Advanced Imaging:
CT and MRI

PIA MARTINY, DVM

CORNELL UNIVERSITY HOSPITAL FOR ANIMALS
ECC DEPARTMENT
1-3-17
Overview

- CT physics
- CT applications
- MRI physics
- MRI applications
X-ray Physics

- Electromagnetic waveform

- X-rays produced from collision of electrons and anode
  - Multiple types of collisions
  - Most involve small energy transfers and ionization of target atoms
Photoelectric effect
- Characteristic x-rays are all absorbed
X-ray Physics: Interaction with Matter

- Compton scatter
  - Decreased contrast between structures
Coherent scatter/Rayleigh scatter

- An x-ray with an oscillating electric field sets the electrons in an atom into momentary vibration
  - Emit radiation of the same wavelength

- Occurs mainly in the forward direction
  - Produce a slightly broadened x-ray beam

- No energy is transferred to kinetic energy
- Limited interest to CT
Conventional Radiography

- Roentgen 1895
- Broad x-ray
- Stationary tube
- 3D volume is compressed in the direction of the x-ray to 2D image
Computed Tomography

- Hounsfield, 1967
- Narrow, fan-shaped beam
- Nonstationary x-ray tube
- X-rays are counted by electronic detectors
- Reconstruction of detector signals
Computed Tomography

- ‘tomos’
  - Imaging of a single plane
  - Elimination of the outline of structures in other planes

1972

Modern CT
Computed Tomography
CT Unit Anatomy

- Generator
- X-ray tube
- Collimators
- Aperture
- Detector ring
- Patient bed

Gantry
CT Unit Anatomy
X-ray Tube Anatomy

- Emitter
- Cathode
- Rotation
- Oil for cooling
- Deflection coils
- Electron beam
- Anode
- Motor
- X-rays
- Focal spot
Gantry Anatomy

- **First generation**
  - Single pencil beam source
  - Single detector
  - Parallel projection measurements
  - One angle
  - ‘translate/rotate scanner’
Second generation
- Fan-shaped beam
- Angularly placed detectors
- Scan times reduced 3x
Gantry Anatomy

- **Third generation**
  - Simultaneous rotation of the x-ray tube and detector array
    - “rotate-rotate geometry”
  - “rotating gantry”
  - Multislice CT systems
Gantry Anatomy

- **Fourth generation**
  - Rotating x-ray tube
  - $360^\circ$ ring of fixed detectors
    - expensive
  - “rotate/stationary geometry”
  - Multislice CT systems
Scan Mode

- **Axial scan**
  - ‘Sequential scanning’
  - Incremental table translation

- **Helical scan**
  - ‘Spiral CT’
  - Continuous x-ray tube rotation
  - Simultaneous and continuous table translation
CT and Nuclear Medicine

- Positron Emission Tomography/CT
- Single Photon Emission CT

Radioisotope provides metabolic and functional information
Slice Thickness

- ‘Thin’ slices
  - 1-2mm
  - Maximal resolution of high contrast structures
  - Eg. inner/middle ear bones

- ‘Thick’ slices
  - 5-8mm
  - Distinguish between tissues of similar attenuation to minimize ‘noise’
Slice Thickness

5mm slice thickness

1mm slice thickness
Properties similar to conventional rads
- Low-density tissues: black
- High-density tissues: white
Image Interpretation: Differences

- Each CT image represents a thin section of the patient
- Multiple images required
Image Interpretation: Differences

- Rads display the sum of attenuation

- CT images display attenuation assigned to each pixel
  - “picture + element”
  - Increased tissue density sensitivity
**Image Interpretation**

- **CT numbers/Hounsfield units**
  - -1,000 HU: air
  - 3,000 HU: compact cortical bone

- **Window adjustment pending tissue type**
  - d/t few grey levels of monitor
  - Wide window: air or bone-containing structures
  - Narrow window: soft tissue and fluids
Image Interpretation

- **Wide window**
  - Tissues with a wide range of HU

- **Narrow window**
  - Differences in organs with a narrow range of HU
Practicalities

• Sternal recumbency

• Chemical restraint
  ○ Monitored with apron and thyroid shield
  ○ Low scatter due to highly collimated xray beam

• Tissue *density* (not opacity)
  ○ Hyperdense, isodense, hypodense
Contrast Media and Applications

- IV contrast media
  - Iodinated, ionic or non-ionic

- Blood flow and vascular permeability dictate tissue enhancement
  - Accumulations in vascular, hemorrhagic or edematous lesions
<table>
<thead>
<tr>
<th></th>
<th>Small animals</th>
<th>Equines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application site</td>
<td>Mostly cephalic vein</td>
<td>Mostly jugular vein</td>
</tr>
<tr>
<td>Type/Agent</td>
<td>Iodine based, ionic or non-ionic</td>
<td></td>
</tr>
<tr>
<td>Dose</td>
<td>600–880 mg iodine (I)/kg body weight (bw)*</td>
<td></td>
</tr>
<tr>
<td>Administration rate</td>
<td>2 ml/s</td>
<td></td>
</tr>
<tr>
<td>Injection mode</td>
<td>Manual or via power injector</td>
<td></td>
</tr>
<tr>
<td>Scan delay</td>
<td>1–3 min after the contrast bolus is complete so as to allow contrast medium to reach the target organ</td>
<td></td>
</tr>
</tbody>
</table>
CT Artifact

Respiratory motion artifact

No respiratory motion
CT Artifact

Contrast-induced artifact
Beam-hardening correction
CT Artifact

Metal artifact

Metal-correction algorithm
Indications: CT

- Alternative to multiple-view rad study
- Following normal rads or US
- Gain more information regarding an abnormality visualized with rad/US
- Guide biopsy
- Determine the extent of a lesion before sx or radiation therapy
CT Applications: Head

- High contrast tissues

- Cross sectional imaging eliminates superimposition artifact

- Pre and post contrast scans
  - Many inflammatory and neoplastic processes cause disruption of the BBB
**CT Applications: Head**

Wide window

Narrow window

HBC CT. Fx of right frontal bone and calvarium. Hyperdense lesion in the right forebrain, representing a hematoma.
CT Applications: Head

- CT images are superior to rads
  - Ability to identify skull anatomy
  - Ability to detect MFT injuries

- Skull radiography is superior for visualizing the mandibular body (LL and OBL views) and dental occlusion (DV view)
CT Applications: Thorax

- Rapid scan times
- Increased sensitivity for pulmonary metastasis
- Nontraumatic/spontaneous pneumothorax
CT Applications: Thorax

Nodule suggestive of pulmonary metastasis

Impingement and possible involvement of the esophagus

Bronchus within the mass and lack of lesions involving the ribs suggests pulmonary mass
CT Applications: Thorax

Comparison of three-view thoracic radiography and computed tomography for detection of pulmonary nodules in dogs with neoplasia

Laura J. Armbrust, DVM, DACVR; David S. Biller, DVM, DACVR; Aubrey Bamford, BS; Ruthanne Chun, DVM, DACVIM; Laura D. Garrett, DVM, DACVIM; Michael W. Sanderson, DVM, MS, DACVIM

- CT was more sensitive than rads for detection of pulmonary nodules
  - Particularly evident in large-breed to giant-breed dogs
- Large-breed and giant-breed dogs with osteosarcoma
  - Thoracic CT recc’d if detection of pulmonary nodules will change treatment
In patients with IMHA and respiratory distress:
- CTPA can confirm and rule out PTE in major pulmonary arteries
- No clinicopathologic data reliably related to the CTPA diagnosis
  - Arterial blood-gases, echocardiographic indices, cardiac troponins
Computed tomographic findings in canine pyothorax and correlation with findings at exploratory thoracotomy

F. Swinbourne, E. A. Baines, S. J. Baines and Z. J. Halfacree

Department of Veterinary Clinical Sciences, The Royal Veterinary College, North Mymms, Hatfield, Hertfordshire AL9 7TA

- May identify lesions that are not overtly evident during surgery
- Does not eliminating the necessity to explore the entire thorax
CT Applications: Abdomen

- CT is useful for elusive structures
  - Pancreas
  - Mesentery
  - Pelvic canal
CT Applications: Abdomen

COMPARISON BETWEEN SURVEY RADIOGRAPHY, B-MODE ULTRASONOGRAPHY, CONTRAST-ENHANCED ULTRASONOGRAPHY AND CONTRAST-ENHANCED MULTI-DETECTOR COMPUTED TOMOGRAPHY FINDINGS IN DOGS WITH ACUTE ABDOMINAL SIGNS

Miriam M. Shanaman, Tobias Schwarz, Arnon Gal, Robert T. O’Brien

- Diagnosis of a surgical condition was only minimally decreased with rads and AUS when compared with CT
  - CT shows only slight improvement in accuracy when differentiating surgical from non-surgical conditions

- Concurrent rads and AUS yielded 100% accuracy in differentiation of surgical from non-surgical conditions
CT Applications: Pelvis

- CT is more sensitive than rads in detecting fractures
  - Multidirectional xray beam
  - Cross-sectional images eliminates superimposition
CT Applications: Pelvis

- **Indications:**
  - Acetabular fractures
  - Dislocations of the hip
  - All potential or recognized sacral fractures
  - All potential or recognized sacroiliac injuries
  - Questionable stability of the pelvis
  - Intrapelvic soft-tissue injuries
CT Applications: Pelvis

COMPARISON OF COMPUTED TOMOGRAPHY, TANGENTIAL VIEW RADIOGRAPHY, AND CONVENTIONAL RADIOGRAPHY IN EVALUATION OF CANINE PELVIC TRAUMA

JASON T. CRAWFORD, DVM, PAUL A. MANLEY, DVM, WILLIAM M. ADAMS, DVM

- CT is superior to rads in the diagnosis of skeletal and soft tissue pelvic injuries
- However, rads detected all clinically important lesions
  - Those requiring surgical intervention
- Consider CT with questionable stability of the hemipelvis, acetabular involvement, or highly comminuted fractures
CT Applications: Spine

COMPARISON BETWEEN NONCONTRAST COMPUTED TOMOGRAPHY AND MAGNETIC RESONANCE IMAGING FOR DETECTION AND CHARACTERIZATION OF THORACOLUMBAR MYELOPATHY CAUSED BY INTERVERTEBRAL DISK HERNIATION IN DOGS

Jocelyn J. Cooper, Benjamin D. Young, John F. Griffin IV, Geoffrey T. Fosgate, Jonathan M. Levine

- Noncontrast CT studies are highly sensitive diagnosis of IVDH
  - Shorter scan times
- Sensitivity of MR (98.5%) > CT (88.6%) for diagnosis of TL:
  - IVDH
- MR had improved:
  - Determination of lesion location
  - Type of disk herniation
  - Lateralization (in some dogs)
CT Advantages

- Short scan time

- Universally applicable
  - Pacemaker and metals not contraindicated
CT Disadvantages

- Limited tissue characterization
- Restriction to transverse slices
- Practical limit on numbers of X-rays which can be produced in the short duration of the scan
...appears to be a possible, borderline, indeterminate, equivocal, suspected pixel, probably of questionable significance. Clinical correlation needed... maybe...
MRI Physics

- Living tissues have magnetic properties
  - Nuclei of certain atoms
  - To be magnetic, a nucleus must have:
    - an unpaired proton
    - an unpaired neutron
    - one of each
MRI Physics: Hydrogen

- Eccentrically located proton
  - Highly magnetic nucleus
  - Spin creates a magnetic field
    - ‘magnetic moment’
  - Constitutes 60-70% body mass
MRI Physics

- Protons normally have random arrangement
  - No net magnetic field

- When in a magnetic field, protons have two motions:
  - Precession
  - Aligned/unaligned orientation
Protons axis motion

- Precession

- Larmor frequency: precession rate
  - Dependent on strength of local magnetic field
MRI Physics: Orientation in a Magnetic Field

- **Aligned**: low energy position**
  - Parallel to magnetic field

- **Unaligned**: high energy position
  - Antiparallel to magnetic field
  - High energy due to thermal energy
MRI Physics: Orientation in a Magnetic Field

- Out of phase
  - Unsynchronized precession

- In-phase
  - Precession of protons together
MRI Physics: Orientation in a Magnetic Field

Out of phase

In phase
MRI Physics: Signal Generation

Longitudinal Magnetization
MRI Physics: Signal Generation

- Radiofrequency applied
  - 50% aligned
  - 50% unaligned
- No net magnetization
MRI Physics: Signal Generation

- Radiofrequency applied
  - Sinusoidal shape ‘pushes’ protons to synchronize
  - ‘Resonance’
  - Transverse Magnetization
    - Detectable
MRI Physics: Signal Generation

- Radiofrequency removed
  - Transverse magnetization lost
  - T2 relaxation
  - ‘spin-spin’ relaxation
- **Radiofrequency removed**
  - Reversal from high to low energy state
  - Longitudinal magnetization
  - T1 relaxation
  - ‘spin-lattice’ relaxation
  - Energy transfer
**Voxel**
- Volume + element
- 1 x 1 x 10mm
- Integrated from hundreds of individual signals

- 215 x 215 - or - 512 x 512 matrix
MRI Basics
MR Spectroscopy

- Allows the determination and quantification of metabolites in living tissue

- Can detect metabolic abnormalities
  - Even when the morphological images are normal
MRI Unit Anatomy
The Inner Workings

Radio Frequency Transmitter & Receiver
Sends and receives radio signals

Main Magnetic Coil
Creates a uniform magnetic field

X Magnetic Coils
Create a varying magnetic field from left to right

Y Magnetic Coils
Create a varying magnetic field from top to bottom

Z Magnetic Coils
Create a varying magnetic field from head to toe

MRI Unit Anatomy
MRI Unit Anatomy
Characteristic proton behaviour

One plane of tissue exposed to a single radiofrequency
- Subsequent perpendicular planes imaged
- Varying frequency intensity and emission

T1 and T2 relaxations can be accentuated
- Characteristic tissue-type behaviour
<table>
<thead>
<tr>
<th>Tissue</th>
<th>T1-Weighted</th>
<th>T2-Weighted</th>
<th>Flair</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSF</td>
<td>Dark</td>
<td>Bright</td>
<td>Dark</td>
</tr>
<tr>
<td>White Matter</td>
<td>Light</td>
<td>Dark grey</td>
<td>Dark grey</td>
</tr>
<tr>
<td>Cortex</td>
<td>Grey</td>
<td>Light grey</td>
<td>Light grey</td>
</tr>
<tr>
<td>Fat</td>
<td>Bright</td>
<td>Light</td>
<td>Light</td>
</tr>
</tbody>
</table>
# MRI Interpretation: Tissue Guide

<table>
<thead>
<tr>
<th>Bright Hyperintense</th>
<th>T1- weighted</th>
<th>T2- weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fat</strong></td>
<td></td>
<td>Increased water</td>
</tr>
<tr>
<td>Subacute hemorrhage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein-rich fluid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paramagnetic substances</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laminar necrosis of cerebral infarction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slowly flowing blood</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Intermediate Isointense</strong></td>
<td>Grey matter darker than white matter</td>
<td>White matter darker than grey matter</td>
</tr>
<tr>
<td><strong>Dark Hypointense</strong></td>
<td>Bone</td>
<td>Bone</td>
</tr>
<tr>
<td></td>
<td>Air</td>
<td>Air</td>
</tr>
<tr>
<td></td>
<td>Increased water</td>
<td>Fat</td>
</tr>
<tr>
<td></td>
<td>Paramagnetic substances</td>
<td>Protein-rich fluid</td>
</tr>
<tr>
<td></td>
<td>Protein-rich fluid</td>
<td>Paramagnetic substances</td>
</tr>
</tbody>
</table>

***Increased water: (edema, tumor, infarction, inflammation, infection, hemorrhage (hyperacute or chronic))

***Paramagnetic substances: gadolinium, manganese, copper
MRI Interpretation: Scans

T1-weighted

T2-weighted

Flair
Contrast Media and Applications

- **IV contrast media**
  - Paramagnetic substances
  - Greatly shorten T2 and T1
  - Rare idiosyncratic reactions

- **Blood flow and vascular permeability dictate tissue enhancement**
  - Accumulations in vascular, hemorrhagic or edematous lesions
MRI Considerations: Pacemaker

- Magnetically sensitive switch
  - Self-test functions

- MR field will likely start the pacemaker's rhythm
  - Probably is harmless in most circumstances

- Tampering with device function
  - Most physicians avoid scanning patients known to have a pacemaker
Ferromagnetic metals
- Concentrate and distort the magnetic field

Proportionally larger region affected

Most surgical metals are not significantly ferromagnetic
MRI Considerations: Tissue Metal Artifact

- **Low ferromagnetism**
  - All steels are predominately iron
    - High nickel content steels (15%+)
  - Dental fillings
    - Mercury-silver amalgam or gold typically
  - Tantalum, silver, copper, plastics, lead bullets

- **MRI ‘ignores’ most metals**
  - Appear as voids (similar to bone)
Indications

- Evidence or suspicion of:
  - CNS neoplasm
  - Meningitis
  - Neurodegenerative disease
  - Acute brain ischemia or infarction
  - Brain developmental abnormality
  - Demyelination or dysmyelination disorder
- Seizures
- Myelopathy in a non-chondrodysplastic
Advantages of MRI

- Tissue can be characterized in a number of ways
- Any plane can be imaged
- Bone is ‘invisible’, so all anatomic regions can be examined
  - Low magnetic susceptibility, little interference with imaging of surrounding tissues
- Contrast medium not required
- No ionizing radiation
4 types of IVDD identified
- Disk degeneration
- Bulging of the intervertebral disk
- Disk protrusion
- Disk extrusion
MRI Applications

IMAGING DOGS WITH SUSPECTED DISC HERNIATION: PROS AND CONS OF MYELOGRAPHY, COMPUTED TOMOGRAPHY, AND MAGNETIC RESONANCE

Ian Robertson, Donald E. Thrall

- CT/myelography may be preferred for the assessment of vertebral fractures
- MRI is superior for assessment of soft tissue injuries associated with vertebral fractures
- MRI can provide prognostic information in spinal patients
Disadvantages of MRI

- Complexity and high cost
- Long scan time
- Noise and isolation experienced by patient during scan
- Exclusion of a substantial fraction of patients due to pacemakers and metallic artifacts
Questions?
Visual Summary

- https://youtu.be/djAxjtN_7VE