Ultrasonography of the kidneys
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Outline
- Imaging kidneys overview
- Basic how to image kidneys
- Imaging anatomy review
- Ultrasonographic anatomy review
- Advanced imaging techniques
- Specific ultrasound kidney descriptors
- Disease
  - Congenital dysplasia
  - Acquired

Imaging Kidneys
- Kidneys can be imaged by
  - Radiographs +/- IV/pyelographic contrast
    - Kidneys are not always visible on radiographs
    - Contrast media can impact kidney function and the risk:benefit ratio may preclude use
  - Ultrasound
    - Excellent kidney visualization
    - Available with variable user confidence
    - Non invasive
    - Interpretation of findings can be difficult

Renal tubular cyst adenocarcinoma
9 yo M(N) Flat coat retriever
Kidneys can be imaged also by
- CT +/- CE and MRI
  - Can be cost prohibitive
  - Limited availability
  - Requires anesthesia
  - CT contrast can have negative side effects
  - MRI contrast can have negative side effects related to kidney function (reported in humans)
- Scintigraphy
  (give injection of radioactive material that is filtered through kidneys, watch with gamma camera)
  - Scintigraphy has poor spatial resolution
  - Great functional information (GFR)
  - Very limited availability

Diagnostic utility for ultrasound has expanded


Most kidneys can be sufficiently imaged with the patient dorsally recumbent

However...

Interstitial and lateral approach

Some kidneys require lateral approach

Lateral approach

Kidney disease is a common cause of morbidity and mortality
Ultrasound is commonly one of the first steps in evaluating kidneys
- Size and shape and internal architecture

B Mode scans
- Static
- Real Time

Veterinary academic use in 1970's
Probe placement

- Lateral recumbency can also be used to image kidneys
  - Very dorsal approach needed
  - Approach just caudal to the ribs on the left
  - Over the last couple of ribs on the right

Fundamental ultrasound technique

- Evaluate fully in two planes (90° to each other)
  - Longitudinal
  - Transverse
  - Fanning across the tissue in in both directions

Imaging Parameters

- Roentgen findings
  1. Position
  2. Size
  3. Shape
  4. Margin
  5. Opacity
  6. Number
  7. Additional ultrasonographic findings
     - Internal architecture
     - Renal pelvis evaluation
     - Parenchymal echogenicity

The kidneys are described as ventrolateral to vertebral bodies, and in the retroperitoneal space.

**Normal Position - DOG**

- Radiographically seen as soft tissue, surrounded by retroperitoneal fat.
- Right kidney in renal fossa of caudate lobe of liver.
- Left kidney is caudal to the fundus and dorsomedial to the spleen.

**Normal Position - CAT**

- Cat kidneys are in basically the same place as dogs, however, they tend to be more at the same level.

**Kidney disease**

- There are many kidney diseases, however, the kidneys' ability to respond to disease is limited.
- Kidneys:
  - Change size and shape
  - Deposit mineral or cysts
  - Have abnormal urine flow
- There is a lot of overlap in DDx list.
- Diagnosing kidney disease can be a challenge:
  - Non-specifically systemically ill patients
  - Non-specific imaging findings
- True kidney diagnosis generally requires cytology or histopathology/biopsy.
- Using imaging information requires inferences and clinical correlation.
**Kidney size**

- **Important indicator of disease**
- **Radiographic size descriptions** – on the VD view
  - Dogs: 2.5 - 3.5 x L2
  - Cats: 2.4-3 x L2 (as 1.9 x L2 in older cats)
  - Obliquity can decrease measurement


- There is correlation between renal length and body weight
- Length seems to be the most useful
- Compensatory hypertrophy occurs


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**Kidney size - ultrasound**

- Ultrasound size measurement have been less well accepted and established
- You can measure length, height and width
- Volume is stated to correlate to renal function
  - prolate ellipsoid methods
  - Not easy or simple
  - And may be limited to being useful when used for serial evaluation of a single kidney in a patient
  - Studied predominantly to evaluate renal transplant rejection
    - Hypertrophy post transplant up to about 20%
    - Rejection volume increased 130%


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**Kidney to Aorta Ratio**

*an attempt to standardize ultrasonographic kidney measurements*

- A K/Ao ratio has been described as between 5.5 – 9.1
  - Measure the kidney length
  - Measure the aortic diameter near the kidney at maximal diameter

They are smoothly margined and have a hilus with the renal artery, vein, and ureter

The kidneys of dogs are "bean" shaped

The kidneys of cats are more round

Kidneys
- Smooth, sharp margin with an echogenic capsular line because fibrous capsule
- Cranial and caudal edges can be indistinct from edge-shadowing artifact
  • Associated with sound wave refraction (no sound makes it around the bend of the kidney to be echoed back to make the image)

These are the radiographic differentials
They can be extended to ultrasound as well, although ultrasound findings often narrow the differentials
**Anatomy- Internal Architecture**
- Cortex and medulla
- Intramedullary papillae
- Arcuate vessels
- Pelvic recess interfaces
- Renal vessels and pelvic fat in the renal hilus

**Anatomy – Cortex**
Echogenicity of the cortex is used to evaluate the kidney and compare to other organs.
- Cortex is defined as finely granular and smooth in echotexture
- Slinky –
  - Spleen → brightest
  - Liver → less
  - Kidney → least

**Anatomy - Cortex**
- However, recent papers describe that the kidney cortex may also be mildly hyperechoic compared to the liver
- It should not be iso or hyperechoic to the spleen
- Cat's kidney: can have very hyperechoic cortex (especially in fat patients increase number of fat vacuoles in the tubular epithelium)

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Anatomy - Medulla

- The medulla is defined as hypoechogenic to nearly anechoic (may be iso to hypoechogenic to the liver).
- However, it can have an echogenic outer layer, that can be hyperechogenic to the cortex.
  - Probably due to increased vessels in this area.
- It is divided into papillae by the diverticular recesses.


Anatomy - Renal pelvis

- The renal pelvis is a line of hyperechogenic tissue corresponding to connective tissue of the pelvis and surrounding hilar fat.
  - In transverse seen as a V shaped line.
  - In longitudinal as a central straight line.
  - The actual pelvis is not seen without diuresis.
- Although, high frequency probes and improved imaging capabilities allow for visualization of:
  - Normal renal pelvis in some animals.
  - Physiologic dilation (IV fluids, diuresis, PU/PD state).

Renal pelvis dilation

- Renal pelvis dilation – anechoic pelvis with near and far walls that are hyperechoic and distinct
- Pyelectasia – term for mild to moderate non obstructive pelvic dilation
- Hydronephrosis – greater degree of renal pelvis and diverticular dilation
- Pelvis dilation can be seen with
  - Renal insufficiency
  - Pyelonephritis
  - Outflow obstruction (also with ureteral ectopia)
- Greater than 13mm – 100% predictive of obstruction


Advanced kidney imaging techniques
### Resistive Index (RI)

- **Pulsed-wave Doppler ultrasound**
  - **Doppler effect** - sound wave frequency changes with movement of the reflector (RBC)
  - **Pulsed wave** - a "gate" is used to sample only the lumen of the blood vessel for ultrasound information
  - **Angular correction and vessels size cancel out**
  - A spectral trace is created, that displaced the flow signal over time

- **Indirect measurement of blood flow resistance**
- can be very useful to evaluate renal blood flow characteristics because renal function (glomerular, tubular and urine flow) needs blood flow
- Used in the kidney, at either the renal artery, interlobar, or arcuate arteries
- Usually used in smaller vessels as this is the region of most interest pathologically
- Measurement of arteriole vascular resistance – calculation to express resistance to blood flow
- Unitless value

\[
RI = \frac{\text{peak systolic velocity} - \text{end diastolic velocity}}{\text{peak systolic velocity}}
\]

- **Elevates with several diseases and is suggestive of tubulointerstitial or vascular disease**
  - Transplant rejection
  - Pyelonephritis
  - Ureteral obstruction
  - Acute renal failure
- **Glomerular dysfunction may not affect RI**

- **Prone to artifact**
  - Affected by cardiac output and rate
  - Level of kidney in relation to the heart
  - Respiratory compromise due to dorsal recumbency
  - Stress levels
  - Sedatives or other medications can affect blood flow through kidney
- Transducer pressure can artificially elevate RI
- Should not be used alone

**RI**

- Different reports on normal
  - Morrow KL et al
    - if RI greater than >0.7 is abnormal
    - normal range 0.56-0.67 (humans N = 0.59-0.63)
  - Chang YJ et al
    - RI normal upper limits 0.73
  - Novellas R et al
    - Normal cat RI - 0.7
    - Normal dog RI - 0.72


**RI to detect urinary tract obstruction**

- Used cut-off RI 0.7
- Surgically induced obstruction and relief of obstruction
- Invasive studies detected rise in renal vascular resistance with urinary obstruction
- High false negative rate (up to 27%) limits clinically usefulness, especially as the condition becomes chronic
  - Because the RI drops back off
  - Renal tissue may be being obliterated by hydronephrosis as well


**Renal biopsy**

- Determine specific disease to target therapy
- High skill set needed
- Invasive, requires anesthesia
- Requires appropriate sample handling
- Complications
  - Hematoma
  - Hemorrhage
  - Non-diagnostic sample
  - Infection
  - AV fistula

However, large multiple biopsies episodes
- No complications
- No affect on GFR
- Scar and fibrin were noted at gross pathology
- Microscopic mild fibrosis or interstitial edema
- One infarct was noted
  - Small wedge shaped lesion in kidney cortex of dogs
  - One infarct was noted
  - Microscopic mild fibrosis or interstitial atrophy
  - One infarct was noted
  - Small wedge shaped lesion in kidney cortex of dogs

Percutaneous Pyelography

- Direct injection of contrast media into the renal pelvis, percutaneously with ultrasound guidance, across the renal parenchyma.
- Nephropyelonecentesis is performed and an equal amount of contrast is injected into the pelvis.
- Followed by radiographs.
- Renal pelvis dilation is necessary to a degree that facilitates needle placement.

Complications:
- Leak of contrast out and around the kidney
- Hemorrhage – Perinephric or intrapelvic (which has the potential to cause obstruction).

Percutaneous ethanol ablation

- Tissue can be ablated with ethanol injections in humans and dogs.
- A paper report case with this procedure performed in a renal cyst in a dog.
- Generally cysts are clinically insignificant; however, if they cause pain, infection, or obstruction they may require intervention.
- Historically, they are treated with drainage, however, they often return.
- Ethanol ablates the cyst lining, preventing recurrence.
- Risk of peri-cyst damage, hemorrhage, and incomplete ablation.


Specific ultrasound kidney descriptors

"See the signs"
- Corticomedullary Rim Sign
- Halo Sign
- Subcapsular Hypoechoic Rim Sign
- Medullary Band Sign
**CM distinction**

- **Corticomedullary distinction**
  - Because the cortex is hyperechoic to the medulla
  - Lose this distinction when
    - Medulla is hyperechoic
  - Increased distinction when
    - Cortex is hyperechoic
  - Both are non-specific and can be present with acute, chronic, and inflammatory disease

**Corticomedullary Rim Sign**

- Curvilinear echogenic line parallel to the corticomedullary junction
- Mineral in the tubular epithelium and basement membrane
- Possible significance: Seen with
  - Ethylene glycol-induced Ca oxalate nephrosis
  - Hypercalciemia
  - Pyogranulomatous vasculitis
  - Idiopathic tubular necrosis
  - Chronic interstitial nephritis
- Although it may indicate poor prognosis when seen with some disease
- Tends persist even if kidney disease appears to resolve

**Halo Sign**

- Unclear usefulness
  - Seen with presumed ethylene glycol toxicity and secondary oxalate nephrosis
  - The cortex and medulla are described as having increased echogenicity with a hypoechoic zone at the corticomedullary junction
  - Is this normal hypoechoic medulla between two hyperechoic regions?
  - Does this represent a different description of the corticomedullary rim sign or even the medullary band?
  - Two additional images included here: one confirmed (a second presumed) end stage kidneys with medullary fibrosis and mineralization – the one on the left had a hypoechoic zone between the cortex and the bright medulla – is this a halo sign?


Subcapsular Hypoechoic Rim Sign

- Hypoechoic subcapsular thickening
- Why – lymphatic drainage for the kidney is formed by a superficial capsular system of capillaries
- Significant association between this and renal LSA
- Extra nodal renal LSA 5-20% of LSA in cats
- Can have renal LSA without rim
- Non specific findings that indicate renal LSA
  - Renomegaly +/- irregular shape
  - Focal nodules/masses (usually hypoechoic)
  - Hypoechoic cortices
  - Subcapsular effusion (? fluid or tissue)
- DDX
  - undifferentiated neoplasia
  - renal anaplastic carcinoma
  - FIP


Medullary Band Sign

- The medullary band is described as a hypoechoic zone, in the (inner) medulla
- Caused by medullary
  - Congestion/Edema
  - Hemorrhage
  - Necrosis
- 20 cases of Leptospirosis
  - 3 had normal kidneys
  - 17 had abnormal kidneys
    - Renomegaly
    - Pyelectasia
    - Post-renal effusion
    - Increased cortex echogenicity
  - 6 had medullary band sign
    - (only seen in the leptospirosis affected dogs?!) 


Ultrasonographic appearance of some kidney diseases

- Congenital
- Acute
- Chronic
- Pseudocyst
- Pyelonephrosis
- Neoplasia
Congenital renal dysplasia

- Renal dysplasia (also called juvenile nephropathy, and familial renal disease)
  - disorganized development of the renal parenchyma leading to small, irregular, fibrosed kidneys
  - Primary differential is end stage chronic kidney disease
- Caused by imperfect inductive interaction between the mesonephric duct and the metanephric blastema, that leads to failure of complete differentiation
- Hereditary versus neonatal infection (can also see hypoplasia, agenesis and congenital cyst)
- Causes renal failure in young animals with a chronic disease appearance

Microscopic changes
- Persistence of primitive kidney form
  - Mesenchyme
  - Tubules/Ducts
  - Nephrons
  - Glomeruli
- Secondary chronic disease
  - Wastes in the parenchyma (dystrophic)
  - Obstruction/inflammation
    - Fibrous tissue
    - Degenerative and inflammatory tissue
  - Lipid in renal tubular epithelium from anoxic or toxic change

Gross pathology findings
- Small kidneys
- Irregular to lobulated from fibrosing bands
- Additional descriptions include
  - A thin cortex
  - Incomplete lobulation of the medullas and pelvic structures

Congenital renal dysplasia case examples

- 5 year old M(N) Labrador Retriever
  - Azotemic, post HBC and fractured hind limb
  - Azotemia persisted, pain, and clinical signs associated with renal failure
  - Short period of stabilization of clinical signs with supportive care for chronic kidney disease
  - Main findings:
    - Small size
    - Lack of normal corticomedullary lobulations

- 1 year old M Shih Tzu
  - Azotemia and unthrifty through entire life
  - A few years of stable disease
  - PTS at 5 years old
  - Main findings:
    - Small size
    - A thin cortex
Acute kidney disease

- Includes
  - Leptospirosis (see earlier slide re the Medullary Band sign)
  - Lyme nephritis (poorly understood pathology and poor prognosis)
  - Toxins
    - Lilly ingestion
    - Grape/Raisin intoxication
    - Non steroidal drugs
    - Ethylene glycol (anti-freeze)

Ultrasonographic appearance of acute kidney disease

- Normal
  
  - Increased renal echogenicity
    - Cortical
    - Medullary
  - Renomegaly
  - Pyelectasia
  - Perirenal fluid/retroperitoneal effusion

OR

- Often ultrasound is used to rule out chronic disease and help make the presumptive diagnosis of acute disease


Chronic disease

- Ultrasonographic appearance
  - Small and irregular
  - Thick and hyperechoic cortices
  - Poor corticomedullary distinction
  - Infarcts
    - Wedge shaped hyperechoic areas (narrow toward the pelvis)
  - Cysts
**Perirenal pseudocysts**

- Radiographic appears as a smoothly margined renomegaly
  - DDX: LSA, FIP, hydronephrosis, pyelonephritis, amyloidosis and less likely polycystic kidney disease (usually irregular)
- Cause is unknown
  - In human – trauma, surgery, neoplasia, venous congestion
  - In veterinary – associated with chronic renal disease or idiopathic
- Azotemia is usually from primary renal disease but can be from compression of the renal pelvis and proximal ureters
- Treat ASAP to preserve renal function
  - manage underlying renal disease
  - Ultrasound guided Percutaneous drainage (may recur or have hemorrhage)
  - surgical capsulectomy

**Pyelonephritis/pyonephrosis**

- Common ultrasonographic appearance
  - Pyelectasia → hydronephrosis
  - Irregular shape to the renal pelvis/diverticula
  - Proximal ureteral dilation/wall thickening
  - Hyperechoic tissue around the renal pelvis
  - Acute kidney disease changes
  - Perirenal/retroperitoneal fluid
  - Pain on probe pressure

**Perirenal pseudocysts case examples**

- 12 yo F(S) DSH Bilateral
- 12 1/2 yo M(N) DSH Left only
- 12 M(N) DSH Right only
- Post draining

**Pyelonephritis/pyonephrosis case examples**

- 9 yo Pomeranian mix chronic hind limb paralysis
- 5 ½ yo German Shepherd systemic Aspergillosis
Neoplasia

- Often renomegaly is note on radiographs
- Usually unilateral lesions
- Can have bilateral tumors
  - multifocal primary neoplasia
    - Carcinoma, nephroblastoma, tubular adenocarcinoma, others
  - multicentric/metastatic neoplasia
    - Hemangiosarcoma, lymphoma
- Hypoechoic, cavitated and heteroechoic mass lesions
- DDx - Cyst, abscess/granuloma, hematoma
- Case examples
  - LSA (multicentric disease)
  - Carcinoma
  - Hemangiosarcoma
  - Tubular adenocarcinoma

Multicentric LSA

Inappetance
- Stranguria/hematuria
- PPHx: SC LSA
- Chronic pancreatitis

Right kidney mass (3cm)

Marked bladder wall thickening

Suspect carcinoma

- 14 yo T (S) Toy poodle
- Chronic kidney disease
- 7 ye M/N Puggle
- Lethargy, PD, pain

Left kidney too!
Hemangiosarcoma
6 ½ yo MN Cocker spaniel
perirenal HSA grade 2

Renal tubular cyst adencarcinoma
9 yo M(N) Flat coat retriever

References
References