How to treat oliguric AKI

Jiwoong Her DVM MS DACVECC
Associate Professor
Emergency and Critical Care
Nephrology and Extracorporeal Therapies
North Carolina State University

Definition

- Normal: UOP 1-2 ml/kg/h
- Polyuria: > 2 ml/kg/h
- Oliguria
  - Relative oliguria: < 2 ml/kg/h with IV fluid, renal disease
  - Absolute oliguria: < 1 ml/kg/h
- Anuria 0-0.05 ml/kg/h

AKI

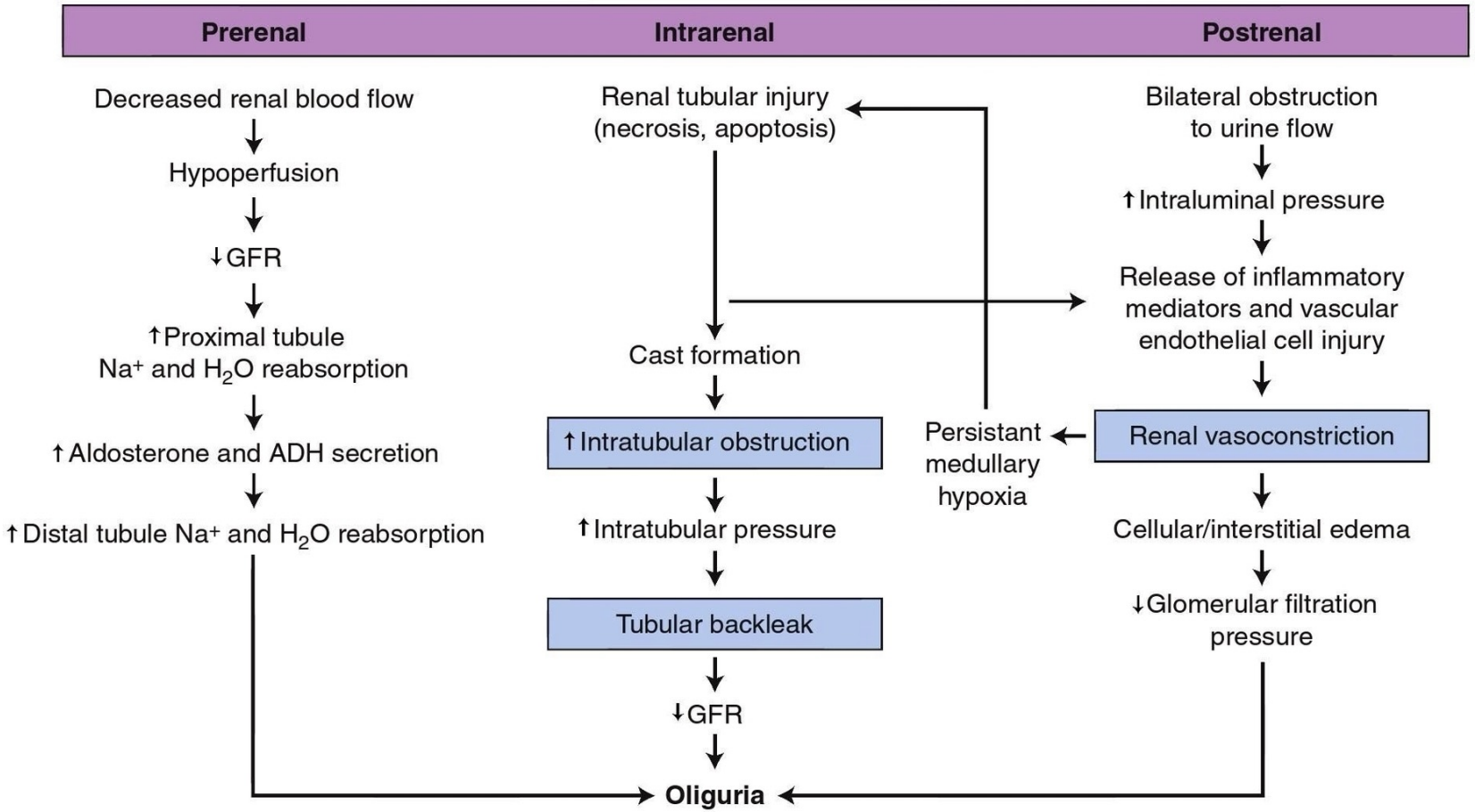
- *Human definition of oliguria: < 0.5 ml/kg/h over 6h (KDIGO)*
- *IRIS AKI guideline: < 1 ml/kg/h over 6 hours*

Why do we care about urine output?

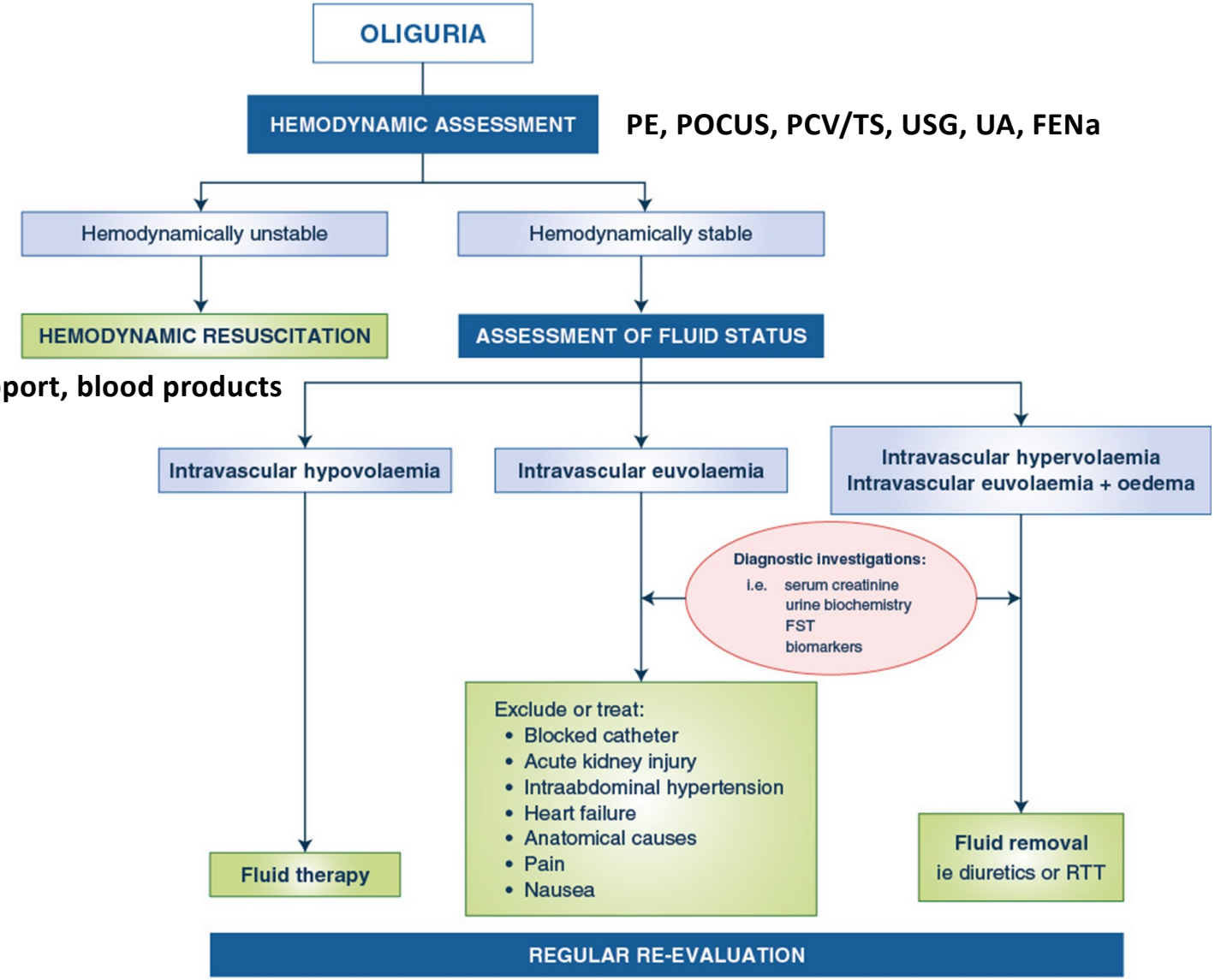
- **Improve diagnostic performance**
  - **UOP + Creatinine** (> Creatinine alone) (Bianchi, JAMA 2021)
- **Complications**
  - Fluid overload, hyperkalemia
- **Prognostication**
  - Oligo-anuria: consistent risk factors for mortality
  - Marker of disease severity
  - Narrow window of opportunity for recovery in the absence of dialytic intervention

  - 29 dogs with hospital-acquired AKI: oliguria (< 0.25 ml/kg/h over 6h) x20 times worse outcome (Behrend 1996)

Mechanisms of oliguria in AKI



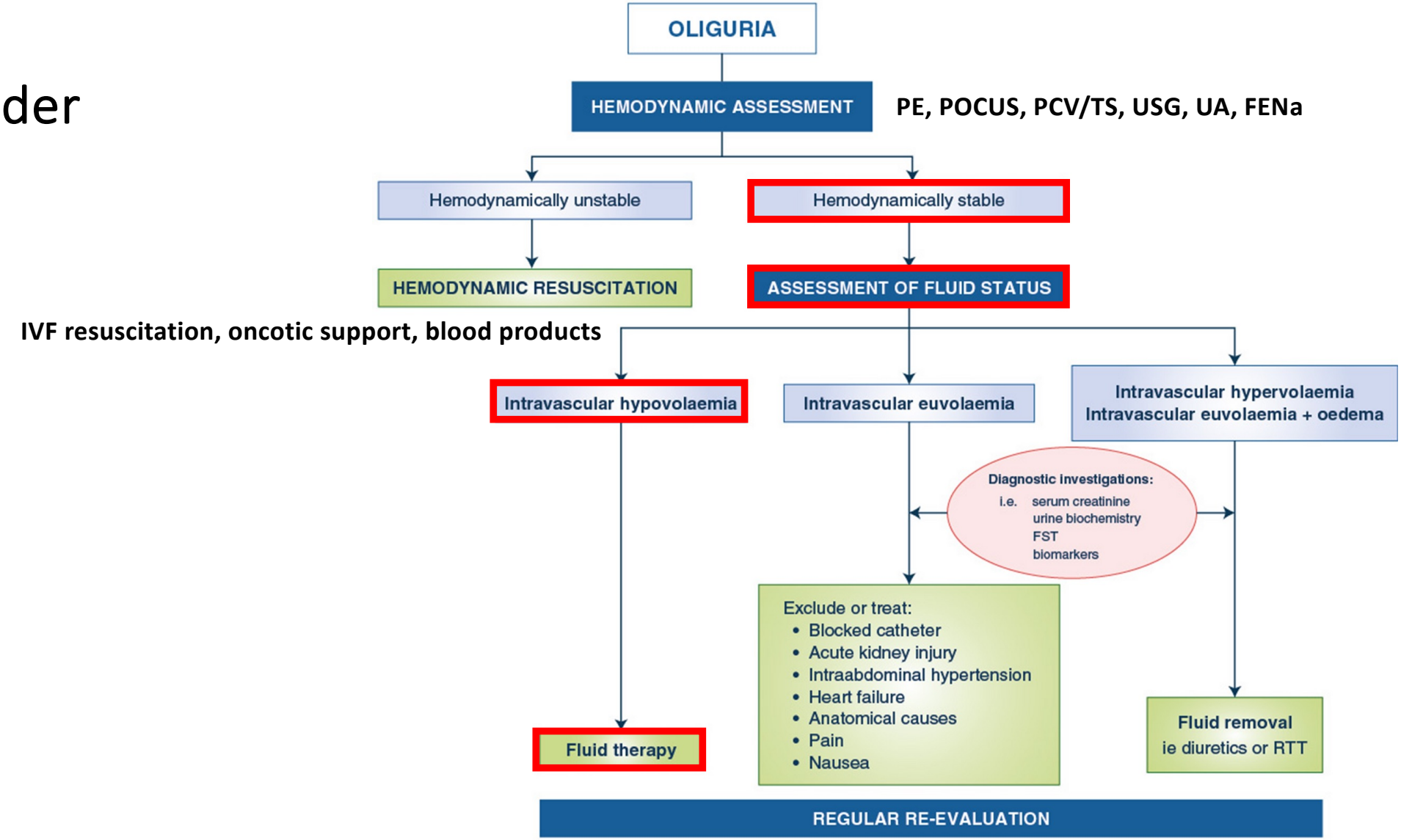
Algorithm


OLIGURIA
HEMODYNAMIC ASSESSMENT
PE, POCUS, PCV/TS, USG, UA, FENa
Hemodynamically unstable
Hemodynamically stable
HEMODYNAMIC RESUSCITATION
ASSESSMENT OF FLUID STATUS
IVF resuscitation, oncotic support, blood products
Intravascular hypovolaemia
Intravascular euvolaemia
Intravascular hypervolaemia
Intravascular euvolaemia + oedema
Diagnostic investigations:
i.e. serum creatinine
urine biochemistry
FST
biomarkers
Exclude or treat:
• Blocked catheter
• Acute kidney injury
• Intraabdominal hypertension
• Heart failure
• Anatomical causes
• Pain
• Nausea
Fluid therapy
Fluid removal
ie diuretics or RTT
REGULAR RE-EVALUATION

Rider, 4 yo MN Mixed

- Progressive lethargy, anorexia for the past 4 days
  - Transferred from primary care vet to NCSU for obtunded mentation, severe hyponatremia (108), azotemia, and hyposthenuria
  - Concern for decreased urine output
- Notable findings on day 1
  - PCV 58, TS 7.7, Lact 4.2
  - BUN 173, Crea 2.4, K 5.0
  - USG 1.009
  - Doppler 90~100 mmHg
  - Na 128, K 5.6

Rider

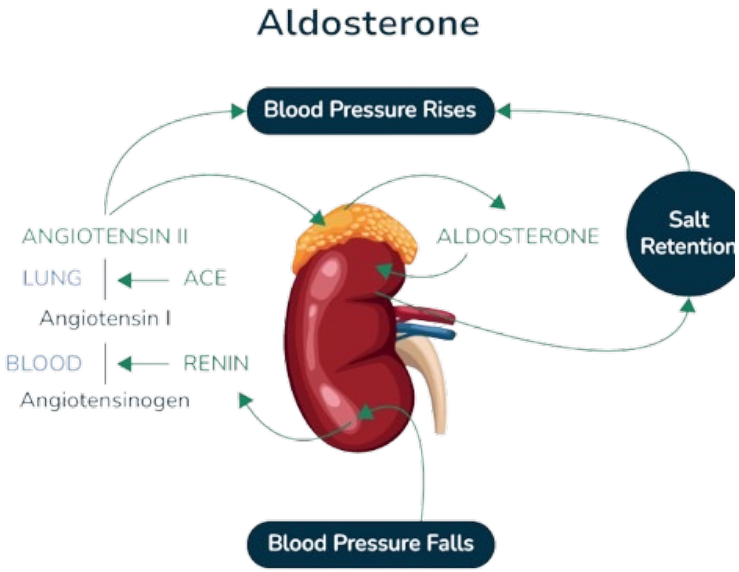

OLIGURIA
HEMODYNAMIC ASSESSMENT
PE, POCUS, PCV/TS, USG, UA, FENa
Hemodynamically unstable
Hemodynamically stable
HEMODYNAMIC RESUSCITATION
ASSESSMENT OF FLUID STATUS
IVF resuscitation, oncotic support, blood products
Intravascular hypovolaemia
Intravascular euvolaemia
Intravascular hypervolaemia
Intravascular euvolaemia + oedema
Diagnostic investigations:
i.e. serum creatinine
urine biochemistry
FST
biomarkers
Exclude or treat:
• Blocked catheter
• Acute kidney injury
• Intraabdominal hypertension
• Heart failure
• Anatomical causes
• Pain
• Nausea
Fluid therapy
Fluid removal
ie diuretics or RTT
REGULAR RE-EVALUATION

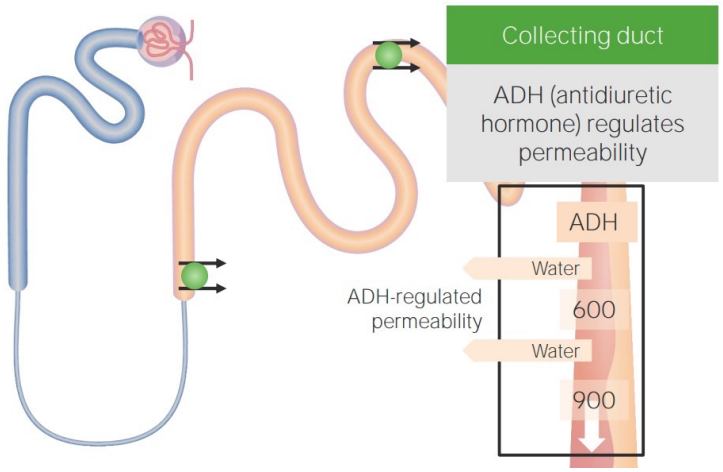
Rider: volume status

- Small left ventricular end-diastolic diameter
- Hyperlactatemia (4.2)
- Elevated PCV/TS
- Perfusion parameters: weak pulse, HR 180, obtunded mentation, injected mucous membrane, CRT < 1 sec
- **Q) Oliguria due to hypovolemia?**
- **Q) Resuscitate with which fluid, how fast?**

Mechanisms of oliguria in hypovolemia

- Renin-Angiotensin-Aldosterone System (RAAS) promote salt/H2O retention
- Anti-Diuretic Hormone (ADH) promote H2O reabsorption





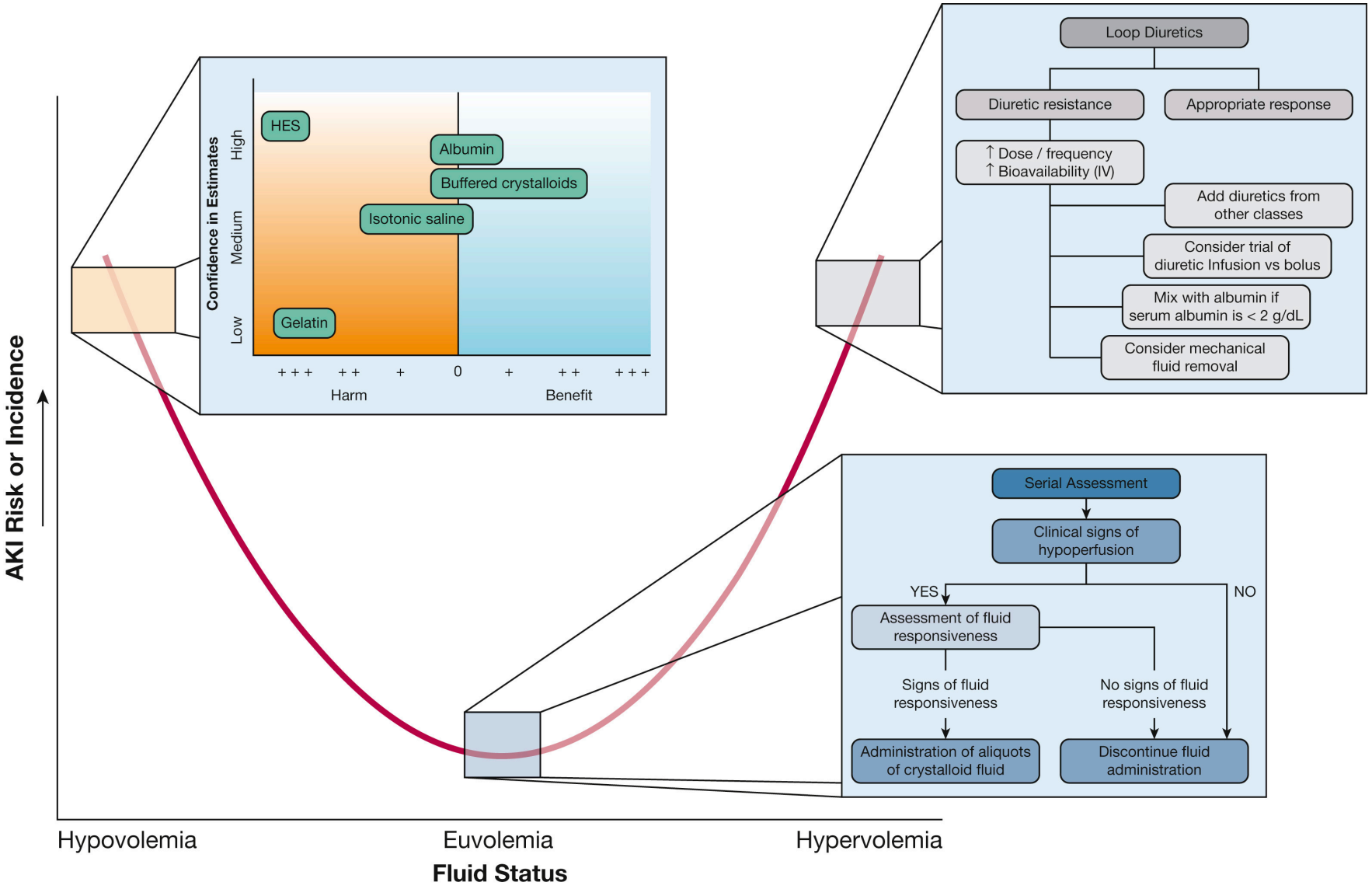
Fractional excretion of sodium

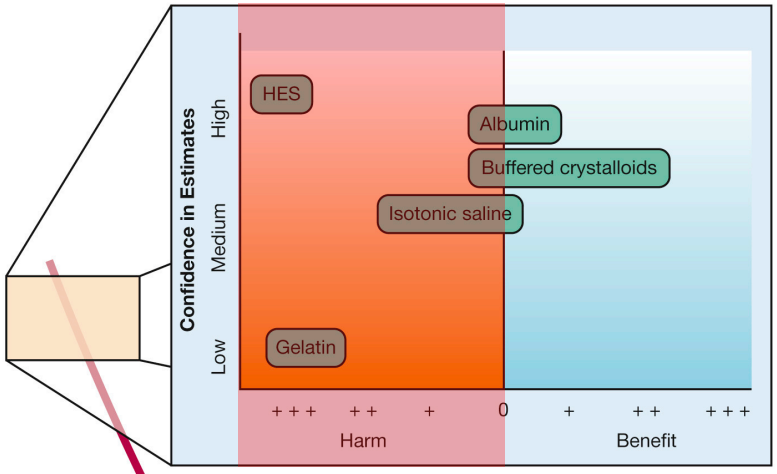
- Normally, sodium reabsorb > 99% of Na = Fractional excretion < 1%
  - FENa = (Urine Na x Serum Crea) / (Serum Na x Urine Crea)
  - Measures the percent of filtered sodium that is excreted in the urine.
- **FENa < 1% indicates volume-responsive (pre-renal) AKI**
  - In pre-renal, kidney attempts to conserve sodium → FENa < 1%
  - Intrarenal AKI, impaired tubular injury leads to higher FENa

Fractional excretion of sodium

- **In mildly azotemic patients**
  - History/PE indicates dehydration/hypovolemia + FENa < 1% = very likely pre-renal azotemia
- *Less reliable in patients who have seen diuretics

Pro	Cons
Spot-check: easy to measure (concurrent urine, serum chemistry)	Generally collected over 24h is more reliable than spot
Despite these (except for breed), FENa is very sensitive test in human AKI	Inter-individual variation (breed, gender, age)
	Intra-individual factors (diet, metabolic alkalosis)
Initial fluid therapy did not impact the utility (JVIM 2018). FENa correlate with GFR despite concurrent IVF (Segev 2015)	Confounders: diuretics, IVF, $NaHCO_3$, alpha-2 agonists, comorbidities (CKD, liver failure, CHF, sepsis-AKI, contrast, pigment nephropathy)
	Cannot measure in anuric patients

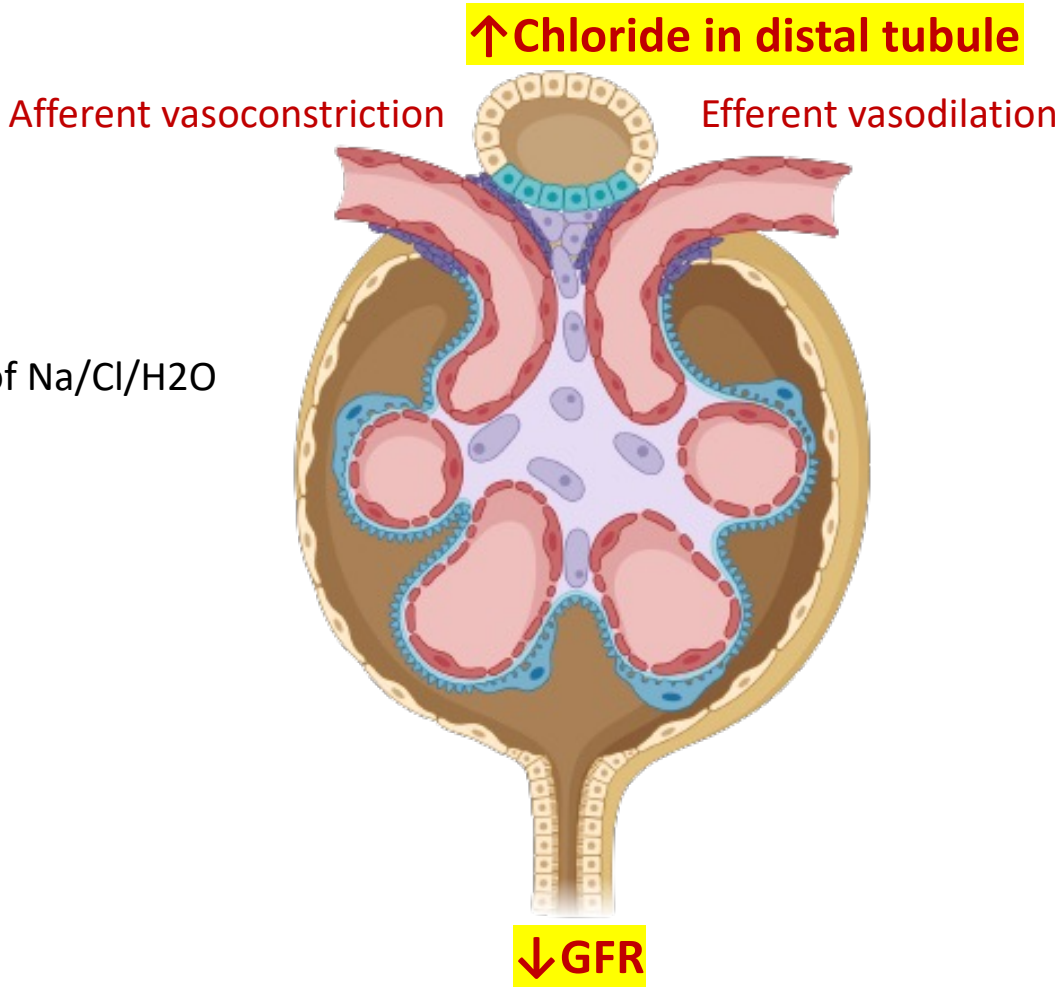

AKI Risk or Incidence
Hypovolemia
Euvolemia
Hypervolemia
Fluid Status
Confidence in Estimates
High
Medium
Low
HES
Albumin
Buffered crystalloids
Isotonic saline
Gelatin
+ + +
+ +
+
0
+
+ +
+ + +
Harm
Benefit
Loop Diuretics
Diuretic resistance
Appropriate response
↑ Dose / frequency
↑ Bioavailability (IV)
Add diuretics from other classes
Consider trial of diuretic Infusion vs bolus
Mix with albumin if serum albumin is < 2 g/dL
Consider mechanical fluid removal
Serial Assessment
Clinical signs of hypoperfusion
YES
NO
Assessment of fluid responsiveness
Signs of fluid responsiveness
No signs of fluid responsiveness
Administration of aliquots of crystalloid fluid
Discontinue fluid administration



	Do	Don't
Indication	IV hypovolemia	Oliguria without hypovolemia
Type of fluid	Buffered crystalloids (P-Lyte, Normosol-R, LRS), Natural colloid (albumin, plasma) *Avoid synthetic colloid, 0.9% NaCl*	Starches
Volume	Boluses of small aliquots *(10 ml/kg in dogs, 5 ml/kg in cats, over 15-20 min)*	High volumes
Duration	Until hypovolemia corrected	Until AKI resolved

Fluid therapy in AKI

- In health, kidneys regulate GFR via
  - Tubuloglomerular feedback
    - ↑ Chloride → ↓ GFR
    - Protective mechanism to prevent loss of Na/Cl/H2O



Yunos, JAMA, 2012

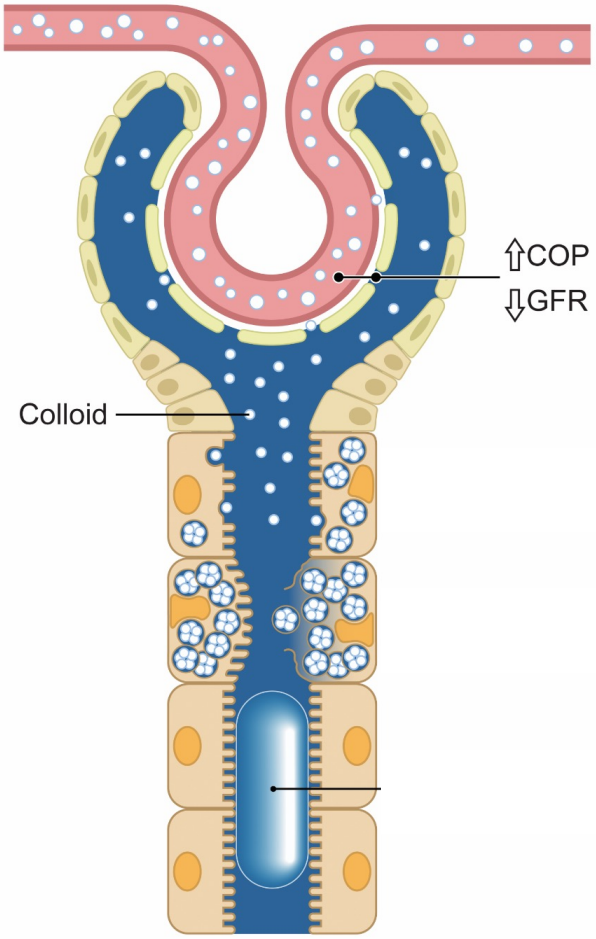
Fluid therapy in AKI

- Avoid 0.9% NaCl
  - **Higher chloride content → decrease in GFR**
  - In human ICU patients, ↑ Chloride is associated with
    - ↑ creatinine
    - ↑ incidence of AKI
    - ↑ need for dialysis

Type	Replacement			Maintenance
Tonicity	Isotonic			Hypotonic
Product	LRS	Normosol-R Plasmalyte	0.9% NaCl	0.45% NaCl
Na mEq/L	130	140	154	77
Cl mEq/L	109	98	154	77
Mg mEq/L	-	3	-	-
K mEq/L	4	5	-	-
Ca mEq/L	2.7	-	-	-
Buffer	D/L lactate	acetate/gluconate		

Synthetic colloid in AKI

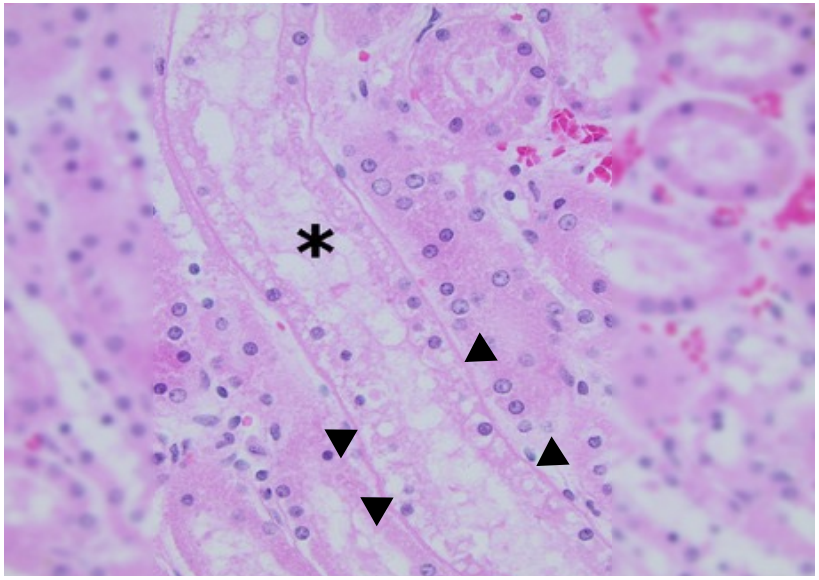
- **Avoid synthetic colloid**
  - ↓GFR
  - Tubular cellular dysfunction
  - Osmotic nephrosis, swell tubular cells
  - Clog up in tubule → ↓UOP
- Therefore,
  - Associated with increased in-hospital mortality
  - Increased need for renal replacement therapy



Adamik, Yozova, Frontiers, 2021

Synthetic colloid in AKI

- What do we know in dogs?
  - Renal tubular vacuolization (= degeneration)
  - For every 1 mL/kg increased in synthetic colloid a dog received, there was 1.6% increased chance of having more severe renal tubular vacuolization



Schmid, JVECC, 2019

Synthetic colloid in AKI

- *What would I do?*
  - *Harm (ischemic injury) from hypovolemia >> Potential, later damage induced by colloid*
    - *Ex) financial constraint in using Plasma, while patient is hypovolemic, hypoalbuminemic: stop crystalloid infusion & good indication for vetstarch bolus (5 ml/kg over 15-30 min) and CRI (20 ml/kg/day)*
  - *Try not to give it as much as I can*

Fluid therapy in AKI

- **After resuscitation**?

1. **Rehydration** phase: **Isotonic crystalloid**
   - 15 kg dog, 5% dehydration (15 x 0.05 x 1,000 = 750 ml) corrected over 24h (31 ml/h) using LRS or Normosol-R

Type	Replacement			Maintenance	Hypertonic
Tonicity	Isotonic			Hypotonic	Hypertonic
Product	**LRS**	**Normosol-R Plasmalyte**	0.9% NaCl	**0.45% NaCl**	7.2% NaCl
Na mEq/L	130	140	154	77	1232
Cl mEq/L	**109**	**98**	154	**77**	1232
Mg mEq/L	-	3	-	-	-
K mEq/L	4	5	-	-	-
Ca mEq/L	2.7	-	-	-	-
Buffer	D/L lactate	acetate/gluconate			

Fluid therapy in AKI

- **After resuscitation**?

1. **Rehydration** phase: **Isotonic crystalloid**
2. **Maintenance** phase: switch to maintenance fluid (**0.45% NaCl**) in euhydrated patients
   - $(BW)^{0.75}$ x 132 ml/day (dogs)
   - $(BW)^{0.75}$ x 70 ml/day (cats)
   - Rider: $(15\ kg)^{0.75}$ x 132 = 41 ml/h

Type	Replacement			Maintenance	Hypertonic
Tonicity	Isotonic			Hypotonic	Hypertonic
Product	**LRS**	**Normosol-R Plasmalyte**	0.9% NaCl	**0.45% NaCl**	7.2% NaCl
Na mEq/L	130	140	154	77	1232
Cl mEq/L	**109**	**98**	154	**77**	1232
Mg mEq/L	-	3	-	-	-
K mEq/L	4	5	-	-	-
Ca mEq/L	2.7	-	-	-	-
Buffer	D/L lactate	acetate/gluconate			

Higher fluid rate does NOT improve GFR

No change in GFR with higher rate of IVF

LRS, 10 mL/kg/h for 4 hours

0.9% NaCl, 6 mL/kg/h for 4 hours

Boscan et al. AVJR 2010, McClellan et al. AJVR 2006

Rider: initial fluid resuscitation

- ***Q) Oliguria due to hypovolemia?***
  - *Yes, suspect*
- ***Q) Resuscitate with which fluid, how fast?***
  - *LRS 10 ml/kg over 15 minutes*
  - *Followed by maintenance rate (41 ml/h, 0.45% NaCl) + 5% dehydration corrected over 24 hours (31 ml/h, LRS)*
- CBC/Chem/UA, CXR, AUS, 4Dx, Lepto PCV/Titer, Urine culture

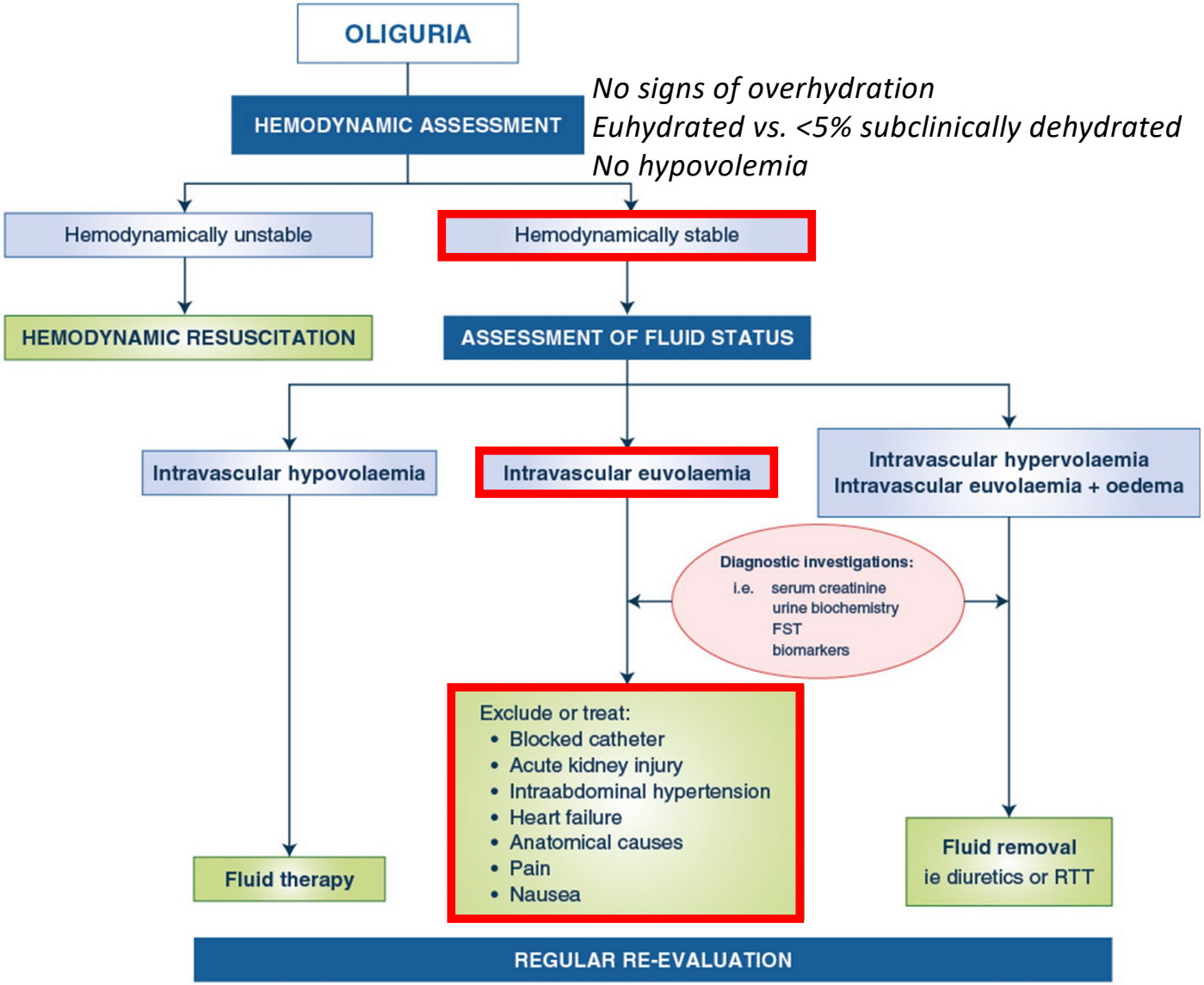
Rider

- Monitor
  - PCV/TS, UOP, USG, POCUS, vBG
- Outcome
  - UOP increased to 4-5 ml/kg/h on day 2, continued medical management. Continued in/out matching
  - AKI of unknown etiology
  - Discharged on day 5

Sarge, 9 yo MN GSD

- Presented for PU/PD (9 days), vomiting (1 day)
- On presentation
  - PCV/TS: 50/8.2
  - POCUS: unremarkable, no free fluid
  - BP: 113/83/81
  - PE: no overt signs of dehydration. Unremarkable perfusion parameters
- Initial diagnostics
  - CXR: unremarkable
  - CBC: HC 47%, WBC 11K, PLT 61K
  - Chem: **BUN 45, Crea 5.1**, P 10.7, Alb 2.9
  - UA: USG 1012, 3+ protein, 3+ blood, 1-3 WBC/hpf
  - Witness **lepto (+)**
  - CT: **bilateral perinephric effusion**

Sarge


OLIGURIA
HEMODYNAMIC ASSESSMENT
No signs of overhydration
Euhydrated vs. <5% subclinically dehydrated
No hypovolemia
Hemodynamically unstable
Hemodynamically stable
HEMODYNAMIC RESUSCITATION
ASSESSMENT OF FLUID STATUS
Intravascular hypovolaemia
Intravascular euvolaemia
Intravascular hypervolaemia
Intravascular euvolaemia + oedema
Diagnostic investigations:
i.e. serum creatinine
urine biochemistry
FST
biomarkers
Exclude or treat:
• Blocked catheter
• Acute kidney injury
• Intraabdominal hypertension
• Heart failure
• Anatomical causes
• Pain
• Nausea
Fluid therapy
Fluid removal
ie diuretics or RTT
REGULAR RE-EVALUATION

Sarge

- Initial fluid therapy
  - **P-Lyte** to cover **rehydration** + **0.45% NaCl** for **maintenance** rate
  - Urinary catheter placed, monitoring TPR, BP, PCV/TS, USG, UOP, POCUS, Renal panel

Monitoring of oliguric patients

- TPR 6-8h
- Daily PCV/TS/Glucose/Lactate, Renal profile
- BP q6-8h
  - Target: Systolic 100~160 mmHg, MAP 60-100 mmHg
- +/- ECG (if concerned hyperkalemia)
- Weight q4-6h
- UOP q4-6h

How to assess urine output?

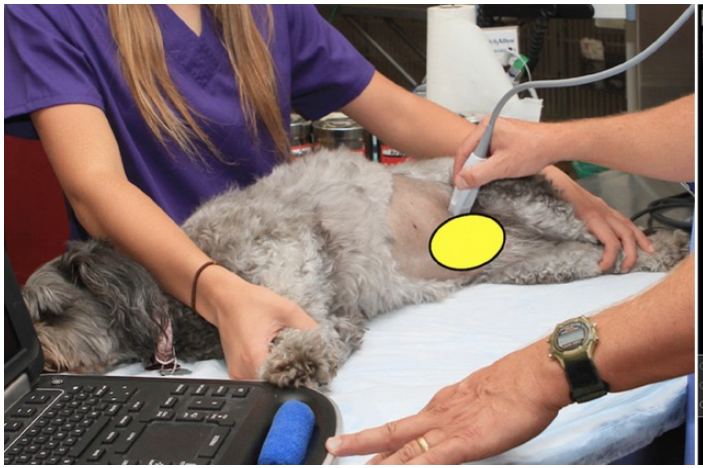
- Indwelling urinary catheter
- Point-of-care ultrasound: accurate estimation (+/- 10% error)

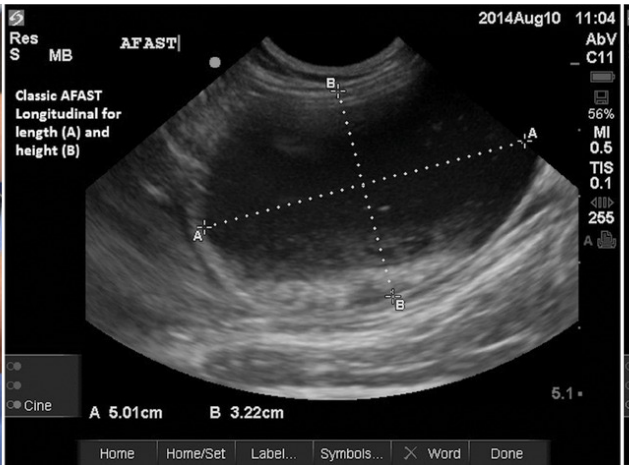
Formula 1: $UV\ (mL) = L \times W \times H \times 0.52$ ***Simplest, easy to remember***

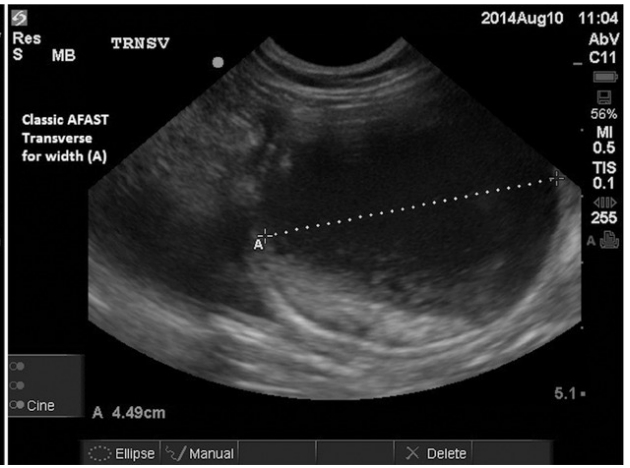
Formula 2: $UV\ (mL) = L \times W \times \frac{DL \times DT}{2} \times 0.625$

Formula 3: $UV\ (mL) = L \times W \times H \times 0.2\pi$

Maximum length (L) and heigh (H) in sagittal, maximum width (w) in transverse







Identify fluid overload

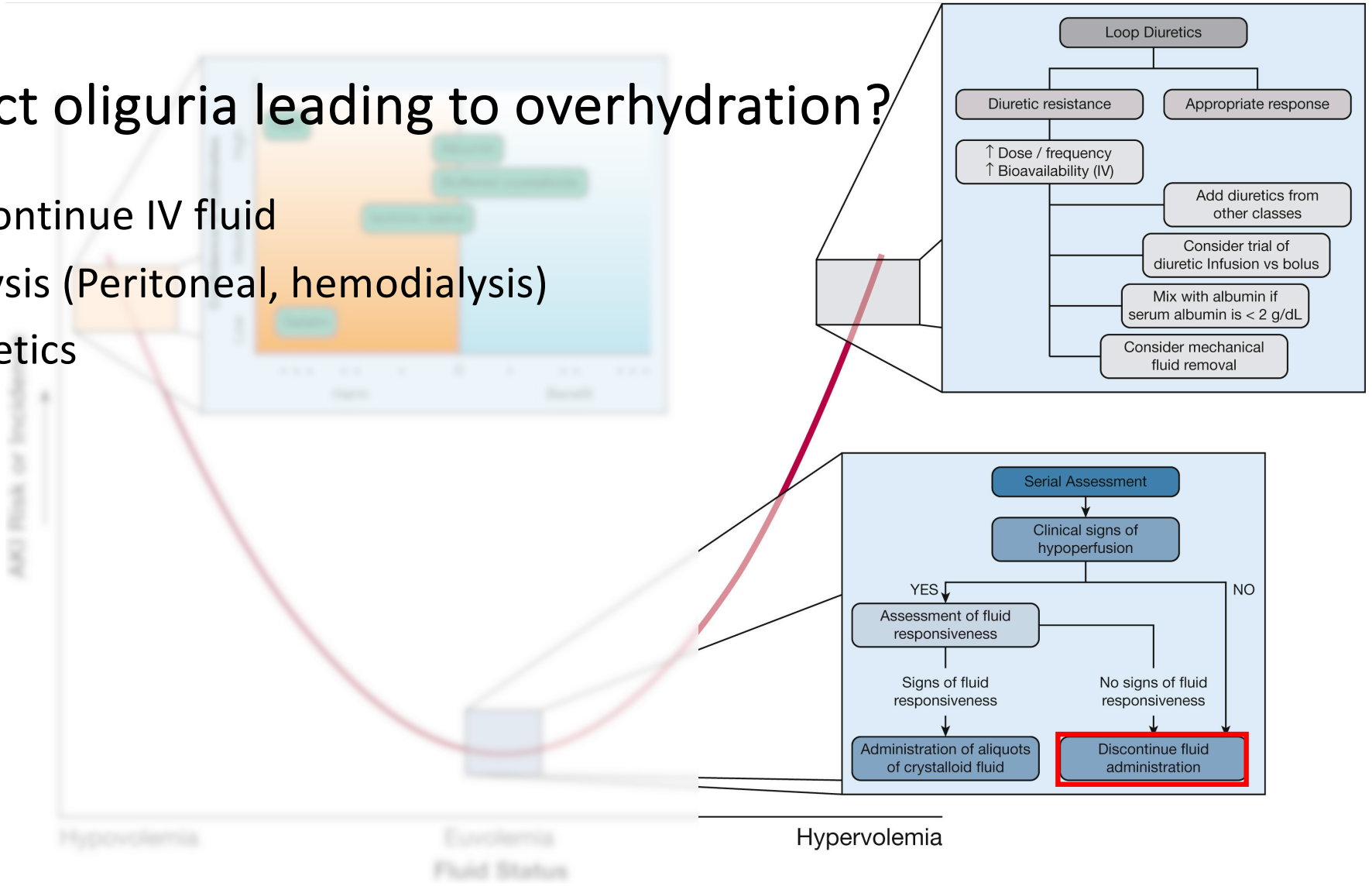
Clinical findings	Radiographic findings	Ultrasonographic findings
Increased weight	Body wall edema	SQ edema
Tissue edema (limb, paw, chemosis, dependent regions)	Pleural effusion	Pleural effusion
Serous **nasal discharge**	Cardiomegaly	B-lines
Increased RR or effort	Enlarged pulmonary artery	Enlarged La:Ao
Reduced SpO2	Enlarged caudal vena cava	Enlarged caudal vena cava
Novel murmur, Novel gallop	Enlarged pulmonary vein	Decreased caudal vena cava collapsibility index
GI signs (vomiting, diarrhea, anorexia)	Loss of serosal detail	Ascites
Hypertension	Distended intestines	Ileus
		Intestinal wall thickening
		Hyperechoic mesentery and pancreas
		Hepatic congestion
		GB wall edema
		Perirenal edema

Sarge, oliguria

- UOP
  - 12a: **1.65** ml/kg/h (**relative** oliguria), weight **44kg**
  - 4a: **1.26** ml/kg/h,
  - 8a: **0.9** ml/kg/h (**absolute** oliguria), weight **47 kg**
- Weight: 44 kg → 47 kg
  - (47-44)/44 = **6.8% weight gain**

Suspect oliguria leading to overhydration?

1. Discontinue IV fluid
2. Dialysis (Peritoneal, hemodialysis)
3. Diuretics



Fluid therapy in oliguric patients

- IVF during oliguric, **euhydrated** patient: use 0.45% NaCl to **match in/out**
- IVF in **overhydrated** patient: **discontinue** IVF

In	Out
NG tube nutrition 15 ml/h	1.5 ml/kg/h in 30 kg dog = 45 ml/h
IV/PO medication, flushes 5 ml/h	
Zero IVF	
Total 20 ml/h	Total 45 ml/h
0.45% NaCl 25 ml/h (45 out – 20 in) until new UOP is measured in 4-6 hours	

Considerations in diuretic use

- **Major indication: attempt to treat hyperkalemia, reduce the degree of volume overload**
  - Diuretics should be avoided in dehydrated, hypovolemic patients
- **Diuretics do NOT treat anuria/oliguria or AKI**
  - Easier to manage non-oliguric patient (less likely to have hyperkalemia, overhydration)
  - ↑ Urine output due to diuretic
    - ≠ improved GFR
    - ≠ improve azotemia
- No evidence for improved outcomes and NOT recommend in human medicine
  - Concern for diuretic delaying dialysis

Diuretics can be considered as a segway to dialysis or if dialysis is not available

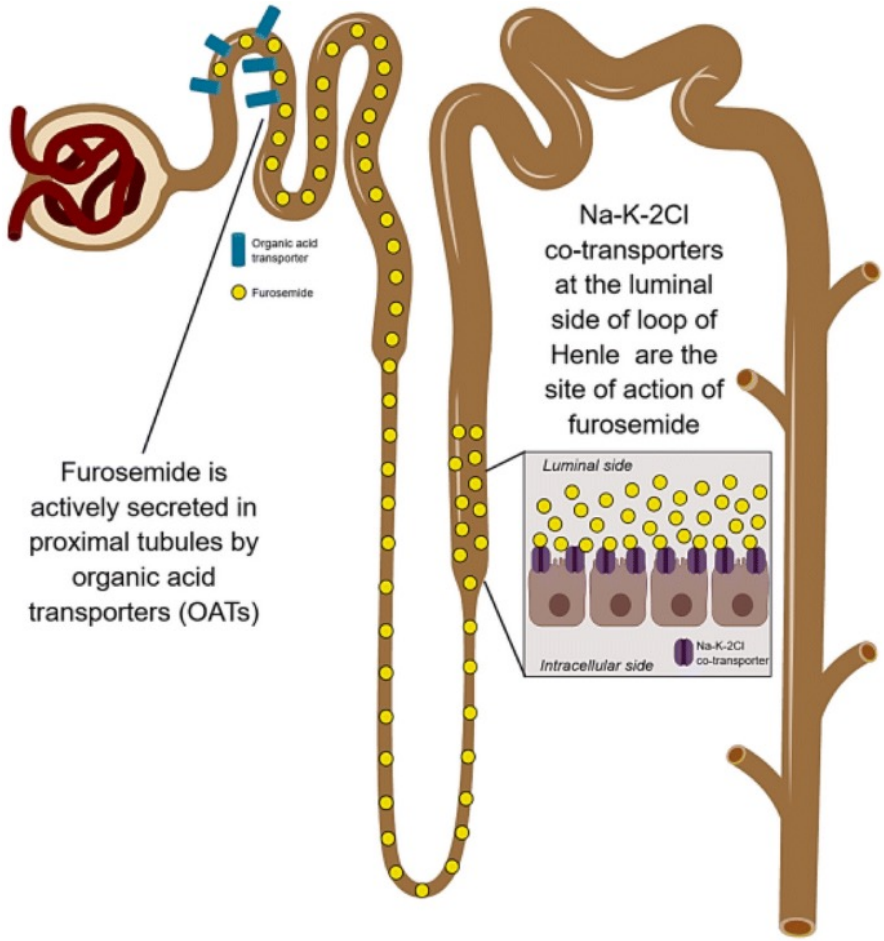
Chapter 3, Canine and Feline Nephrology and Urology

Commonly considered drugs to convert oliguria to polyuria

1. Furosemide
2. Mannitol
3. Dopamine
4. Fenoldopam
5. Diltiazem

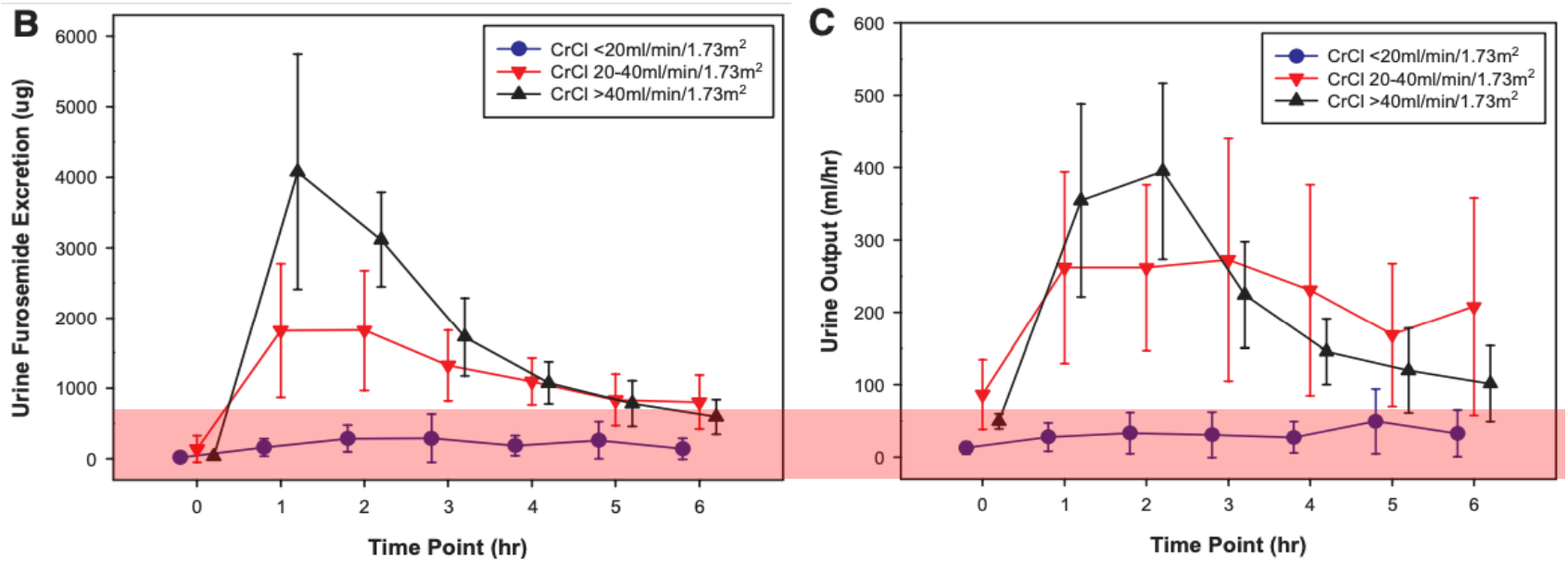
Furosemide

- Mechanism of action
  - Adequate delivery/renal blood flow
  - Secreted into proximal tubule
  - Transported to TAL, bind NKCC
- Goal of furosemide
  - Increase urine flow → flush cast
  - Reduces energy requirement of cells
  - Managing fluid balance, hyperkalemia
- **Dose**
  - 1-4 mg/kg then q6-12h as needed to effect
  - 0.25-1 mg/kg/h for up to 6 hours



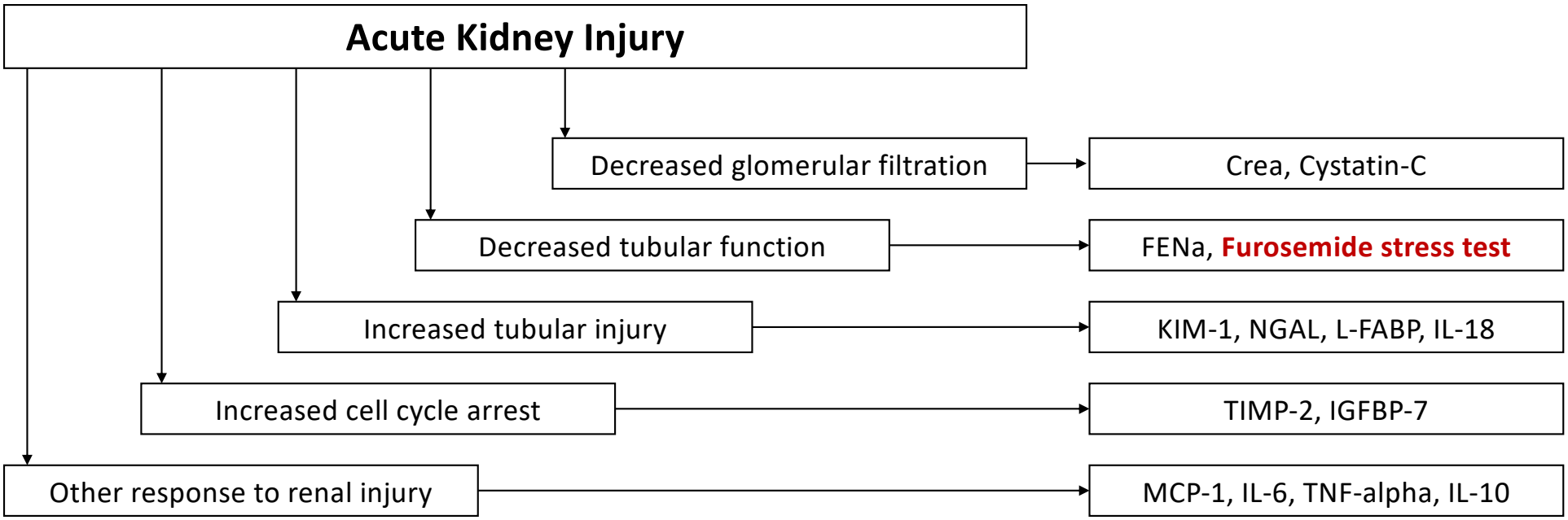
Furosemide PK/PD in severity of AKI

- Urine response to furosemide differed according to the estimated GFR
  - Single IV bolus (20, 40, or 80 mg per average 90 kg patient), critically ill human patients
- ↓ eGFR (6h CrCl), ↓urine furosemide excretion, ↑plasma half-life
- **Worse the kidney function (lower eGFR), less likely to observe respond to furosemide**



Furosemide Stress Test: Biomarker

- Furosemide stress test: *dynamic functional assessment* of renal function



FST predicts the need of dialysis

- **Lack of response may indicate severe AKI or predictive of dialysis**
  - Mechanism of action
    - Secreted in proximal tubule
    - Carried to loop of Henle
    - Block Na-K-2Cl channel
  - **"Furosemide stress test" check tubular integrity**
- Safe, feasible, well-tolerated in critically ill human patients
- Generally, **FST outperform other biomarkers** in predicting progression to severe AKI/hemodialysis

FST : Humans

- Single dose 1~2 mg/kg IV, assess UOP in 2-6h
  - Higher dose (2 mg/kg) if patient received diuretics within 7 days
  - Patients are kept on IVF to match urine output
  - In well-resuscitated, was/on IVF (absent pre-renal)
- Responders if (definition varies across study)
  - UOP jumps twice
  - UOP > 1.5 ml/kg/h
- Non-responders
  - Lower the UOP, worse AKI/outcome
  - Not only Y/N, but also quantification indicates the severity

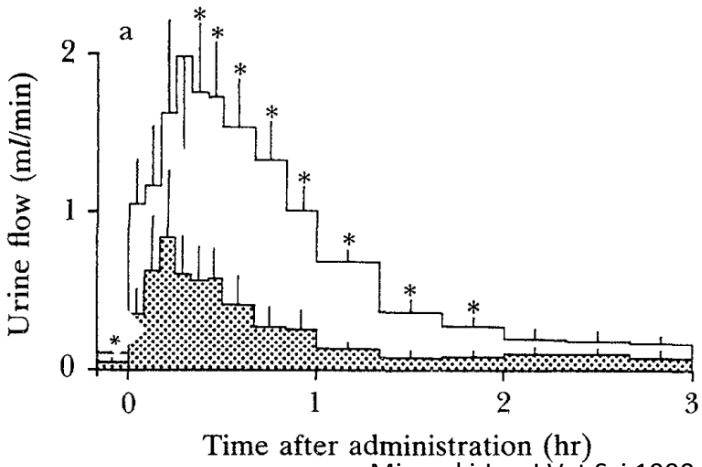
Definition of FST used	Clinical Outcome
IV furosemide 1 mg/kg in diuretic naïve patients and 1.5 mg/kg in non-naïve patients.	UOP <200 ml 2 h post furosemide predicts severe stage 3 AKI
IV furosemide 80–160mg	UOP >200/h, Urine Osm from 600 mOsm/l–400 mOsm/l, no change in FWC and subsequent development of AKI
Postoperative IV furosemide (0.8–1.2 mg/kg per dose between 8 and 24 h after cardiac surgery	Lack of furosemide responsiveness defined a priori as UOP < 1 mL/kg/h after furosemide predicted subsequent development of AKI
IV furosemide (median dose of 0.9 mg/kg) administered 14 hours post cardiac surgery	The 2- and 6-hour urine flow rates were significantly lower in patients in whom AKI developed
Postoperative IV furosemide (mean dose 1.1 +/− 0.3 mg/kg) with median of 7.7 hours after cardiac surgery	Lack of furosemide responsiveness defined a priori as 6-h UOP less than or equal to 5.6mL/kg predicted fluid overload and prolonged peritoneal dialysis
Variable furosemide dose used. Furosemide responsiveness (FR) was defined as total UOP in 2 h (mL) divided by the dose of bolus furosemide (mg) administered.	FR could predict AKI progression in patients with high plasma NGAL levels (>142 ng/mL), while few patients with low plasma NGAL levels exhibited AKI progression
Intravenous furosemide (1 mg/kg in furosemide-naive patients or 1.5 mg/kg in previous furosemide users). FST-nonresponsive patients (urine output less than 200 mL in 2 h) were randomized to early (initiation within 6 h) or standard (initiation by urgent indication) RRT.	AKI: timing of RRT initiation. Only 6/44 (13.6%) FST-responsive patients ultimately received RRT while 47/60 (78.3%) nonresponders randomized to standard RRT either received RRT or died ($p < 0.001$).
After cessation of CVVH the first 4 h of urine was collected for measuring creatinine clearance. Patients were subsequently randomized to furosemide (0.5 mg/kg/h) or placebo by continuous infusion.	Furosemide by continuous infusion in the recovery phase of hemofiltration-dependent AKI did increase urinary volume and sodium excretion but did not lead to a shorter duration of renal failure or more frequent renal recovery.
Furosemide (one time intraoperative dose of 100mg) can predict delayed graft function post deceased donor kidney transplantation (DDKT). Furosemide can predict delayed graft function post DDKT transplantation	The FST predicted DGF with an area-under-the curve of 0.85 at an optimal urinary output cutoff of <600 mL at 6 h.
Single dose of intravenous furosemide, 1.5 mg/kg at 3 h after allograft reperfusion. Urine volume recorded hourly after FST until 6 h. FST was compared to urine NGAL.	The 4-h urine volume less than 350 mL (FST non-responsive) was the best cutoff value in predicting DGF with 87.5% sensitivity, 82.9% specificity, and 82.5% accuracy. The FST is a more accurate biomarker than urine NGAL

FST: Evidence in Dogs and Cats?

- No specific study investigating FST in vet med
- Case series/reports describing furosemide
  - JVIM 2018 FENa in dogs with AKI
    - UO response after furosemide 10/32 dogs
  - BSAVA 2017, Positive response to furosemide (from oligo-anuric to >1 ml/kg/h or a doubling of UOP) was NOT associated with survival to discharge in 8 dogs and 4 cats.
    - 5/12 animals responded to furosemide
  - JVECC 2007, diltiazem +/- furosemide in AKI lepto dogs
  - Other case report/series describing the use and response to furosemide (leptospirosis in dogs, cat with severe AKI-lily toxication, etc.

FST: How to do in Dogs and Cats

- Indicated: **AKI, earlier stage (+/- advanced), resuscitate, rehydrated**
- **Single, IV, 2 mg/kg**
- Indwelling u-catheter to quantify UOP
- In dogs, diuretic response peak within 1h, **assess UOP in 2h** seems reasonable target
- **FST's main utility is to predict the need for dialysis**
  - **No response in 2h = Strong indicator of dialysis**



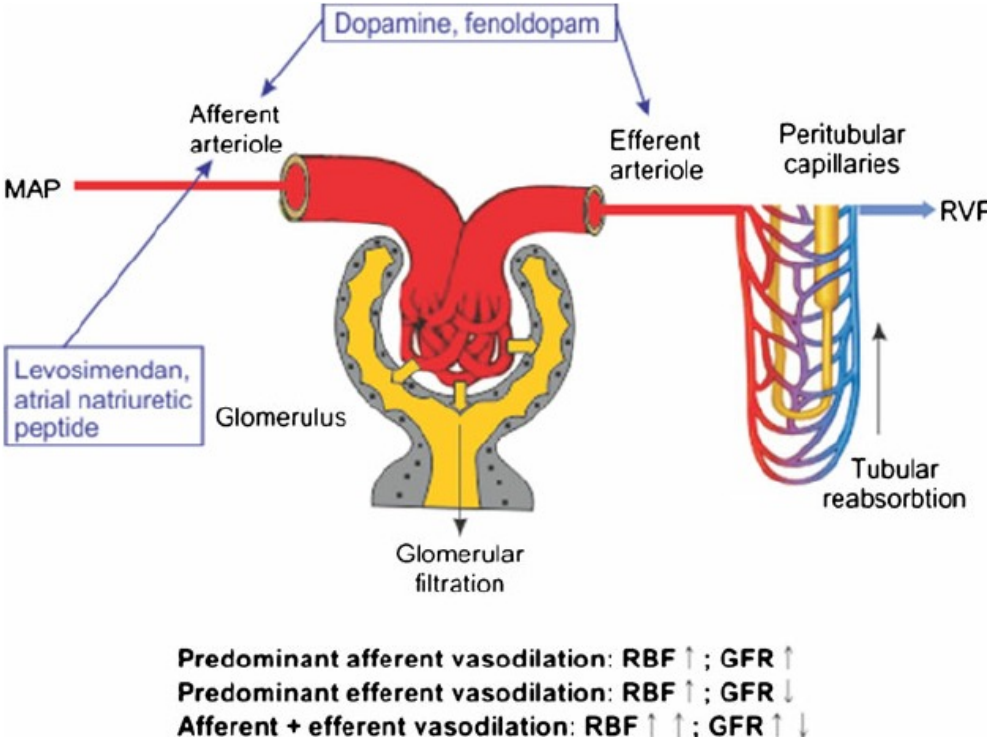
Miyazaki Jpn J Vet Sci 1990

Mannitol

- Pros: free radical scavenger, reduces post-ischemic swelling
- Cons: high risk of fluid overload and pulmonary edema if patient doesn't convert to polyuria
  - Human guideline suggest that mannitol should NOT be used in patients with AKI
- Dose
  - 0.25-1 g/kg over 15-20 minutes q4-6h (do not exceed 2 g/kg)
  - 60-120 mg/kg/h

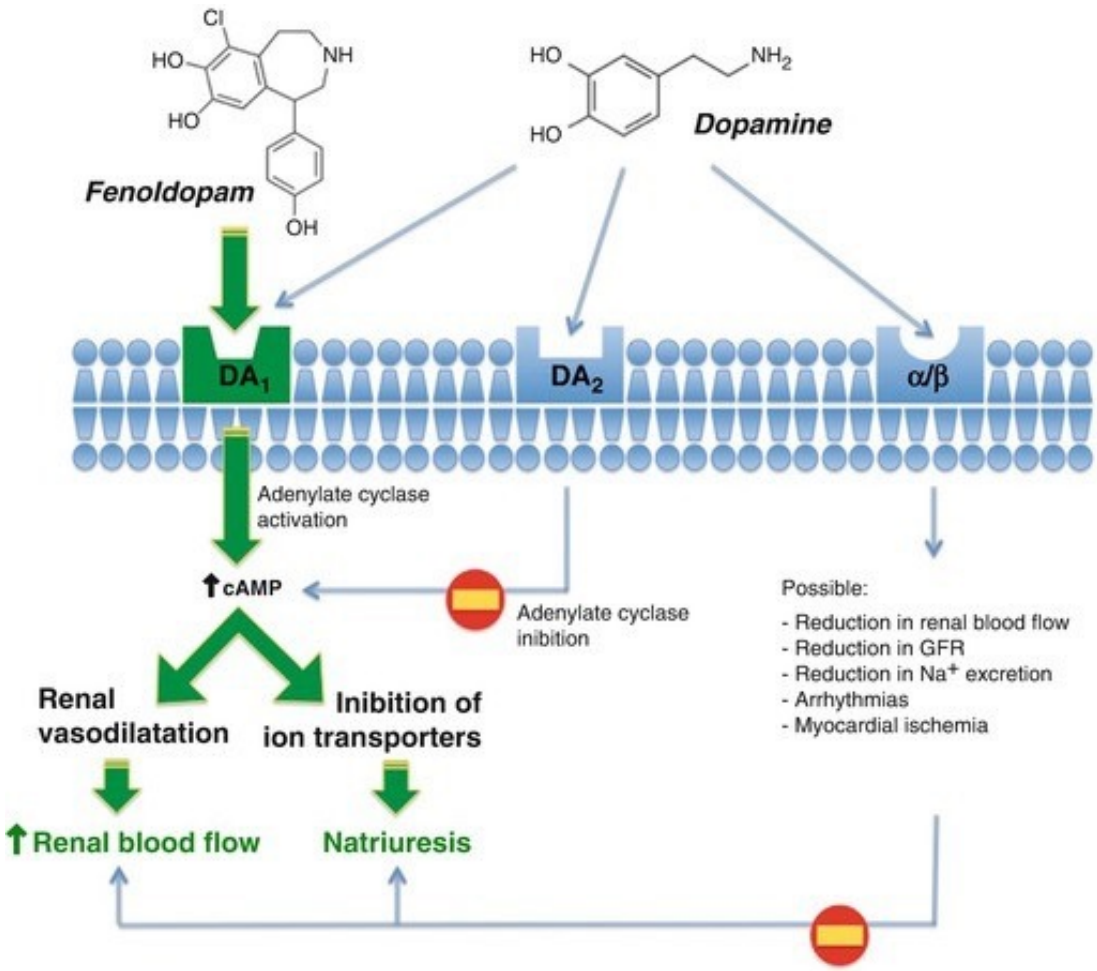
Dopamine

- Mechanism: Renal vasodilation, induce natriuresis, diuresis
  - So-called “Renal dose” dopamine (1-3 mcg/kg/min)
- Human studies failed to show benefit (no improvement in morbidity, mortality, the need for dialysis)
  - Potential risk: tachyarrhythmias, myocardial ischemia, hypertension
- Dopamine is NOT recommended in treating AKI and humans



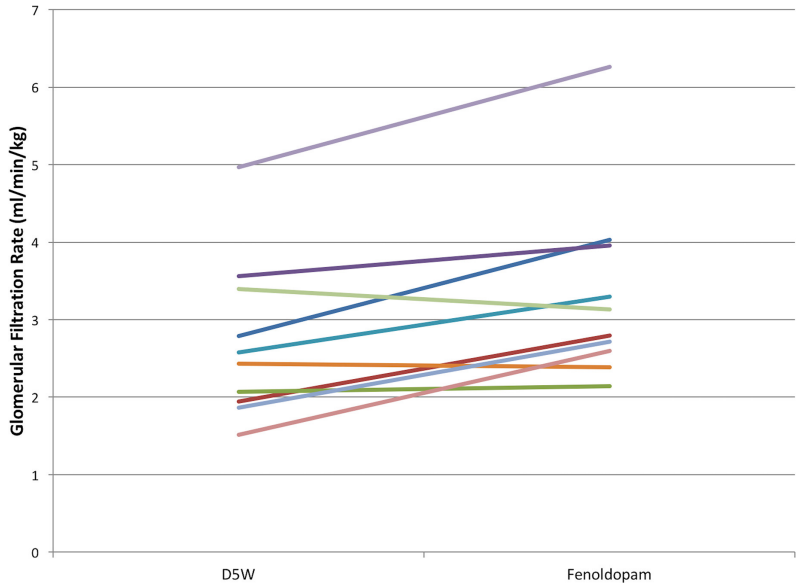
Fenoldopam

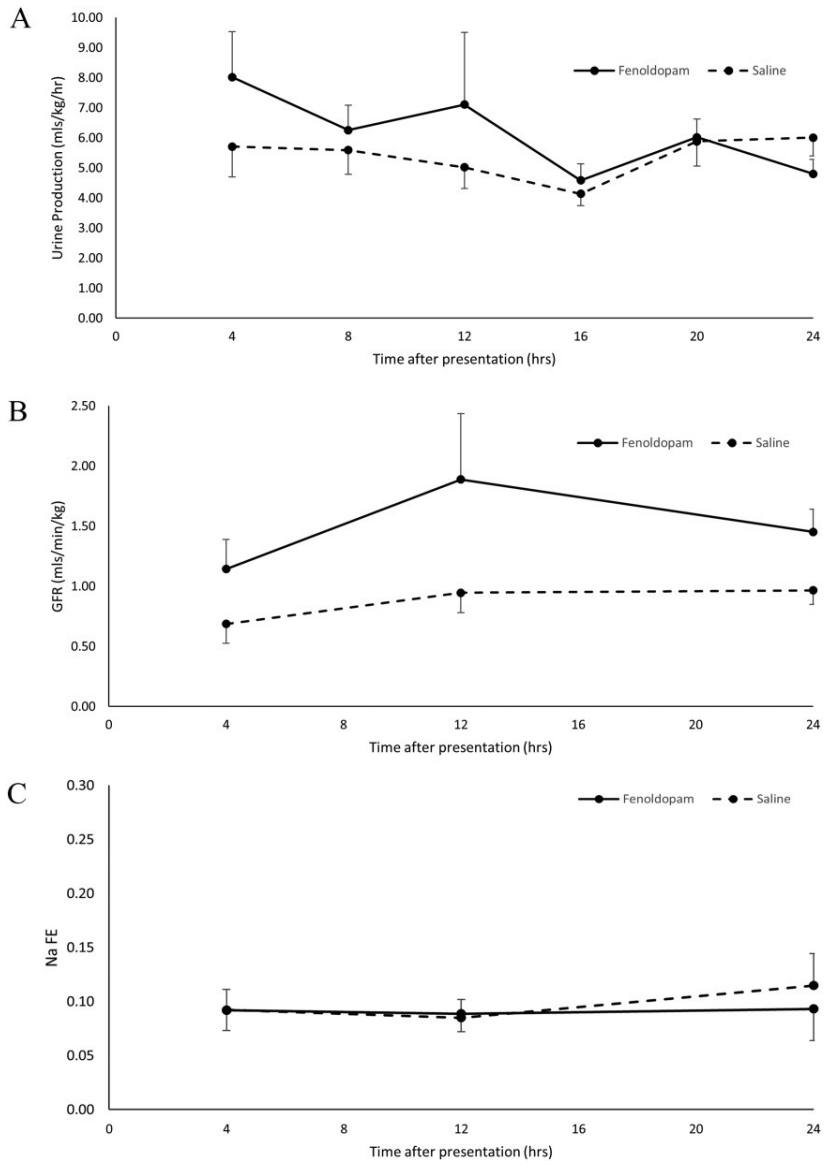
- Selective DA1 (dopamine receptor) agonist
  - More potent renal vasodilation and natriuresis than dopamine



Fenoldopam

- Increased UOP in healthy cats
- Increased diuresis and FENa in healthy dogs



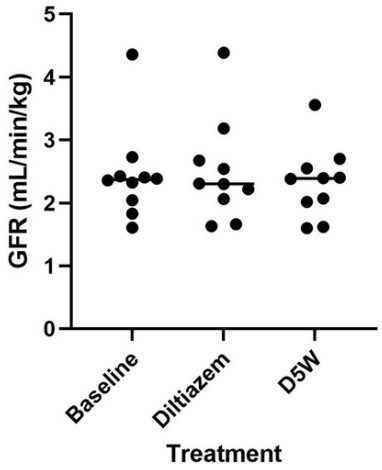


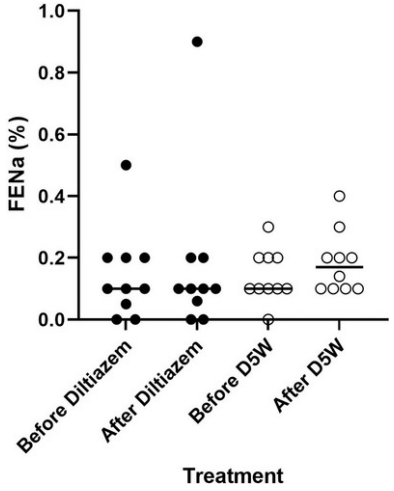
Fenoldopam

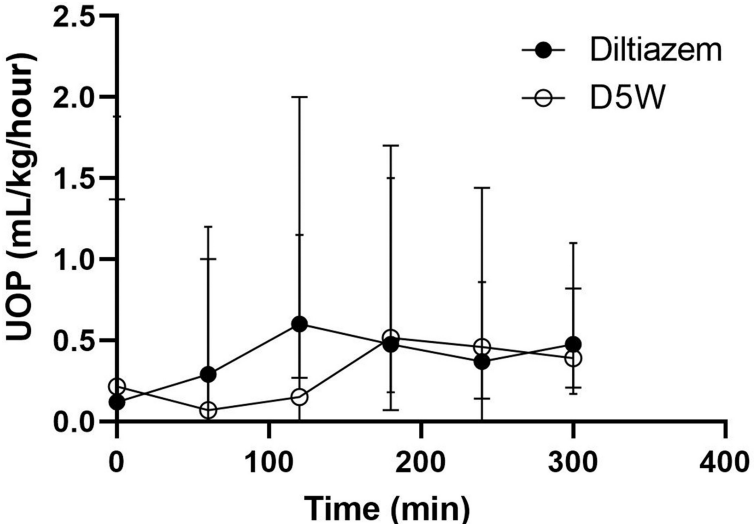
- Retrospective study in dogs failed to show benefit
  - 0.1 mcg/kg/min in heat stroke-AKI
  - No changes in Crea, UOP, GFR, FENa
- Retrospective study in dogs and cats with AKI failed to show benefit
  - 0.8 mcg/kg/min in dogs, 0.5 mcg/kg/min in cats
  - Hospital stay, survival, adverse effect, changes in Crea, BUN
  - Relatively safe, but risk of hypotension (lower SVR): 7%
- In human,
  - Fenoldopam may be helpful in preventing AKI
  - Fenoldopam does not improve outcome in people with AKI

Diltiazem

- Mechanism: calcium channel blocker
  - Afferent arteriolar (> efferent) vasodilation, improve RBF, GFR, and UOP
  - Prevent cellular necrosis (inhibit calcium influx into cell)
  - Risk: hypotension
- Healthy dogs (JVIM 2022)
  - Diltiazem didn't improve GFR, FENa, and UOP

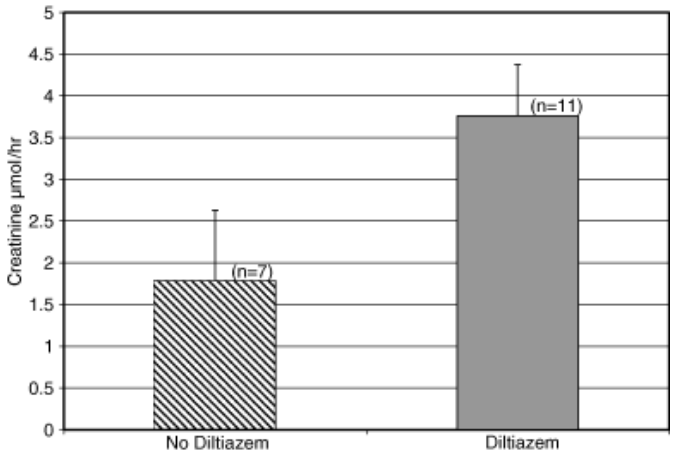


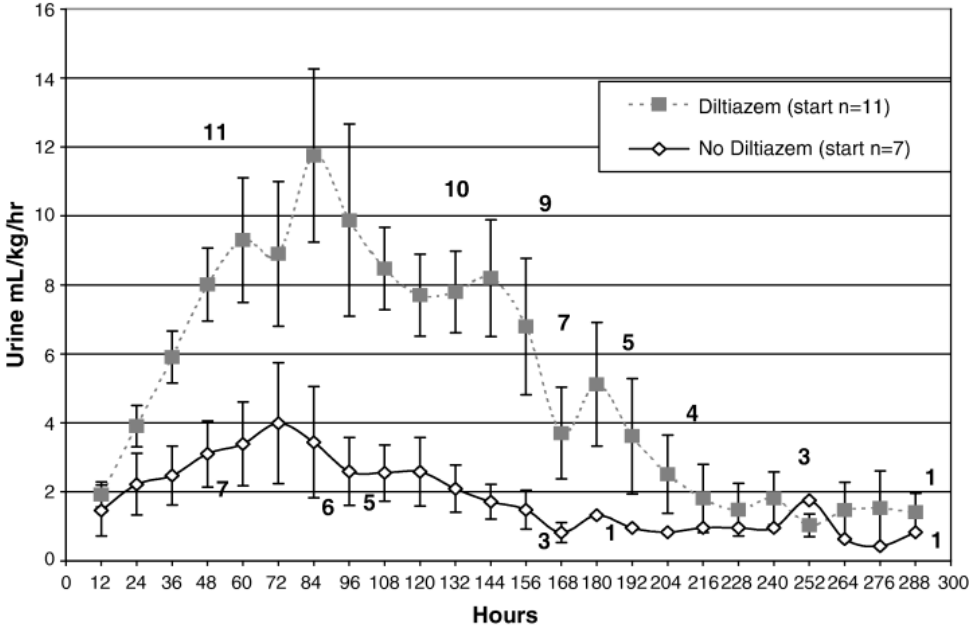




Diltiazem

- AKI-lepto dogs, diltiazem
  - Improved urine output, creatinine clearance
  - Didn't improve
    - Renal function
    - Survival
  - **Confounded by dopamine, furosemide*





Back to Sarge

- UOP
  - 12a: **1.65** ml/kg/h (**relative** oliguria), weight **44kg**
  - 4a: **1.26** ml/kg/h,
  - 8a: **0.9** ml/kg/h (**absolute** oliguria), weight **47 kg**
- Weight: 44 kg → 47 kg
  - (47-44)/44 = **6.8% weight gain**
- **Potassium increased to 6.5 mEq/L**
- **Doppler 200 mmHg**

Recommended hemodialysis to owners. In the meantime, furosemide 2 mg/kg didn't improve urine output (0.9 to 1.2 ml/kg/h)

Sarge: outcome

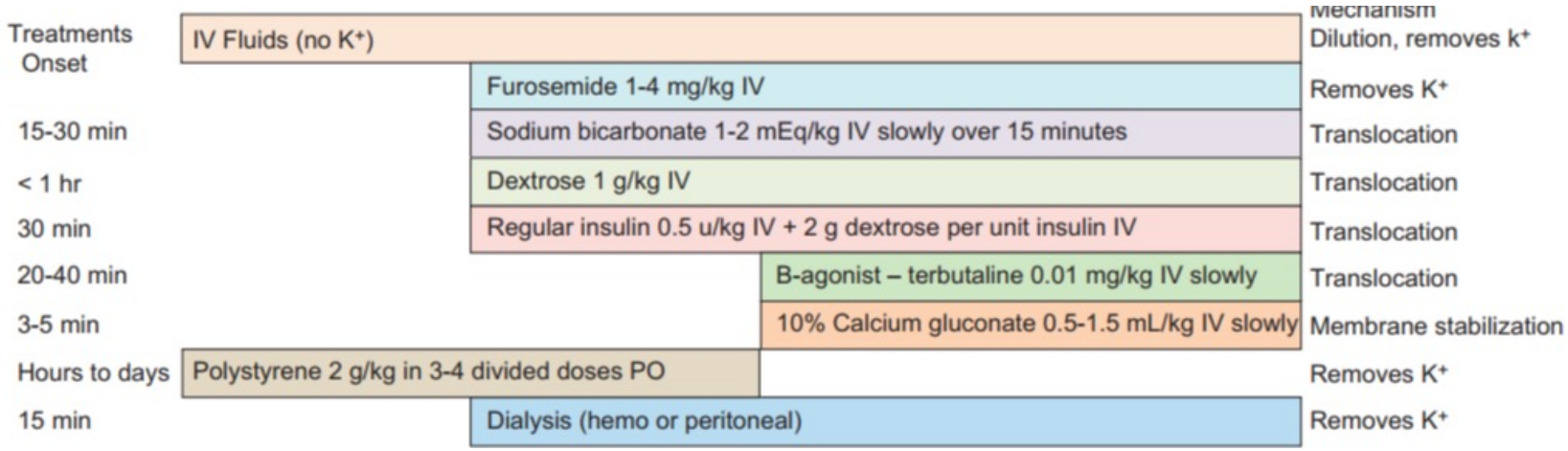
- x4 treatments over a week (inpatient), followed by 5 additional treatments over two more weeks
- Managed as CKD afterward

Hyperkalemia: how common in AKI?

- Hyperkalemia (> 5.5 mEq/L) is common with AKI, but severe hyperkalemia (> 7.5 mEq/L) is NOT common.
- Severe hyperkalemia is more common with obstructions (post-renal)

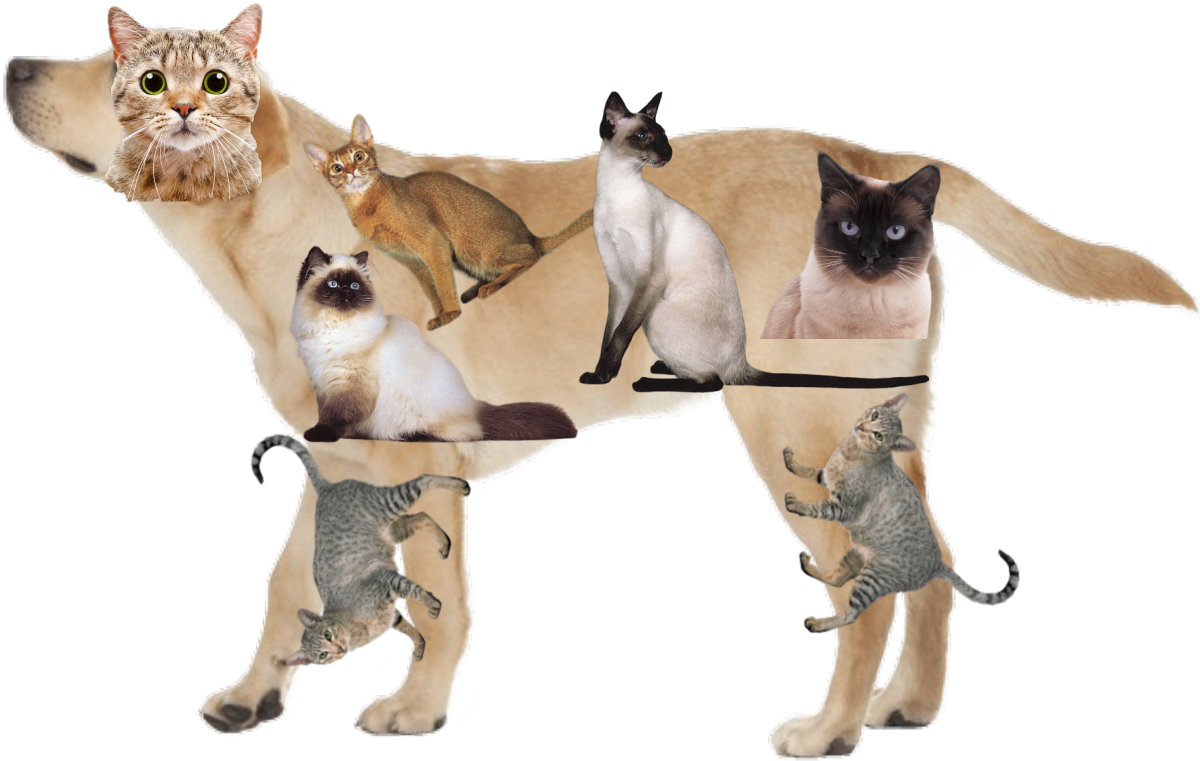
Hyperkalemia

- Emergency: **10% Calcium Gluconate**, 0.5-1.5 mL/kg IV slowly (**3 mL per cat**)
  - 1st choice for emergency cases: EKG changes, severe bradycardia
  - Trade off: ↑Ca x P mineralization
- Stable patients
  - Regular insulin 0.5 u/kg IV + 2 g dextrose per unit insulin IV; consider 1.25-2.5% dextrose CRI for 4-6h
  - Terbutaline 0.01 mg/kg IV (slow) or IM/SC

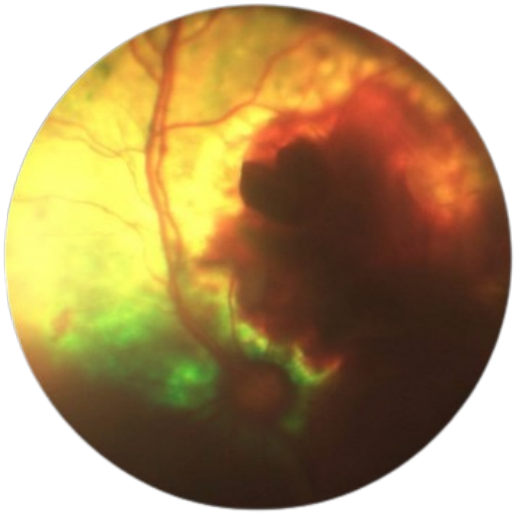


Hyperkalemia

- Emergency: **10% Calcium Gluconate**, 0.5-1.5 mL/kg IV slowly (**3 mL per cat**)
  - **Dog?**
    - **How many cats in the dog?**
    - **6 cats x 3 mL = 18 mL**



Hypertension in AKI



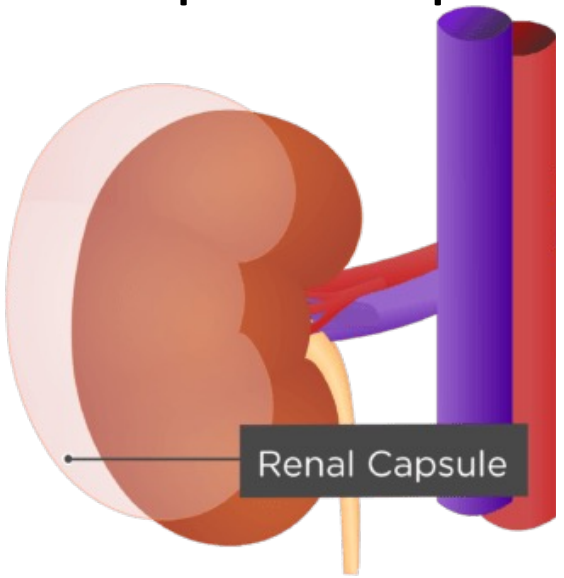
- Hypertension occurs with AKI
  - Severe hypertension (≥ 180): 15-62% (Dogs), 20-28% (Cats)
  - Hypertensive retinopathy: 16% in dogs with AKI
- **No association with severity of azotemia**
  - Regardless of azotemia, check BP
- **Fluid overload is associated with hypertension**
  - Judicious IVF therapy
  - Achieve fluid balance with dialysis
- **Goal: control SBP ≤ 160 mm Hg**
  1. Pain/anxiety control
  2. Amlodipine (0.1-0.5 mg/kg PO q24h), acepromazine (0.01-0.05 mg/kg q6-12h), hydralazine

Hemodialysis

- Worsening azotemia refractory to medical management
- Severe metabolic disturbances
  - Hyperkalemia
  - Acidemia
- Oliguria/Anuria
- Fluid overload

Congestive nephropathy

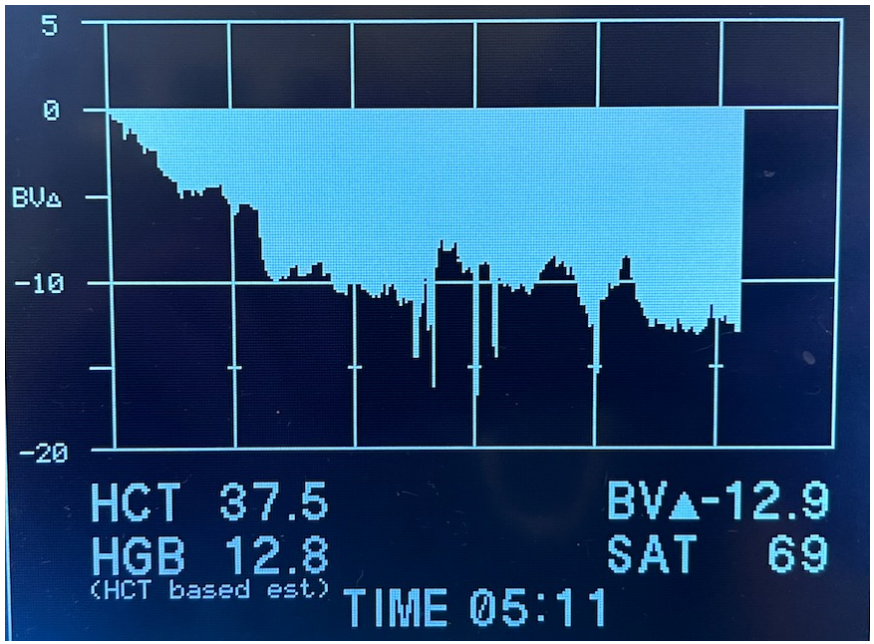
- Kidney is encapsulated in rigid capsule
- **Congested kidneys within renal capsule leads to decreased renal perfusion, reduced urine output**
- **Hemodialysis is an effective way to decongest kidneys and improve renal perfusion**



Video credit: Dr. Jeongmin Lee

Ultrafiltration

- Efficient way to remove fluid from overhydrated patients
- Monitor the degree of fluid removal via changes in hematocrit, SvO2



CarpeDiem

- Designed to deliver continuous renal replacement therapy for infant, neonates
- 32-45 ml extracorporeal volume
- Small dogs and cats (e.g., 2.5 kg dog) can be treated safely (15% of blood volume in the circuit) without the need for blood prime

Prognosis of AKI-hemodialysis

- **Acute Kidney Injury**
  - **Prognosis for recovery: 50%**
  - Residual CKD possible, but a lot of them make complete recovery

Etiology	Survival rate
Obstructive (cats)	70-75%
Infectious (e.g., Leptospirosis)	58-86%
Metabolic/hemodynamic	56-72%
Toxic	18-35%
Other	29-56%

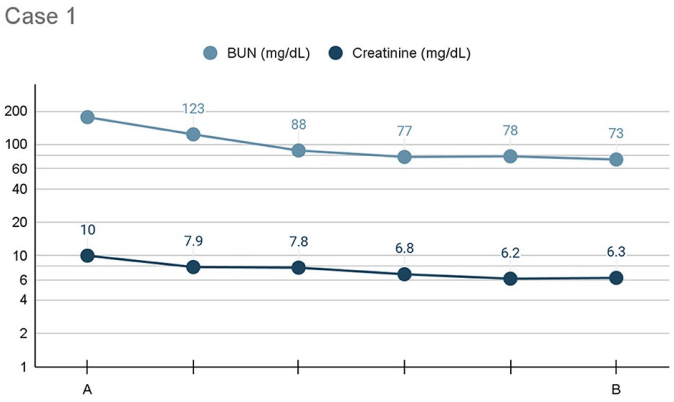
Dialysis not available? Peritoneal dialysis

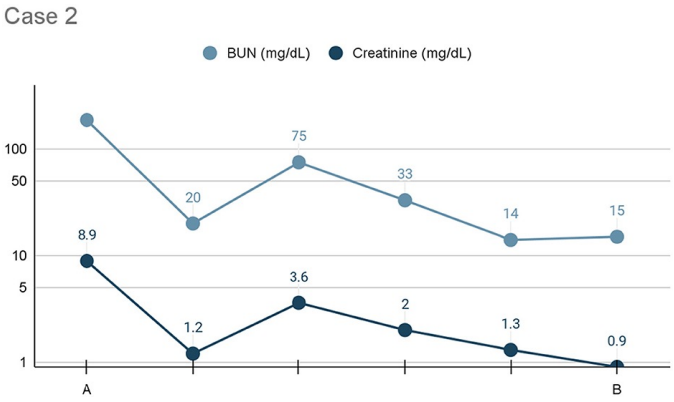
- “Low tech” but requires intense, continuous monitoring
- Use peritoneum as semipermeable membrane to clear uremic toxins and manage overhydration
- Contraindicated in
  - Abdominal wall trauma
  - Peritoneal infections

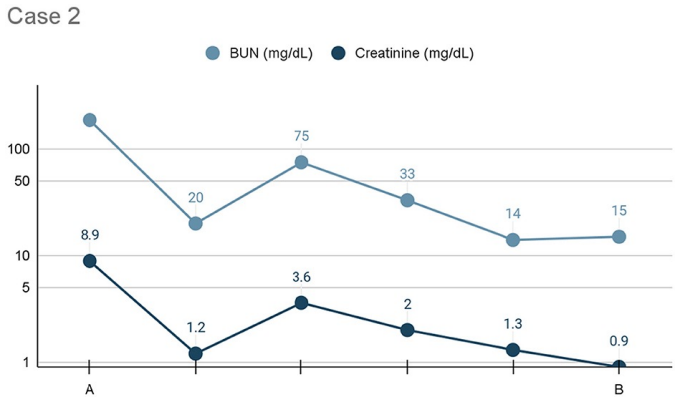
What if both HD and PD are not available?

Pleural dialysis

- Pleural membrane can act as a filter like peritoneum
- Well-tolerated, as effective of peritoneal dialysis in three cats (Frontiers 2024)
  - Cats with post-SUB placement, when IHD wasn't available, hemodialysis catheters couldn't be placed, etc.

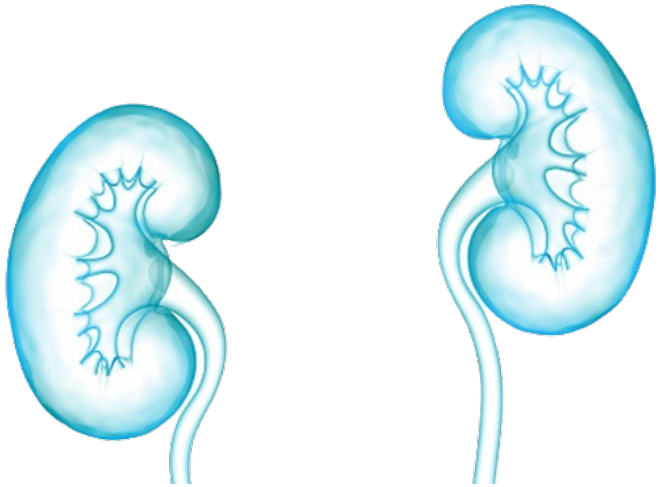






Summary

- Successful outcome of oliguria is dependent on early identification
- IV fluid therapy is tailored to the individual patient
- Fluid overload is even worse than dehydration
- Diuretics do not treat kidney diseases
- Hemodialysis is mainly used for management of oliguric AKI in veterinary medicine




THANK
YOU!