/Q) is the amount of air that is breathed in and perfused into the blood
- V/Q affected by
  - Gravity
  - Normal physiology
  - Disease

Lung Zones

1. Zone 1: V > Q
   - Hypotension
   - Hyperexpanded alveoli
2. Zone 2: V = Q
   - Normotensive
   - Normally expanded
3. Zone 3: V < Q
   - Hypertension
   - Collapsed alveoli

Gravity Affects V/Q

- Zone 1: V > Q
- Zone 2: V = Q
- Zone 3: V < Q

Physiologic Regulation of V/Q

- Normal breathing = tidal breath
  - Half of the alveoli are normally collapsed
- Improve V/Q across lung zones
  - Take a deep breath
  - Hypoxic vasoconstriction
    - The alveoli that are not well ventilate stimulate arteriole vasoconstriction to those alveoli and increases blood flow to the rest of the lung
      - Reduces size of Zone 3
      - Increases size of Zone 2

8-year-old, F, Golden Retriever
Atelectasis

4-year-old, F, Saanan Goat
Blood Pooling
Hypoxic Vasoconstriction

- Normal Lungs
  - Only well ventilated alveoli receive blood flow
  - Poorly ventilated alveoli are not perfused

1. Lung Zone
   - V > Q
2. V = Q
3. V < Q

Hypoxic Vasoconstriction

- Pulmonary Inflammation
  - Increased vasodilation
    - Perfusion to non-ventilated lung
    - V/Q mismatch
  - Decreased oxygen saturation
    - "Functional R-L shunt"

Atelectasis

- Can be a technical complication
- Can cause decreased V/Q
  - An important component of the disease process due to reduced gas exchange
  - A source of "shunt" in anesthetized patients
    - Hypoxic vasoconstriction ineffective in anesthesia

Atelectasis as a Diagnostic Clue

- Indicator of lung disease and process
- Differentiating types of atelectasis
  - Not always possible
  - Regional vs diffuse
  - Acute vs chronic

The Fully Expanded Lung
Importance of Lung Size

- Altered Lung Opacity
  - Reduced Size
  - Normal-to-Increased Size
- Technical Complication
  - Incidental
  - Obscurred Pathology
  - Misidentified Pathology

The Fully Expanded Lung

- The opacity of the lung
- Appearance of increased opacity
- Macroscopic distribution of altered opacity

Lung Opacity

- Decreased
- Normal
- Increased

Decreased Lung Opacity

- Classic description
  - Interstitial pattern
  - Alveolar pattern
  - Bronchial pattern
  - Vascular pattern
  - Mixed pattern

Appearance of Increased Lung Opacity

Hypovolemia
Appearance of Increased Lung Opacity

- **Classic description**
  - Interstitial pattern
  - Alveolar pattern
  - Bronchial pattern
  - Vascular pattern
  - Mixed pattern

- **Variable terminology**
  - Interstitial
    - Unstructured
    - Structured
      - Nodular
      - Reticular
  - Alveolar
    - Alveolointerstitial
    - Airspace

Disease of Pulmonary Blood Vessels

- **Vascular pattern**
  - Pulmonary artery enlargement
  - Pulmonary venous congestion
  - Pulmonary over-perfusion

Disease of the Pulmonary Parenchyma

- **Classic description**
  - Interstitial pattern
  - Alveolar pattern

  - Clear glass
  - Ground glass
  - Opaque glass

- **Respiratory Zone**

- **Terms**
  - Fully aerated
  - Partially aerated
  - Void of air

*Terms apply to incompletely and fully inflated lungs*

Fleischner Society: Glossary of Terms for Thoracic Imaging

In all 3 examples, the lungs are fully expanded.
Disease of the Pulmonary Parenchyma

Relates to the ability to see the pulmonary blood vessels

Ground-glass opacity
Consolidated

Atelectasis

Consolidated Lung
(Pulmonary Blood Vessels Obscured)

Without air bronchograms
With air bronchograms

Groundglass Opacity vs. Consolidation

• Due to differences in lung density
  – Important for patient management
  – Defined by how much air is displaced from lungs
    • Filling the alveolar spaces with fluid or cells
    • Filling the alveolar walls with fluid or cells
    • Partial or complete collapse
    • Increased blood flow

Air Is Displaced From The Lungs By

A. Normal lung
B. Atelectasis
C. Hyperemia
D. Thick interstitium
E. Filled alveoli
F. Thick alveolar wall & filled alveolar space

Attenuation of the voxel or X-ray path
Acute Respiratory Distress Syndrome

- Lung inflammation can cause acute lung injury (ALI)

Lung Inflammation

- Inhaled
  - Burns
  - Infections
  - Chemicals
- Hematogenous spread of inflammatory mediators
  - Ischemic gut
  - Infection elsewhere

Lung is "first stop" for inflammation elsewhere in the body

Lung Inflammation

- Acute respiratory failure
- Chronic respiratory failure

Pulmonary Pathophysiology

- Acute respiratory failure
  - Leaky capillaries & vasodilation
    - Pulmonary edema
      - Decreased diffusion/hypoxia
  - Flooding of alveoli
  - V/Q mismatch (R-L shunt)
  - Decreased surfactant
  - Decreased compliance
- Chronic respiratory failure
  - Fibrosis
    - Decreased diffusion
    - Decreased compliance

Pulmonary Pathophysiology

- Acute respiratory failure
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Neutrophil influx damages Type II pneumocytes
Pulmonary Pathophysiology

- Acute respiratory failure
  - Leaky capillaries & vasodilation
    - Pulmonary edema
      - Decreased diffusion/hypoxia
    - Flooding of alveoli
  - V/Q mismatch (R-L shunt)
    - Decreased surfactant
    - Decreased compliance
- Chronic respiratory failure
  - Fibrosis
    - Decreased diffusion
    - Decreased compliance

It is Understandable

- Why lung patterns are commonly thought to refer to the microscopic localization of lung lesions
  - Interstitial pattern
  - Alveolar pattern
- However, the appearances relates to severity of air displacement and not the underlying cause of disease

Compare, For Example

- Left congestive heart failure causes increased hydrostatic pressure
  - Interstitial pattern
    - Leaky capillaries & vasodilation
    - Alveolar pattern
    - Flooding of alveoli

Disease of the Pulmonary Parenchyma

- Groundglass opacity or interstitial pattern
  - Affected lungs are partially aerated
- Consolidation or alveolar pattern
  - Affected lungs are void of air

What the pathologist calls "interstitial disease" is different from what a radiologist calls an "interstitial pattern." Suter & Lord

Disease of the Bronchovascular Bundle

- Classic description
  - Bronchial pattern

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Disease of the Bronchovascular Bundle

- Classic description
  - Bronchial pattern

Conducting Zone
Differentiate bronchovascular disease from an air bronchogram (parenchymal disease)

Bronchovascular Pattern

- Bronchovascular bundle
  - Bronchi
  - Arteries
  - Veins
  - Lymphatic vessels

- Bronchiolovascular bundle
  - Bronchioles
  - Arterioles
  - Venules
  - Lymphatic vessels

Blastomycosis

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10-year-old, FS, German Shepherd

Bronchiectasis

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6-weeks later lung and bronchus are better aerated
Some Take-Home Messages

• The different appearances of increased opacity differentiates:
  - Bronchovascular diseases
  - Parenchymal diseases
  - Nodular diseases

Some Take-Home Messages

• Different appearances of parenchymal disease is determined by the ability to see the margins of the pulmonary blood vessels.
  - This is helpful for determining disease severity and not forming the differential diagnosis.

Some Take-Home Messages

• Interstitial pattern or groundglass opacity indicates that the lungs are partially aerated
  - Not that disease is necessarily localized to interstitium

• Alveolar pattern or consolidation indicates that the lungs are void of air
  - Not that disease is necessarily localized to the alveolus

• Bronchial or bronchovascular pattern indicates that disease is centered in or around the bronchial wall

Some Take-Home Messages

• Lung lobe size
• Opacity of the lung
• Appearance of increased opacity
  - Macroscopic distribution / shape of lesions
  - Additional signs

Forming the Differential Diagnosis

Macroscopic Distribution of Lung Disease

• Cranioventral
• Caudodorsal
• Diffuse
• Lobar
• Locally extensive — “sublobar”
• Focal
• Multifocal
• Patchy/asymmetric

Macroscopic Distribution of Lung Disease

• Cranioventral
• Caudodorsal-to-diffuse
• Focal
• Multifocal
• Patchy/asymmetric
Cranioventral & Caudodorsal Distributions

Cranioventral Parenchymal Disease
- Pneumonia
  - Aspiration
  - Bronchopneumonia
- Hemorrhage
- Neoplasm
- Lung lobe torsion

Caudodorsal-to-Diffuse Parenchymal Disease
- Cardiogenic pulmonary edema
- Non-cardiogenic pulmonary edema
  - Upper airway obstruction
  - Toxin inhalation
  - ALI (SIRS/ARDS)
  - Near drowning
  - Neurogenic
  - Vasculitis
  - DIC
- Lymphoma

Example of Diffuse Distribution

Diffuse Parenchymal vs. Generalized-Random

Normal | Generalized random | Diffuse

Diffuse Bronchovascular Disease
- All causes of bronchitis
  - Allergic
  - Infectious
  - Immune mediated
- Lymphatic spread of tumor
- Early pulmonary edema
Diffuse Bronchovascular Disease

Bronchocentric Distribution

- Bronchocentric
  - Involves the pulmonary parenchyma around the bronchovascular bundle

Bronchocentric Differential Diagnosis

- Inflammatory
- Neoplasm

Lobar/Sublobar Distributions

Lobar Parenchymal Disease

- Pneumonia
  - Aspiration
- Bronchopneumonia
- Hemorrhage
- Neoplasm
- Lung lobe torsion

Sublobar Parenchymal Disease

- Pneumonia
  - Aspiration
- Bronchopneumonia
- Hemorrhage
- Neoplasm
Aspiration Pneumonia
Left Cranial Lobe (Caudal Part)

Focal Distribution
- Focal
  - Milliary (<1 mm)
  - Nodule (<3 cm)
  - Mass (>3 cm)

Focal/Multifocal Differential Diagnosis
- C.H.A.N.G.
  - Cyst
  - Hematoma
  - Abscess
  - Neoplasm
  - Granuloma

Ossifying Pulmonary Metaplasia

Patchy Distributions
- 1 lesion
- Multiple lesions

Patchy/Asymmetric Distribution
- Does not conform to other distributions
Patchy/Asymmetric Parenchymal Disease

- Trauma
- Infection
- Neoplasia
- Hemorrhage
- Inflammation

Central & Peripheral Distributions

- Central lung (hilar)
- Central lobe
- Peripheral lung
- Peripheral lobe

Hilar

Secondary Pulmonary Lobule Distributions

A. Centrilobular
B. Panlobular
C. Perilobular

Perilobular & Centrilobular Distributions

- Use cautiously
  - Often there is a mix, but we conclude the most severe
- Not the same as an asymmetric distribution
**Hemangiosarcoma**

- 8-year-old, FS, German Shepherd

**Additional Signs**

- **Pulmonary**
  - Bullae
  - Cavitary
  - Mineralization
- **Non-pulmonary**
  - Pleural fluid
  - Heart enlargement
  - Lymph node enlargement

**Lung Lobe Torsion**

**Pulmonary Adenocarcinoma**

- 12-year-old, MC, DSH

**Pulmonary Thromboembolism**

- 6-year-old, FS, Labrador retriever

**Summary**
Summary

• Pulmonary anatomy
• Selecting the imaging examination
• Principles of radiographic interpretation
• The incompletely expanded lung
• The fully expanded lung
• Summary

Key Points

• Pulmonary imaging interpretation
  – Anatomy
  – Pathophysiology
  – Physical principles of imaging modalities
• Pulmonary patterns are a combination of signs
  – Degree of lung expansion
  – The opacity of the lung
  – Appearance of increased opacity
  – Macroscopic distribution of altered opacity
  – Additional signs

Lung Expansion & Opacity

• Size
  – Small
  – Normal
  – Enlarged
• Opacity
  – Decreased
  – Normal
  – Increased

Appearance

• Bronchovascular disease
• Parenchymal disease
• Nodular disease
• Vascular disease

Appearance

• Bronchovascular disease
• Parenchymal disease
  – Groundglass opacity
  – Consolidation
  – Atelectasis
  – Collapse
• Nodular disease
  – Miliiary
  – Nodule
  – Mass
• Vascular disease

How much gas is displaced from the lungs
### Distribution

- Cranioventral
- Caudodorsal
- Diffuse
- Lobar
- Sublobar/locally extensive
- Focal
- Multifocal
- Patchy/asymmetric
- Secondary pulmonary lobule

### Quantify Disease Severity

- Normal
- Questionable
- Mild
- Moderate
- Severe

### Putting It Together

- Severe, cranioventral, lung consolidation
- Large, focal, lung mass
- Large, focal, cavitary lung mass
- Moderate, generalized random, nodules
- Moderate, diffuse, atelectasis
- Mild, diffuse, groundglass pattern
- Mild, diffuse, bronchovascular pattern

**Severity, distribution, appearance**

### Pulmonary Pattern Interpretation

- Definitive diagnosis
- Differential diagnoses
- No diagnosis possible