

Urolithiasis

Renal calculi and urinary tract stones

Etiology • crystal formation • morphology • clinical consequences

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Learning objectives

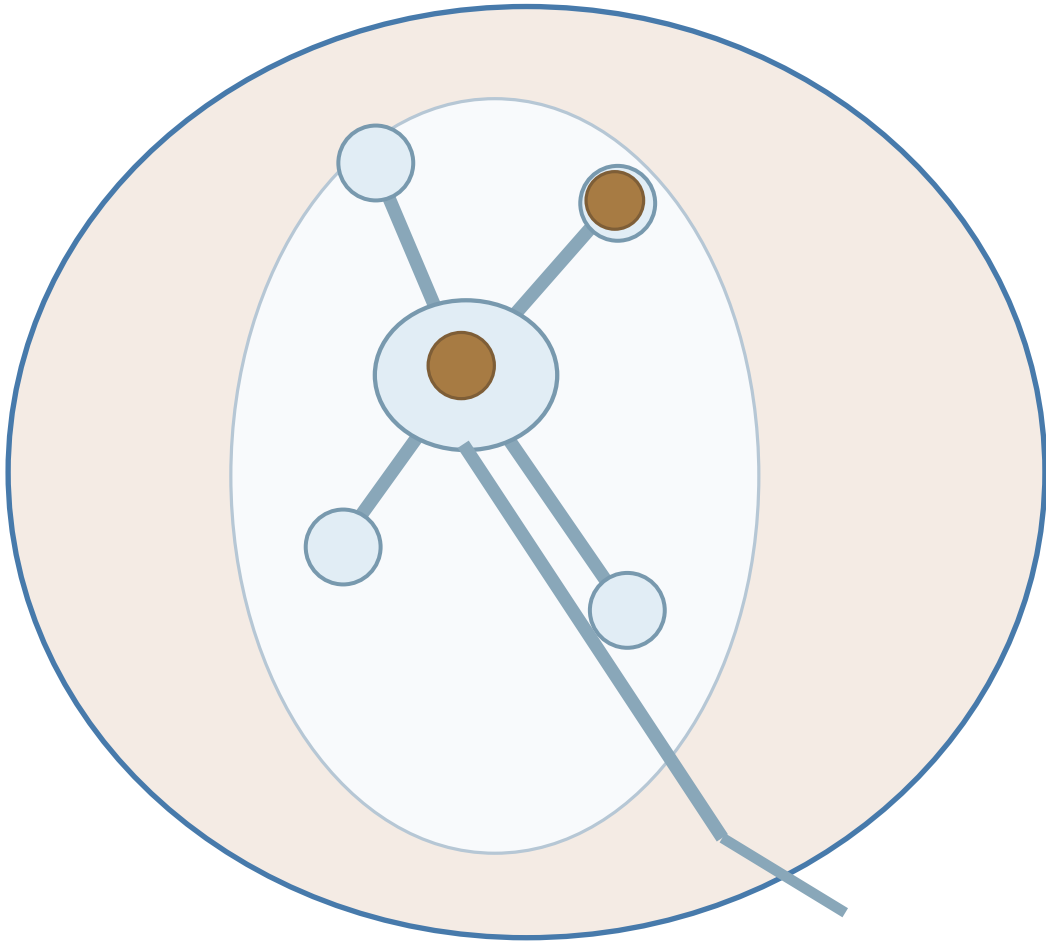
- Explain why urinary supersaturation favors calculus formation.
- Distinguish calcium, struvite, uric acid, and cystine stones.
- Connect stone composition and morphology with clinical injury.
- Interpret short clinicopathologic teaching cases.

Urolithiasis is stone formation in the urinary tract

Most stones arise in the kidney, although calculi can occur throughout the urinary tract.

Stone disease spans silent incidental findings, renal colic, infection, and structural damage.

Sites of calculus formation



- Renal calyces and pelvis are important stone-forming locations.
- Calculi can also occur in the bladder and elsewhere in the urinary tract.

Lifetime occurrence in the United States

5%–10%

This lifetime range for the U.S. Population;
It is a textbook figure, not a new
population estimate.

Age and sex distribution

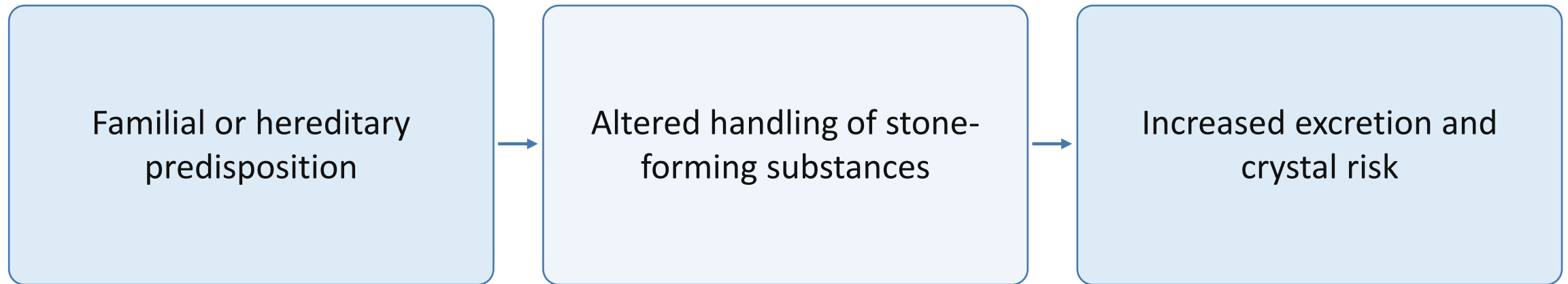
Sex pattern

Males are affected more often than females.

Age at onset

Peak age at onset is reported between 20 and 30 years.

A familial predisposition can underlie stone disease



Conceptual sequence — direction indicates the causal relationship described in the source

Two inherited metabolic examples

Cystinuria

Abnormal renal reabsorption
increases urinary cystine.

Primary hyperoxaluria

An inherited metabolic disorder
increases oxalate burden.

Four principal stone classes

Class	Principal constituent	Approximate share in Robbins
Calcium	Calcium oxalate $\pm$ phosphate	~70%
Struvite	Magnesium ammonium phosphate	5%–10%
Uric acid	Uric acid	5%–10%
Cystine	Cystine	1%–2%

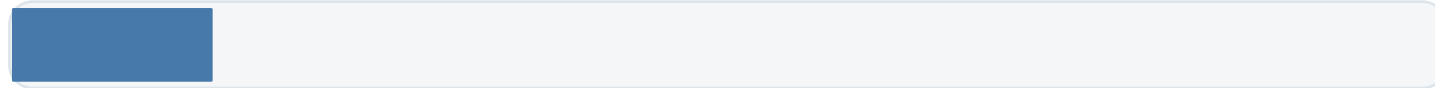
Calcium stones predominate

Calcium



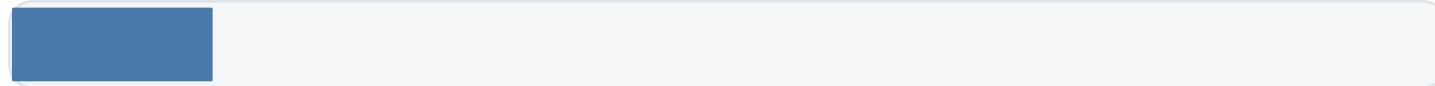
~70%

Struvite



5%–10%

Uric acid



5%–10%

Cystine



1%–2%

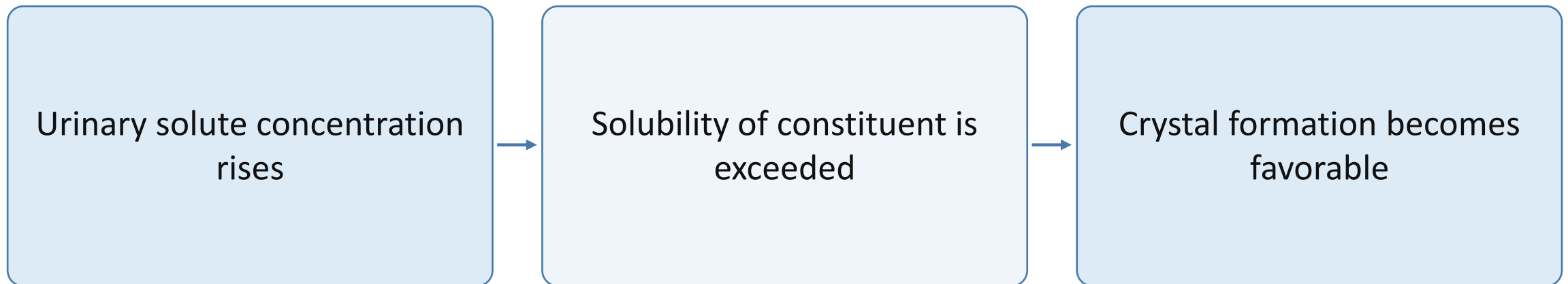
Struvite, uric acid, and cystine shown at reported upper bounds; Bars are not parts of a normalized whole.

Every calculus contains an organic matrix

A mucoprotein matrix accounting for approximately 1%–5% of stone weight.

Stones are not simply pure, freely precipitated inorganic crystals.

The central process is urinary supersaturation



Conceptual sequence — direction indicates the causal relationship described in the source

Supersaturation is a qualitative threshold

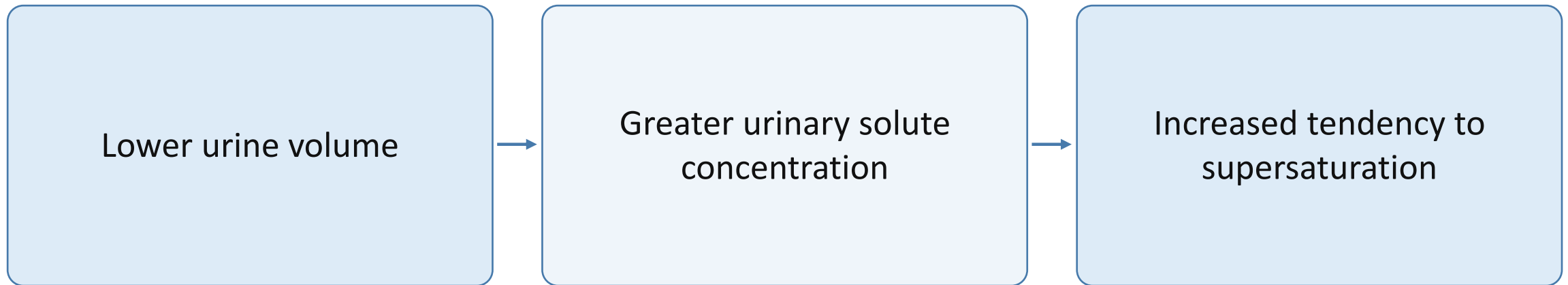
Below constituent solubility limit

Below solubility limit: The constituent remains in solution.

Above constituent solubility limit

Above solubility limit: Precipitation becomes thermodynamically favorable.

Low urine volume can increase crystal risk



Conceptual sequence — direction indicates the causal relationship described in the source

Several variables influence calculi

Urinary chemistry

Constituent concentration and
urinary pH

Urinary environment

Urine volume, bacteria, and crystal
inhibitors

A coherent model of stone pathogenesis

Solute load

Ca / oxalate / urate / cystine

Solution state

Volume + pH

Biological modifiers

Bacteria + inhibitors

Outcome

Crystal formation / stone growth

Calcium stones are chemically heterogeneous

Most contain calcium oxalate or a mixture of calcium oxalate and calcium phosphate.

The same broad stone class can arise through different metabolic disturbances.

Calcium stone pathways: Two serum-calcium settings

Hypercalcemia with hypercalciuria

One recognized setting; Associated with conditions elevating serum calcium.

Hypercalciuria without hypercalcemia

A larger source-described group; Abnormal urinary calcium despite normal serum calcium.

Hypercalcemia-associated calcium oxalate stones

About 5%

This subset with both hypercalcemia and hypercalciuria.

Systemic settings of hypercalcemic stone risk

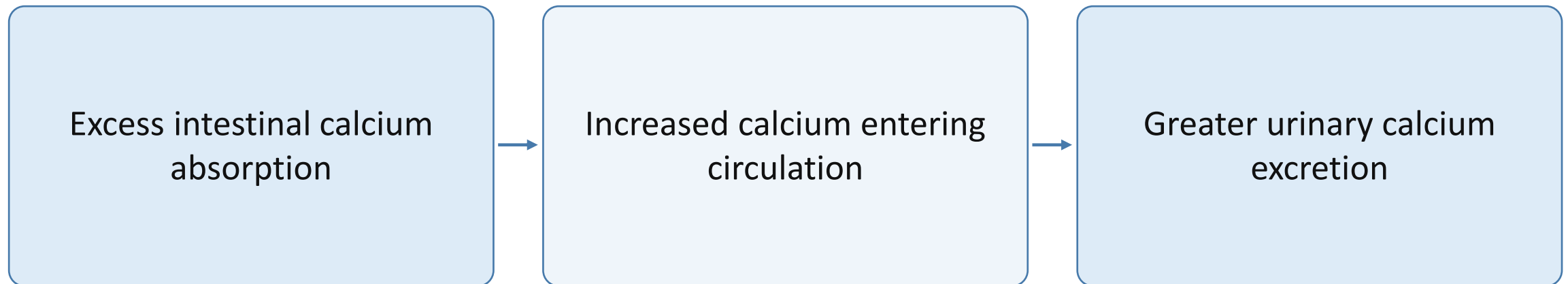
- Hyperparathyroidism increases circulating calcium.
- Diffuse bone disease can contribute to hypercalcemia.
- Sarcoidosis and other hypercalcemic states are also named.

Hypercalciuria despite normocalcemia

About 55%

This calcium oxalate stone subgroup
without elevated serum calcium.

Absorptive hypercalciuria



Conceptual sequence — direction indicates the causal relationship described in the source

Renal hypercalciuria

Intrinsic impairment of
tubular calcium reabsorption



Reduced renal conservation
of calcium



Hypercalciuria despite
normocalcemia

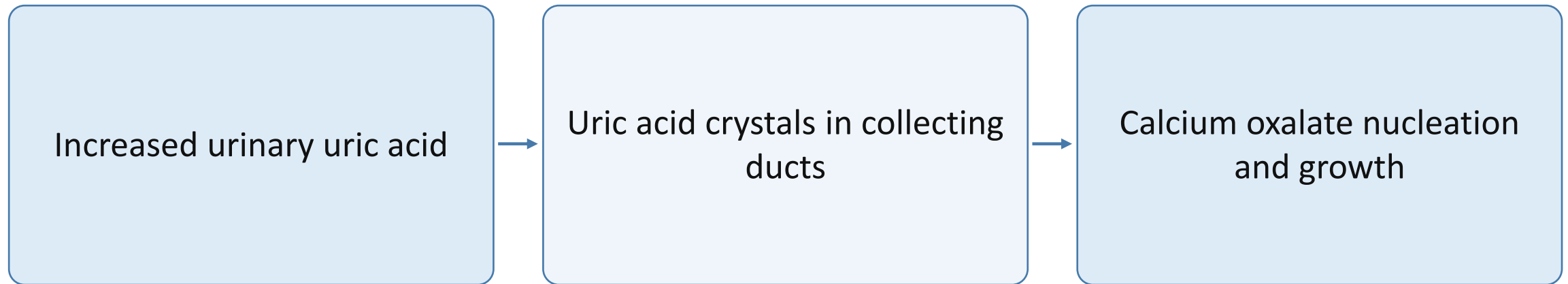
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Idiopathic fasting hypercalciuria

The calcium-stone differential includes fasting hypercalciuria with normal parathyroid function.

The label does not imply that the underlying transport mechanism has been fully established.

Uric acid can nucleate calcium oxalate



Conceptual sequence — direction indicates the causal relationship described in the source

Hyperuricosuric calcium nephrolithiasis

Up to 20%

Calcium oxalate stones may be associated with increased urinary uric acid, with or without hypercalciuria.

Two major hyperoxaluria pathways

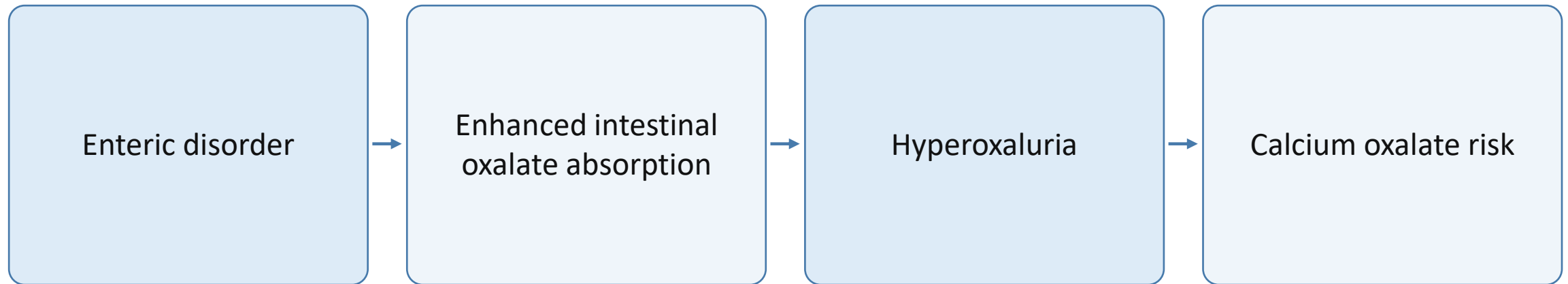
Primary

Hereditary oxalate overproduction or abnormal metabolism.

Enteric

Acquired intestinal overabsorption in enteric disease.

Enteric disease and oxalate stones



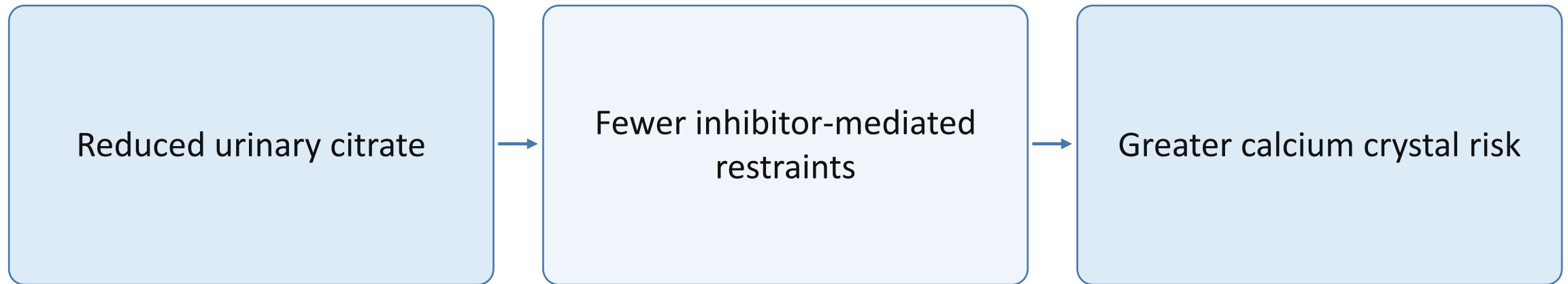
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Primary hyperoxaluria is a hereditary stone risk

Primary hyperoxaluria among inborn errors associated with stones.

For a calcium stone, excess oxalate can be the key abnormal urinary constituent.

Hypocitraturia removes a protective influence



Conceptual sequence — direction indicates the causal relationship described in the source

Clinical contexts of hypocitraturia

- Hypocitraturia may be idiopathic.
- It may accompany acidosis.
- Chronic diarrhea of unknown cause is another association.

Idiopathic calcium stone disease is a real category

No cause is found in a variable proportion of patients with calcium stones.

Absence of an identified abnormality should not be presented as absence of stone-forming pathophysiology.

Calcium stone mechanisms: Compare the drivers

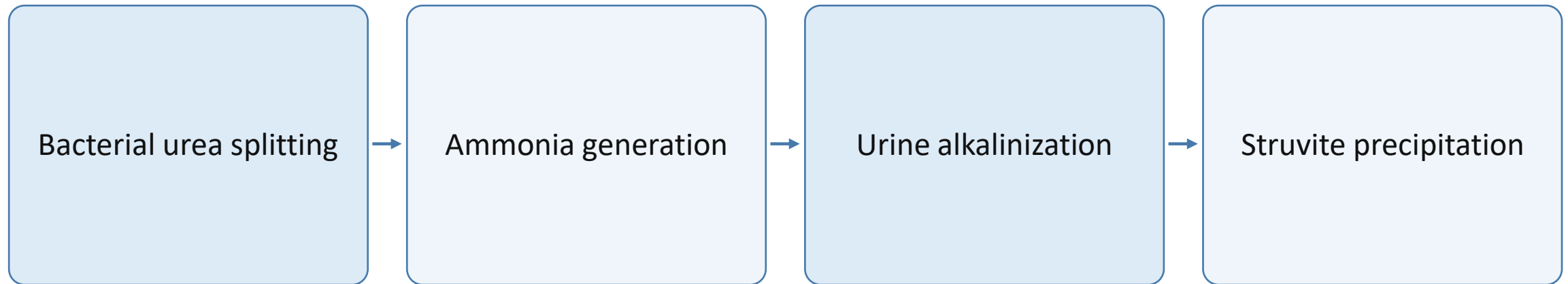
Driver	Primary disturbance	Stone-forming consequence
Calcium	Hypercalcemia or hypercalciuria	↑ urinary Ca
Urate	Hyperuricosuria	Ca oxalate nucleation
Oxalate	Primary or enteric hyperoxaluria	↑ urinary oxalate
Citrate	Hypocitraturia	Reduced inhibition

Struvite is an infection-associated calculus

Struvite consists principally of magnesium ammonium phosphate.

Stone formation is strongly linked to infection by organisms able to split urea.

Urea-splitting bacteria change urinary chemistry



Conceptual sequence — direction indicates the causal relationship described in the source

Which organisms are implicated?

Common example

Proteus species are specifically cited.

Additional example

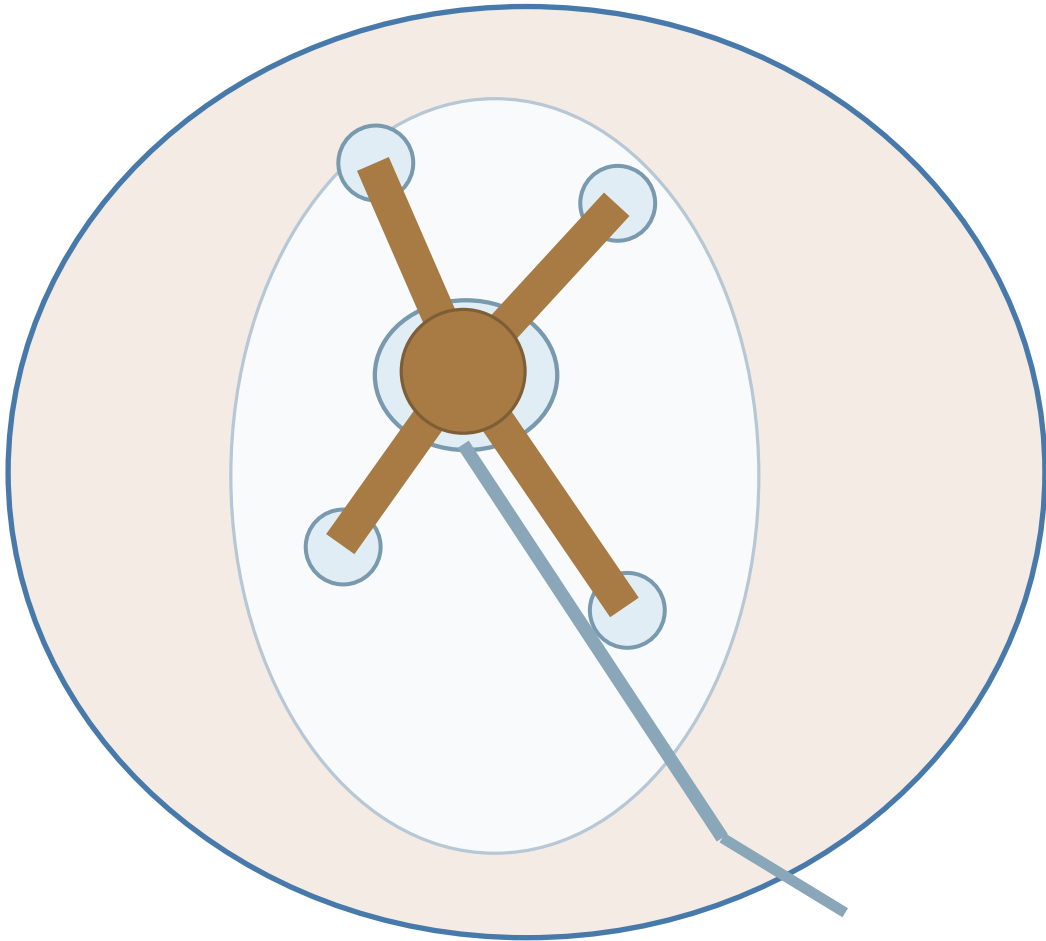
Some staphylococci can also be urea-splitting.

Alkaline urine favors struvite precipitation

Ammonia produced by urea splitting raises urinary pH.

The altered pH environment permits magnesium ammonium phosphate salts to precipitate.

Infection stones can form branching staghorn casts



- Progressive salt accretion can occupy large portions of the renal pelvis.
- The stone may extend into calyces and mold to the collecting system.

Uric acid stones: Systemic associations

- Hyperuricemia can be present in patients with gout.
- High cell turnover, exemplified by leukemia, is another association.
- Serum urate alone does not explain most uric acid stones.

Normal systemic urate does not exclude uric acid calculi

**More than
half**

More than half of patients with uric acid calculi lack hyperuricemia or increased urinary uric acid excretion.

Acidic urine favors uric acid calculi

Less acidic than the stated risk setting

Urinary pH < 5.5

A tendency to urinary pH below 5.5 in this subset.

Uric acid is poorly soluble in acidic urine.

Radiographic distinction: Calcium versus uric acid

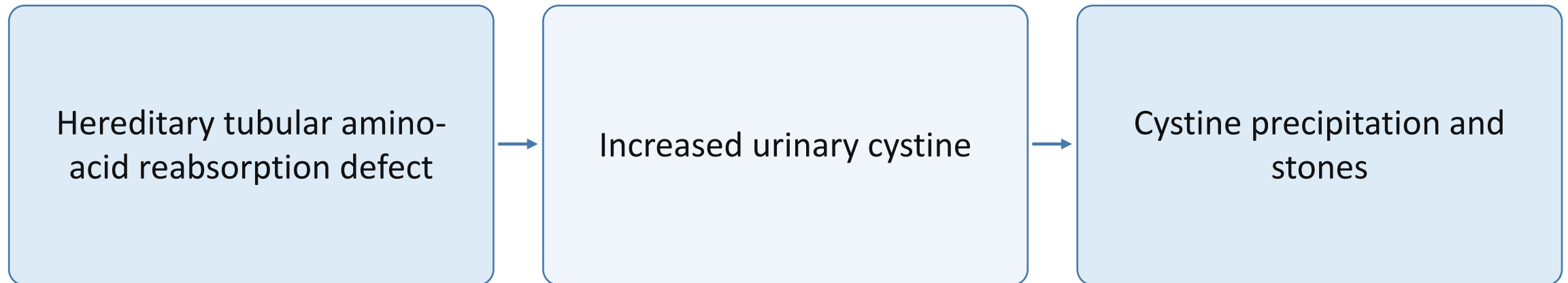
Calcium stones

Radiopaque on conventional radiography.

Uric acid stones

Radiolucent on conventional radiography.

Cystinuria produces cystine stones



Conceptual sequence — direction indicates the causal relationship described in the source

Cystine stones also favor low urinary pH

Low pH is described in the formation of cystine stones.

The underlying defect is impaired renal reabsorption of cystine-containing amino acids.

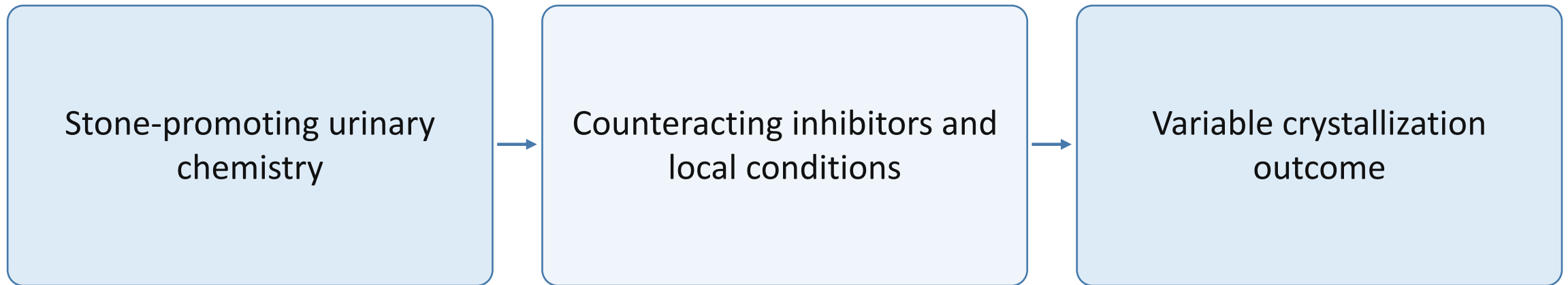
Acidic urine: Two distinct stone mechanisms

Feature	Uric acid	Cystine
Underlying basis	Poor solubility of uric acid	Cystinuria: amino-acid reabsorption defect
Urinary pH	Acidic; Robbins discusses pH < 5.5	Low urinary pH favors formation
Hereditary driver	Not necessary	Intrinsic to cystinuria

Urinary constituents that inhibit crystals

Low-molecular/ionic inhibitors	Other named inhibitors
Citrate	Glycosaminoglycans
Pyrophosphate	Osteopontin
Diphosphonates	Nephrocalcin (glycoprotein)

Why similar solute abnormalities need not yield stones



Conceptual sequence — direction indicates the causal relationship described in the source

A biochemical predisposition is not destiny

Patients with hypercalciuria, hyperoxaluria, or hyperuricosuria often do not develop stones.

This observation supports the importance of inhibitory and local urinary factors.

Stone determinants must be interpreted together

Solute

Amount excreted

PH

Species solubility

Volume

Concentration

Inhibitors

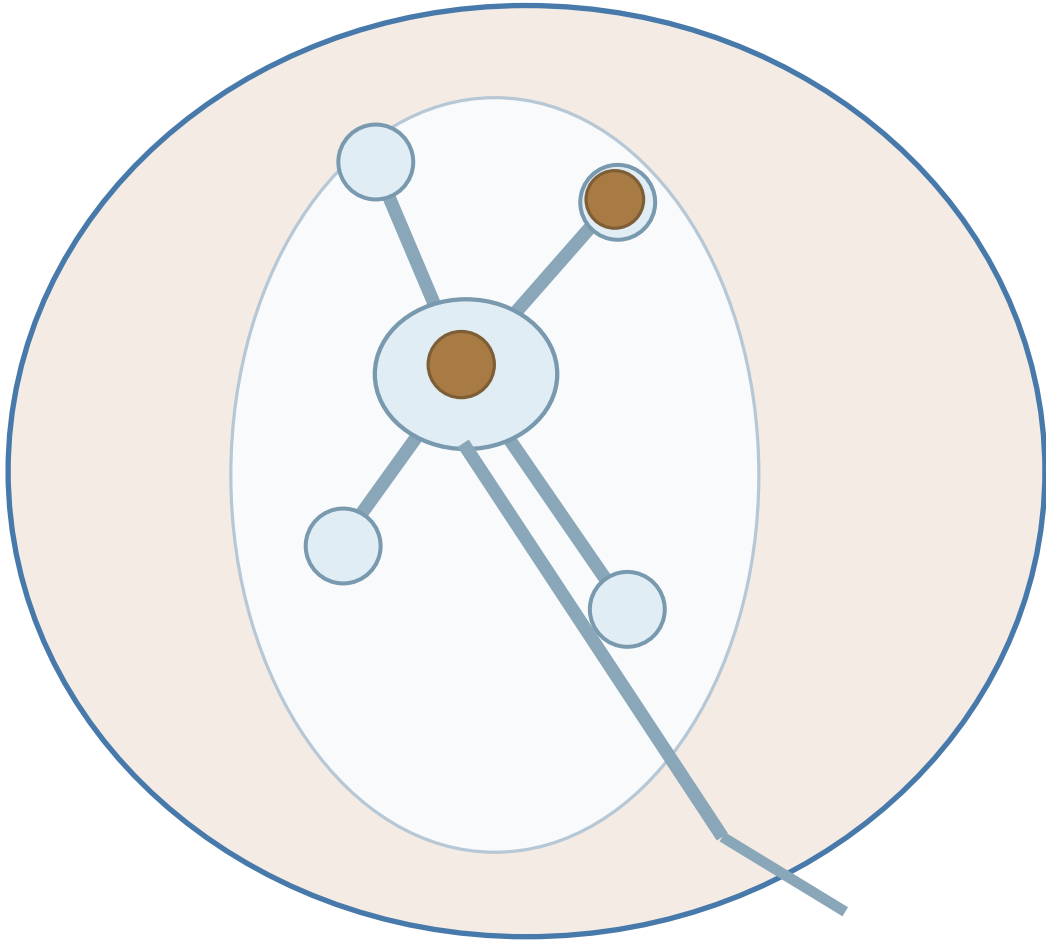
Crystallization restraint

Renal calculi are often unilateral

About 80%

Unilateral disease in roughly 80% of patients with stones.

Typical anatomic distribution



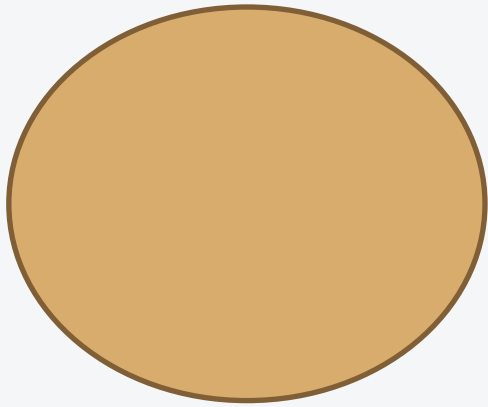
- Calyces and renal pelvis are common locations.
- Bladder stones are also recognized in the same disease spectrum.

Many renal-pelvis stones are small

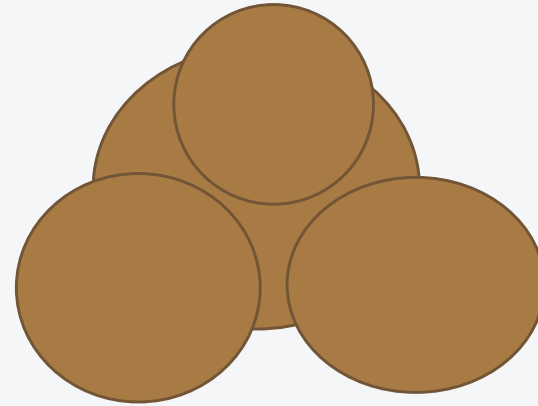
2–3 mm

This average diameter for stones forming in the renal pelvis.

Calculi differ in surface contour



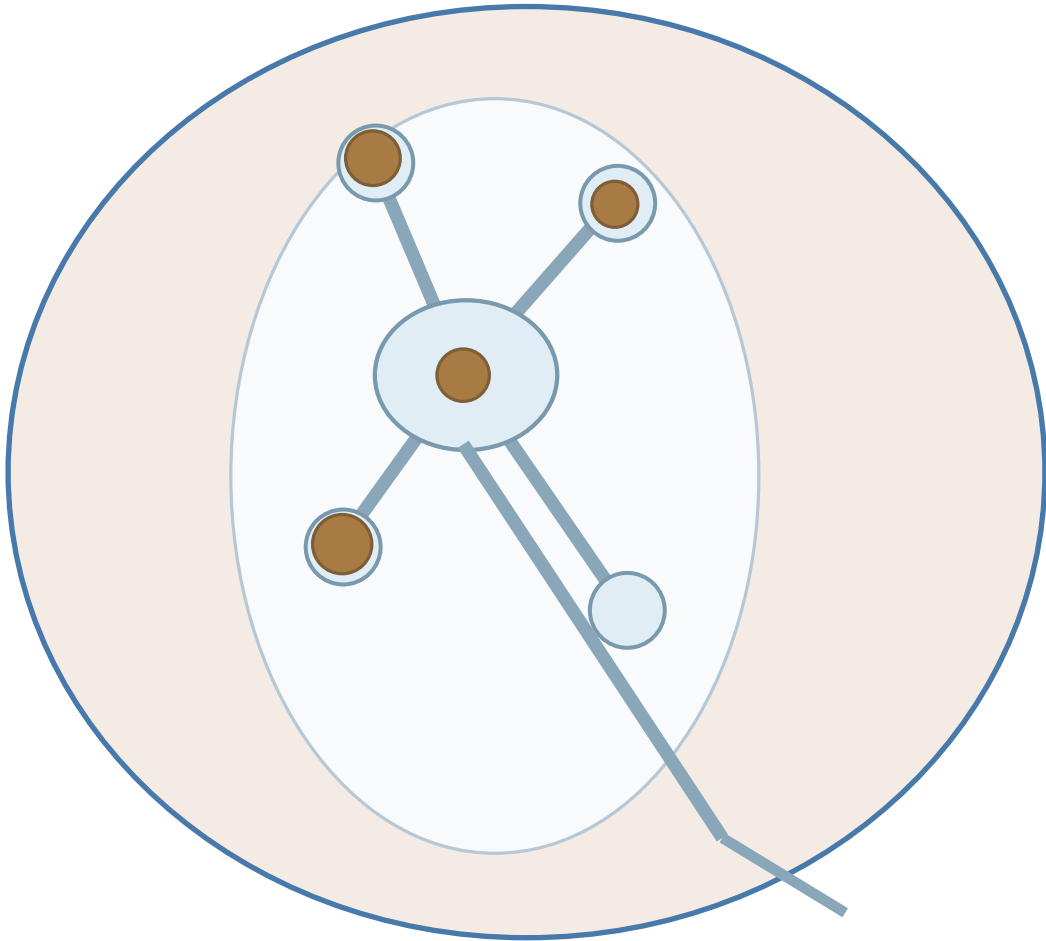
Smooth contour



Jagged or spiculated contour

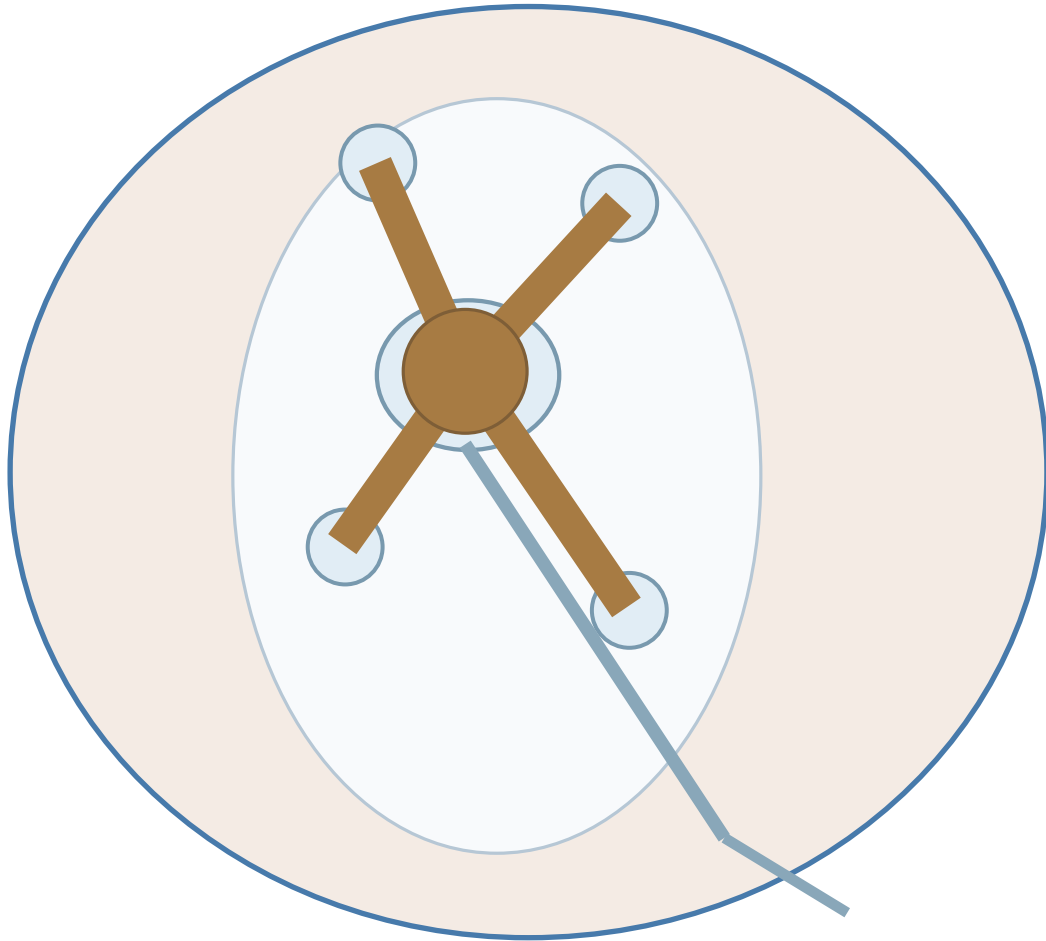
Schematic contours only; Not a photograph of stones

A kidney may contain multiple calculi



- Several stones may occupy separate areas in one kidney.
- Multiplicity does not imply that both kidneys are involved.

Staghorn calculi mirror collecting-system shape



- Branching structures form with progressive accretion of salts.
- Large calculi can cast the pelvis and calyces.

Clinical course varies widely

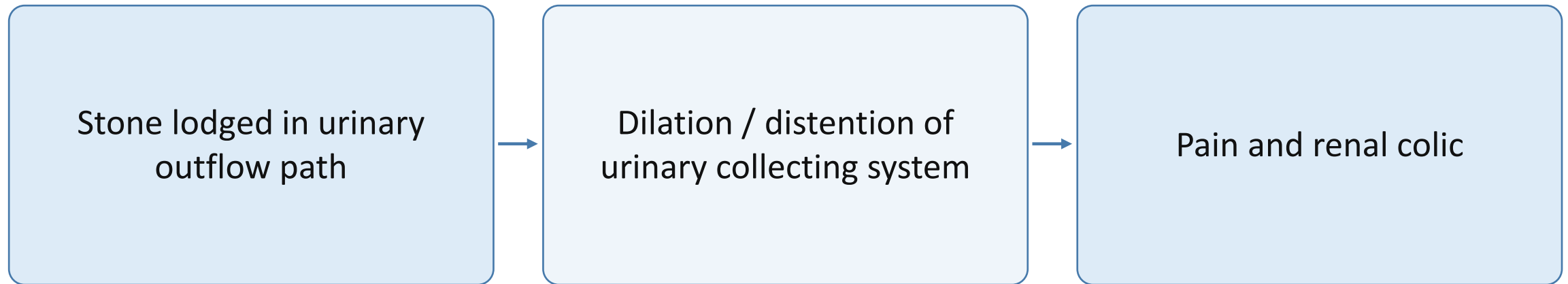
Silent disease

A calculus may produce no symptoms.

Symptomatic disease

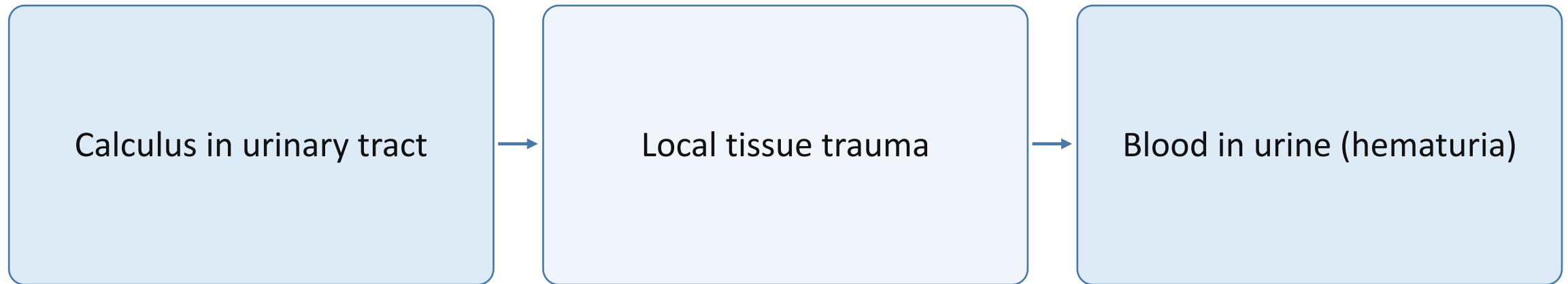
Renal colic, abdominal pain, hematuria, or renal damage may occur.

Obstructing calculi can provoke renal colic



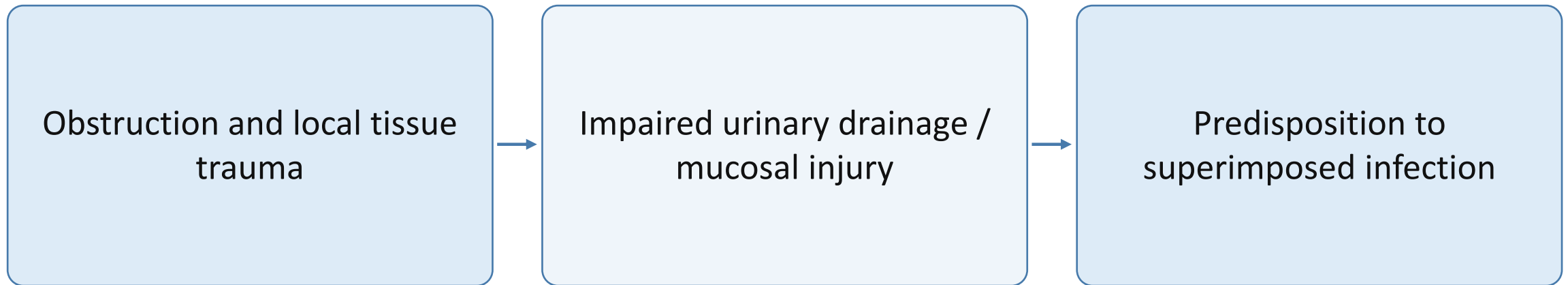
Conceptual sequence — direction indicates the causal relationship described in the source

A calculus can cause hematuria



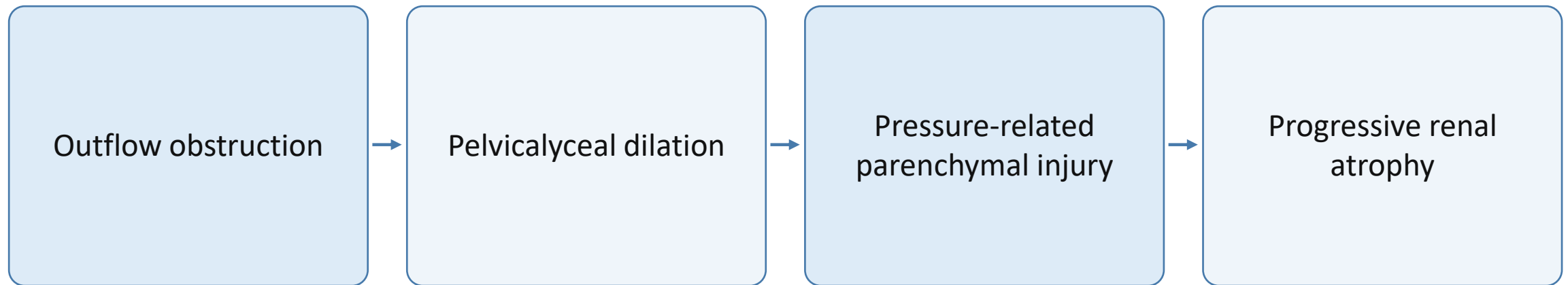
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Stones increase susceptibility to infection



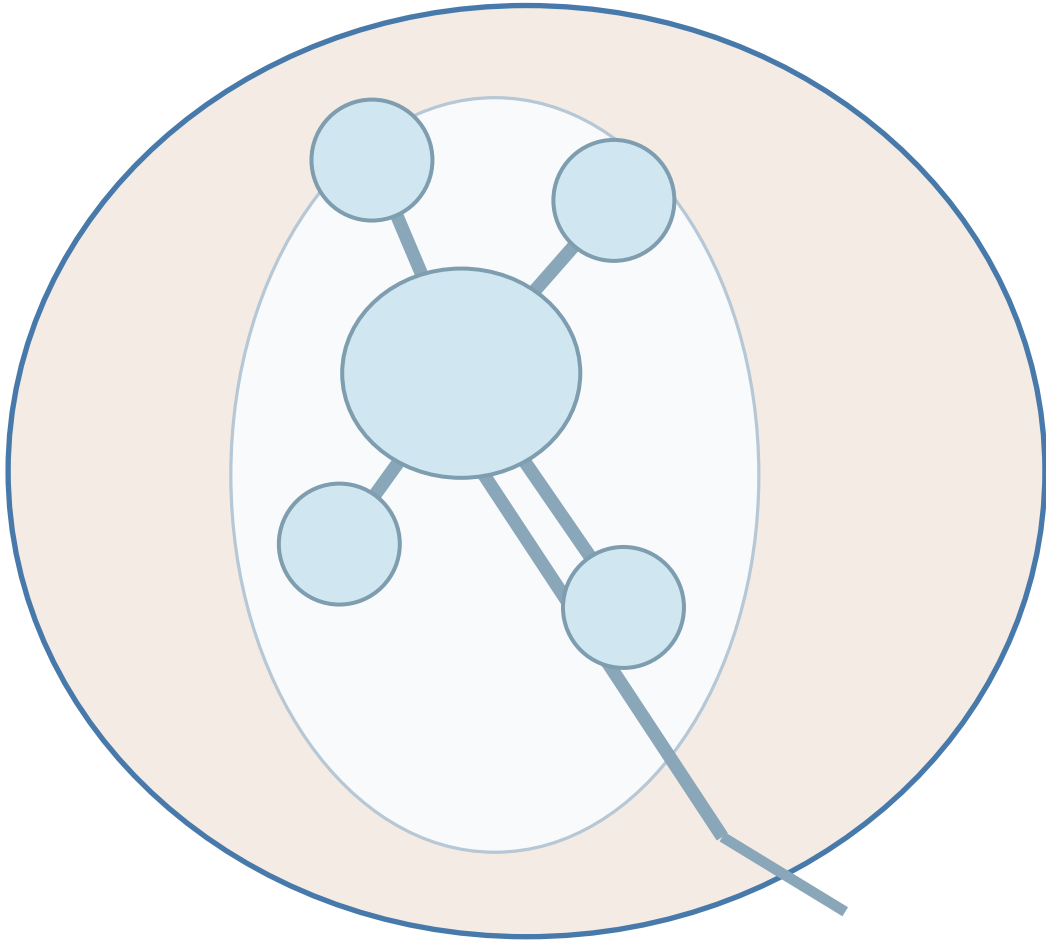
Conceptual sequence — direction indicates the causal relationship described in the source

Persistent stone obstruction injures the kidney



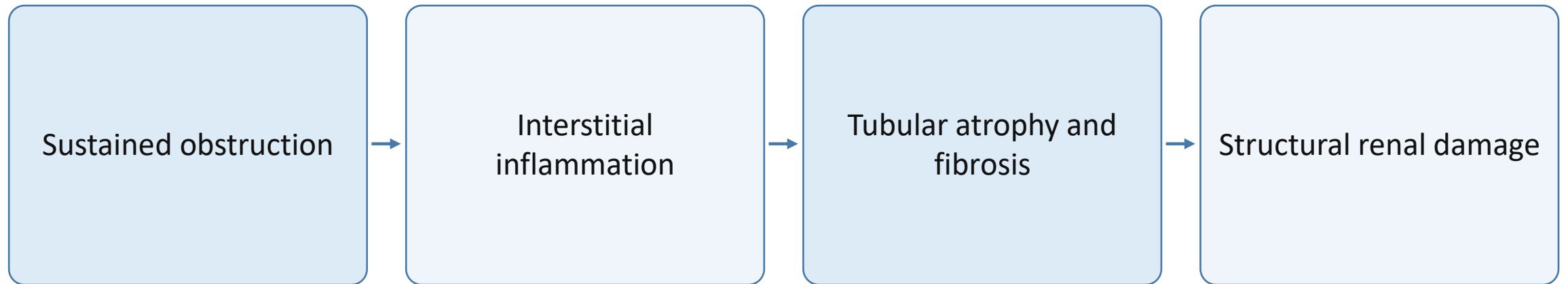
Conceptual sequence — direction indicates the causal relationship described in the source

Hydronephrosis is dilation with progressive atrophy



- Obstruction can dilate the renal pelvis and calyces.
- Prolonged pressure is associated with loss of renal parenchyma.

Chronic obstruction evolves beyond dilation



Conceptual sequence — direction indicates the causal relationship described in the source

Teaching case: Recurrent calcium-type risk

A patient has calcium oxalate stones and increased urinary calcium, but normal serum calcium.

Question: Which metabolic category is supported? What mechanisms should be considered?

Case interpretation: Normocalcemic hypercalciuria

The pattern is compatible with hypercalciuria without hypercalcemia.

Possible categories include increased intestinal absorption, tubular reabsorption impairment, or idiopathic fasting hypercalciuria.

Teaching case: Large branching calculus

A patient has a staghorn-shaped calculus and an infection caused by a urea-splitting organism.

Question: Which stone type is most plausible, and why?

Case interpretation: Infection-associated struvite

A urease-positive infection can raise urinary pH through ammonia generation.

Alkalinization favors magnesium ammonium phosphate precipitation and large branching calculi.

Teaching case: Stone invisible on plain radiography

A patient with a stone has persistently acidic urine; The calculus is radiolucent on plain radiography.

Question: What composition is most strongly suggested by Robbins?

Case interpretation: Uric acid stone

Acidic urine promotes uric acid precipitation.

Radiolucency supports uric acid rather than a typical calcium stone; Serum urate need not be elevated.

Integrative differential at a glance

Stone class	Most discriminating source-based feature
Calcium	Common; multiple possible urinary metabolic drivers
Struvite	Urea-splitting infection → alkaline urine; may be staghorn
Uric acid	Acidic urine; radiolucent on plain radiography
Cystine	Hereditary amino-acid transport defect; acidic urine

Clinicopathologic synthesis

- Supersaturation is central, but urinary pH and inhibitors modulate crystal formation.
- Calcium stones have heterogeneous mechanisms; Struvite, uric acid, and cystine have distinct clues.
- Stone shape, location, obstruction, and infection determine clinical consequences.
- Stone chemistry and renal morphology should be interpreted together.

Primary source and scope

- Robbins, Cotran & Kumar. Pathologic Basis of Disease. 11th ed. 2026. Chapter 20: The Kidney, pp. 861–862.
- The obstructive uropathy section in the same chapter was used for consequences of persistent obstruction.
- Figures in this lecture are original editable schematics, not patient specimens or textbook reproductions.