

Blood pressure regulation

Mechanisms linking the heart, vascular tone and renal sodium balance

Dr Abu Suraih Sakhri

MBBS, MD (Pathology)

www.abusuraihsakhri.com

Learning objectives

Relate systemic arterial pressure to cardiac output and resistance.

Explain neural, humoral, local, and renal control of pressure.

Trace renin–angiotensin–aldosterone and natriuretic responses.

Apply normal physiology to selected forms of secondary hypertension.

Why arterial pressure requires regulation

- Adequate pressure sustains organ perfusion despite unequal tissue demands.
- Insufficient pressure can cause dysfunction or tissue death.
- Excess pressure contributes to cumulative end-organ injury.

Pressure too low

Reduced organ perfusion

Ischemic dysfunction

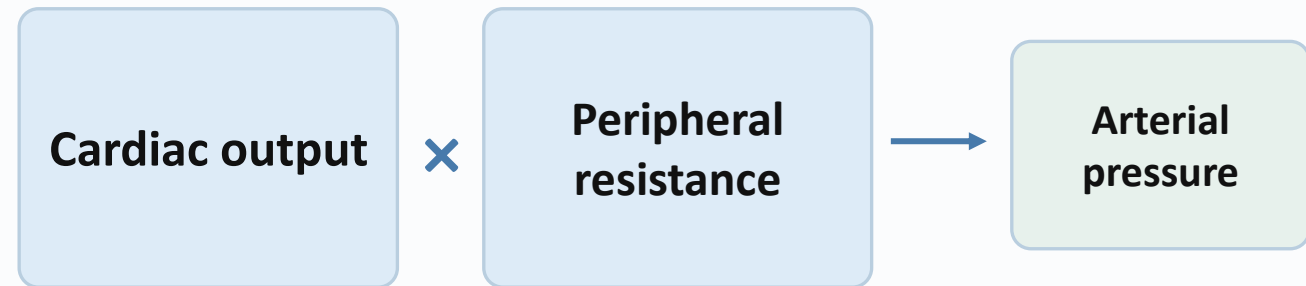
Pressure too high

Vascular load and injury

Target-organ damage

Two determinants of systemic pressure

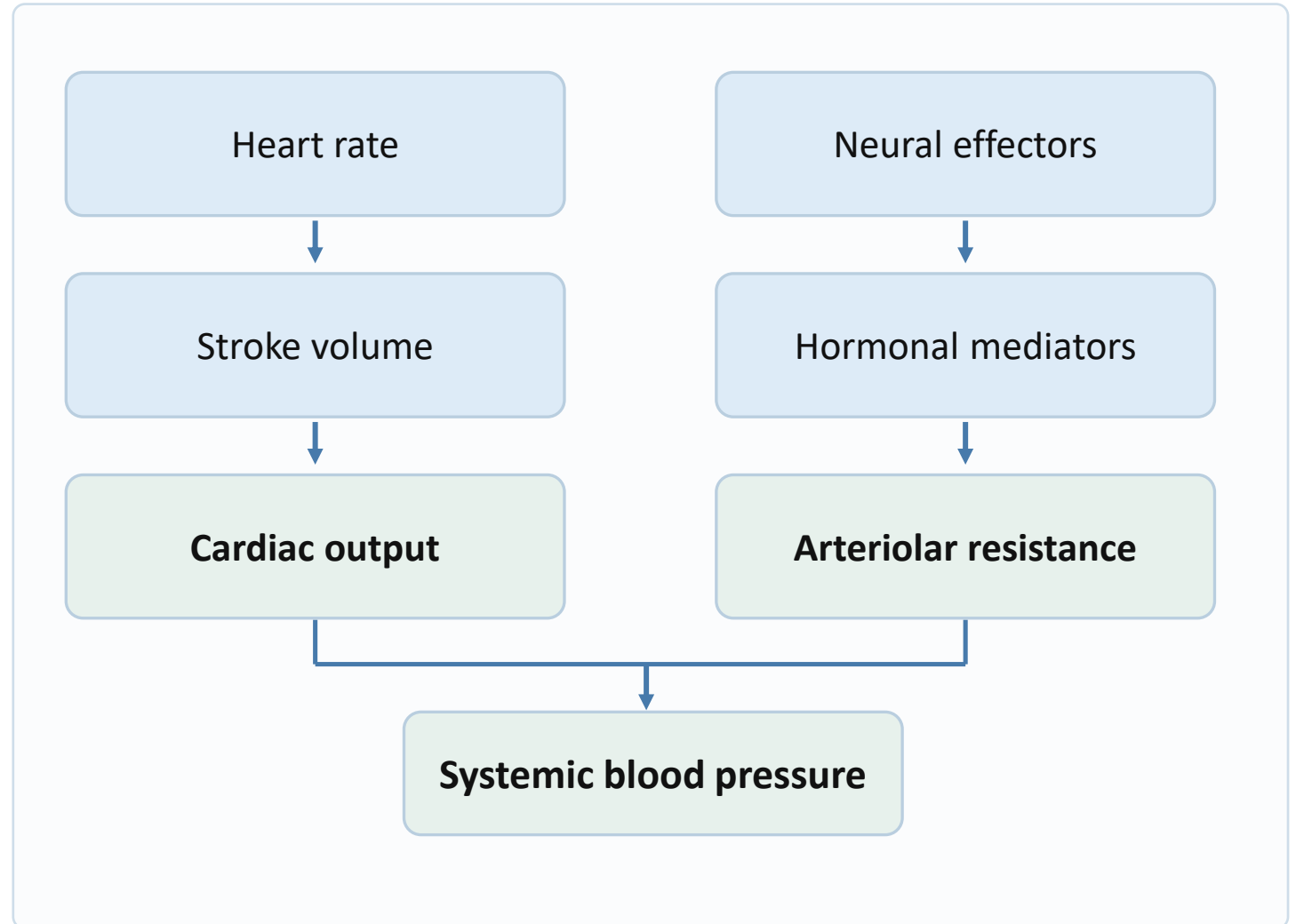
- Cardiac output determines the volume delivered per unit time.
- Peripheral resistance opposes flow through the systemic circulation.
- Either determinant can change measured arterial pressure.



Functional relationship

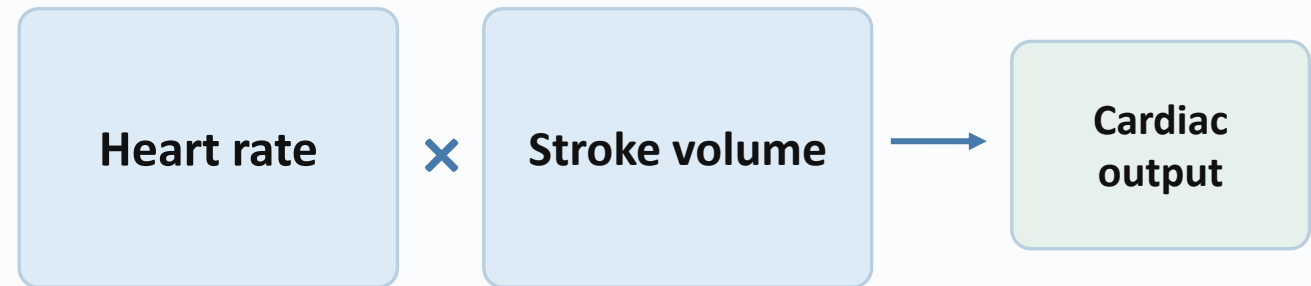
Integrated control: Multiple linked effectors

- Cardiac factors, blood volume, and arteriolar tone act together.
- Renal, neural, hormonal, and local signals continually interact.
- A single measured pressure may reflect different physiologic mechanisms.



Cardiac output has two components

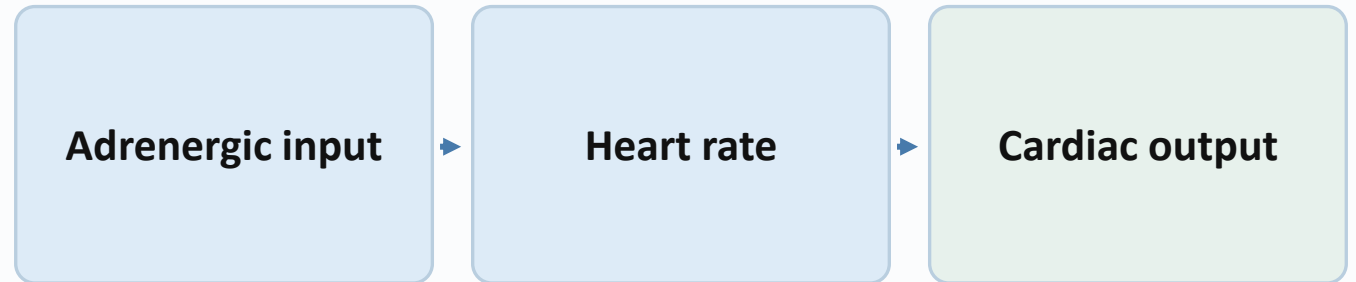
- Heart rate is the number of ventricular beats per unit time.
- Stroke volume is the blood ejected with each beat.
- A change in either component may alter total cardiac output.



Functional relationship

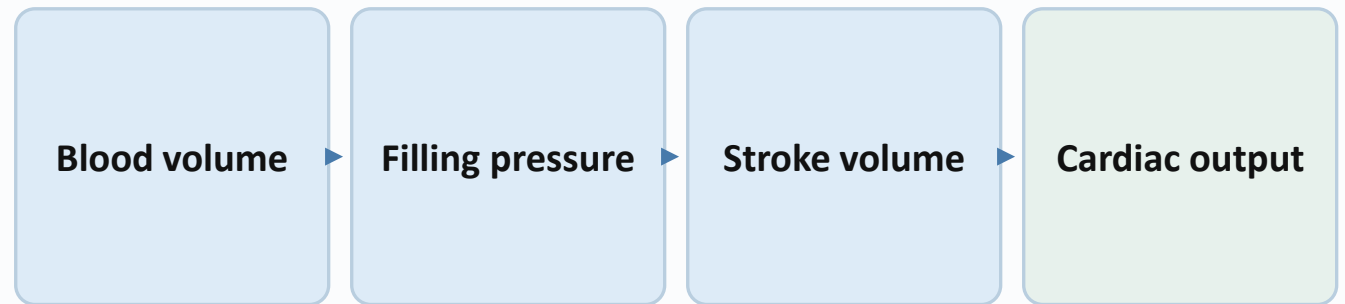
Heart rate: Autonomic control

- Adrenergic neural signaling affects cardiac pacing.
- An increase in rate can increase cardiac output if other determinants are maintained.
- Rate changes need interpretation alongside stroke volume.



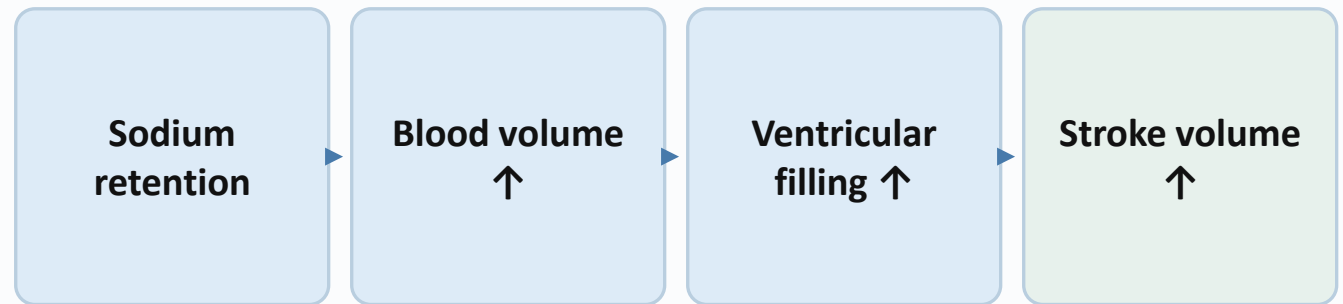
Ventricular filling drives stroke volume

- Ventricular filling pressure is a major determinant of stroke volume.
- Filling depends strongly on the circulating blood volume.
- Renal sodium balance therefore influences cardiac output indirectly.



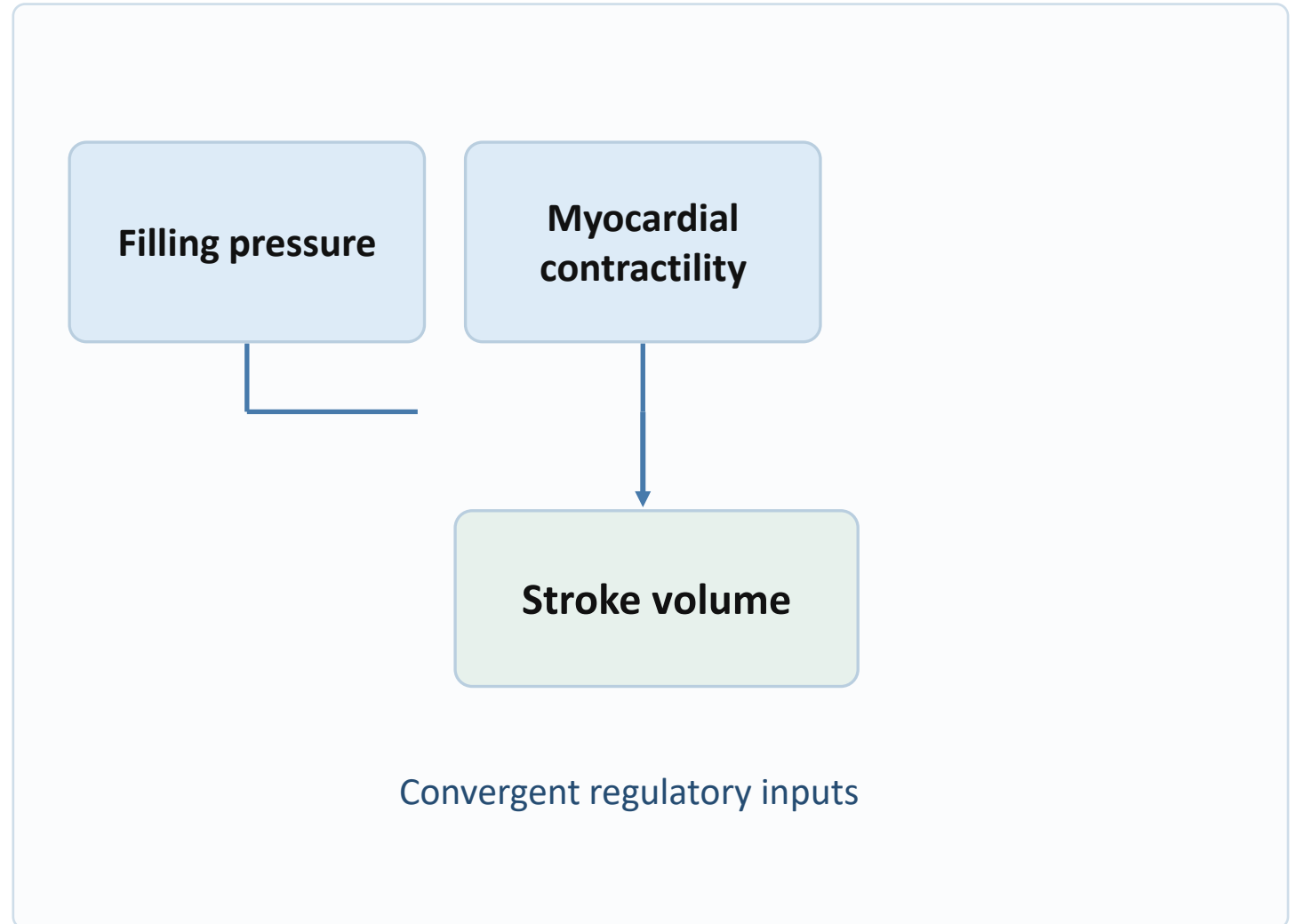
How sodium balance affects ventricular filling

- Retained sodium favors retention of body water.
- An increase in blood volume can increase filling pressure.
- Enhanced filling can increase stroke volume and cardiac output.



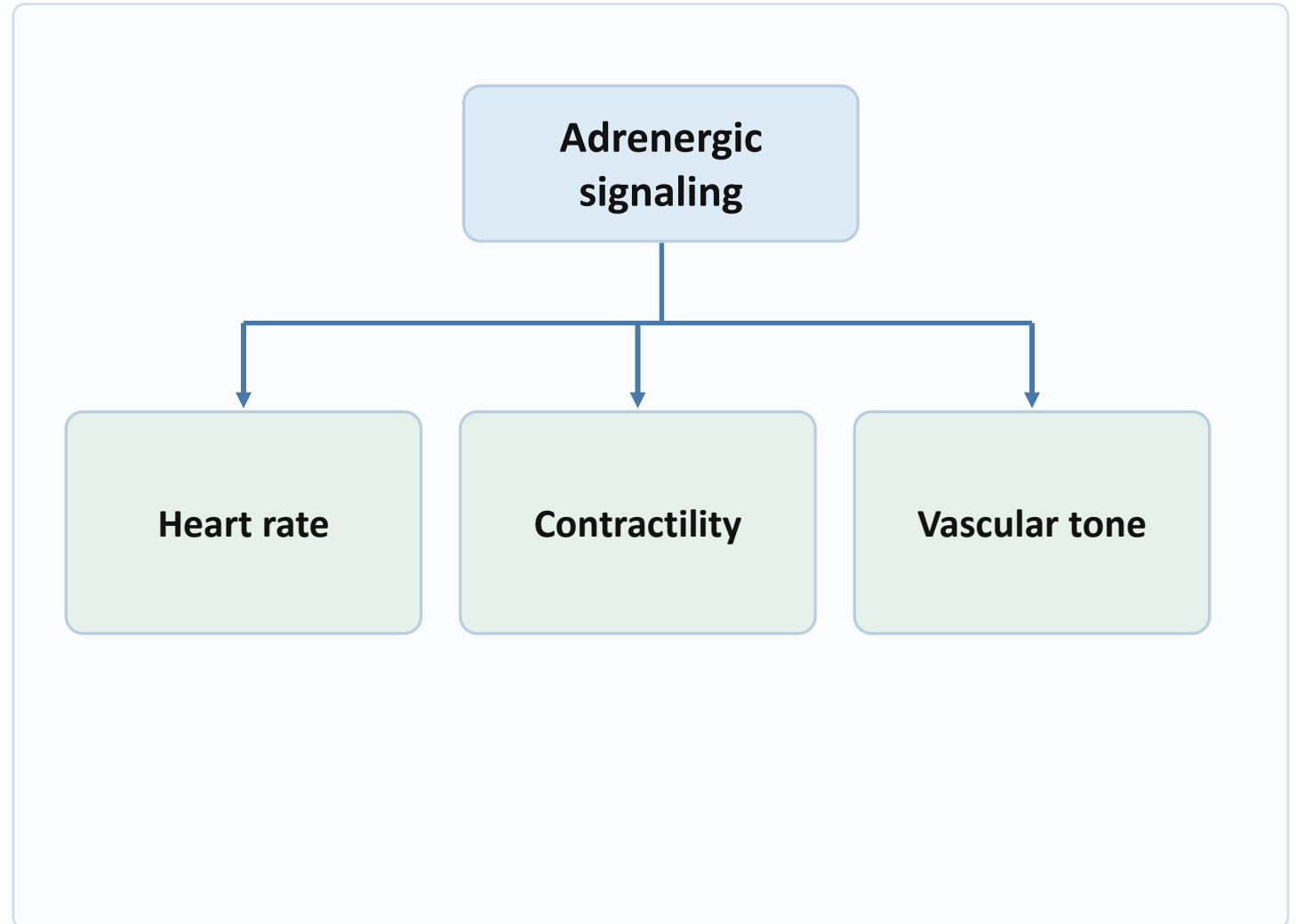
Contractility is a second stroke-volume determinant

- Myocardial contractility modulates stroke volume beyond filling effects.
- Adrenergic signaling influences contractile force.
- Blood pressure can therefore vary even when blood volume is unchanged.



Adrenergic systems act on heart and vessels

- α - and β -adrenergic pathways regulate cardiac performance.
- Adrenergic signaling also alters vascular tone.
- The same systemic stimulus may affect cardiac output and resistance.



Cardiac output: Distinguish two mechanisms

- Volume-mediated change: Sodium balance alters filling and stroke volume.
- Neural-mediated change: Adrenergic input influences rate and contraction.
- Both routes converge on cardiac output but begin at different effectors.

Volume route

Renal Na⁺ retention

↑ filling → ↑ stroke volume

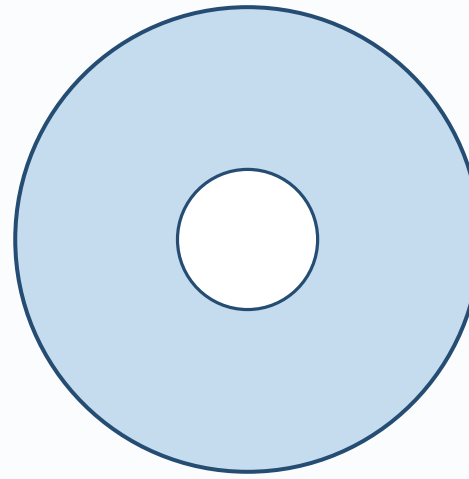
Adrenergic route

Autonomic signal

Heart rate / contractility

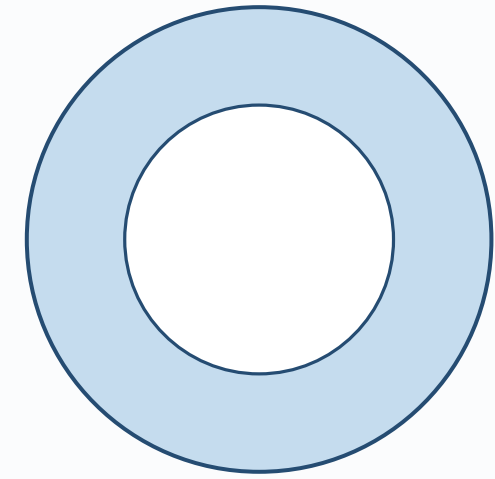
Arterioles are the major resistance vessels

- Peripheral resistance is regulated predominantly at the arteriolar level.
- Changes in arteriolar smooth-muscle tone change vascular caliber.
- Resistance can change independently of blood volume.



Contracted wall

Narrower lumen

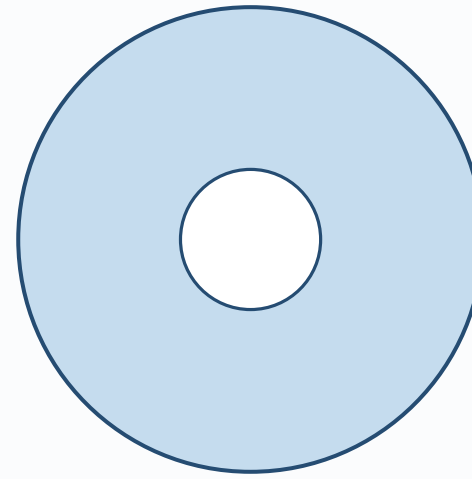


Relaxed wall

Wider lumen

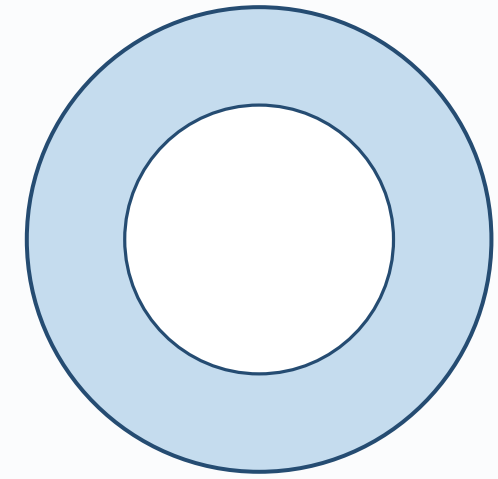
Vascular smooth-muscle contraction changes resistance

- Contraction narrows the arteriolar lumen and raises resistance.
- Relaxation enlarges the lumen and reduces resistance.
- The relevant final effector is the arteriolar smooth-muscle cell.



Contracted wall

Narrower lumen

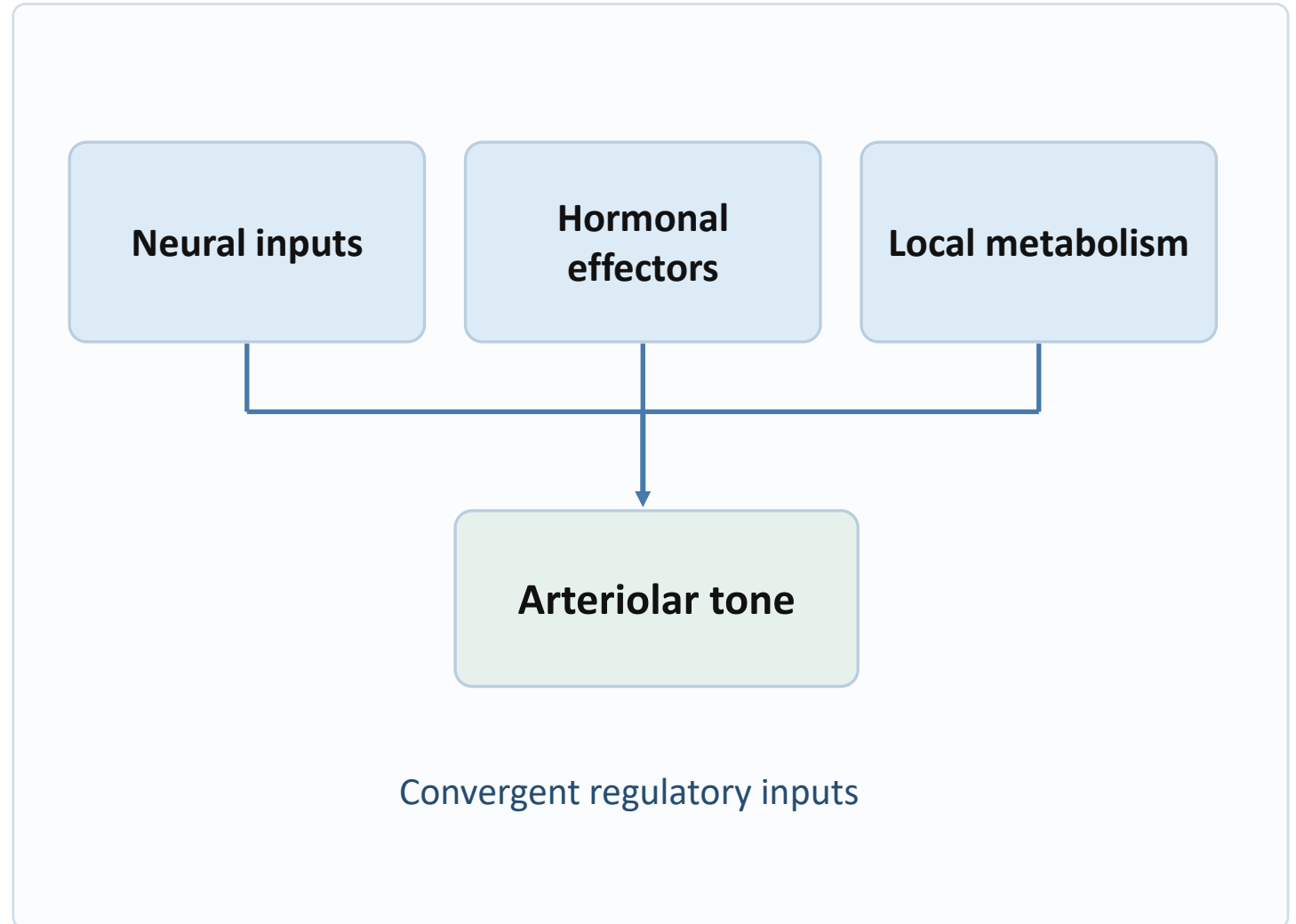


Relaxed wall

Wider lumen

Neural and humoral input to arteriolar tone

- Neural signals provide coordinated changes in vascular resistance.
- Circulating hormones provide additional vasomotor control.
- Local tissue signals adjust tone to regional requirements.



Principal vasoconstrictor mediators

- Angiotensin II promotes vascular smooth-muscle contraction.
- Catecholamines participate in vasomotor regulation.
- Endothelin contributes to the constrictor side of vascular tone.

Angiotensin II

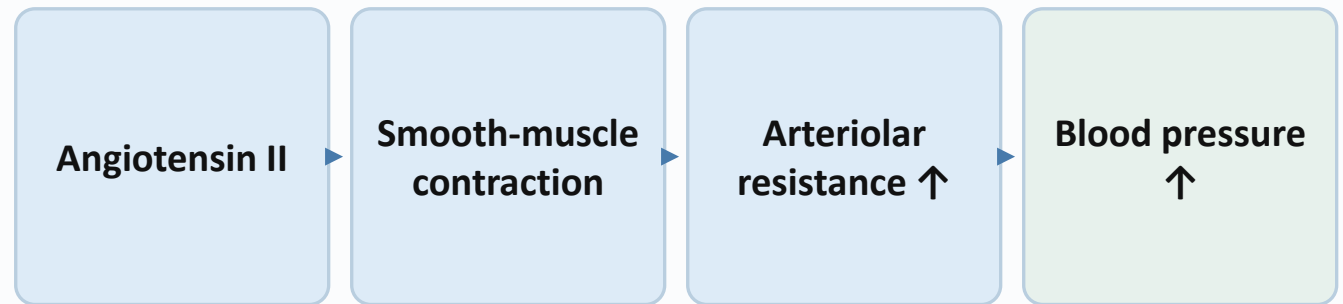
Catecholamines

Endothelin

Vasoconstriction → resistance ↑

Angiotensin II: A direct pressor action

- Angiotensin II acts on vascular smooth muscle to increase tone.
- The resulting rise in peripheral resistance increases blood pressure.
- This is distinct from its sodium-retaining actions in the kidney.



Principal vasodilator mediators

- Kinins and prostaglandins can promote vascular relaxation.
- Nitric oxide (NO) is an important vasodilator.
- Their effects counterbalance vasoconstrictor influences.

Kinins

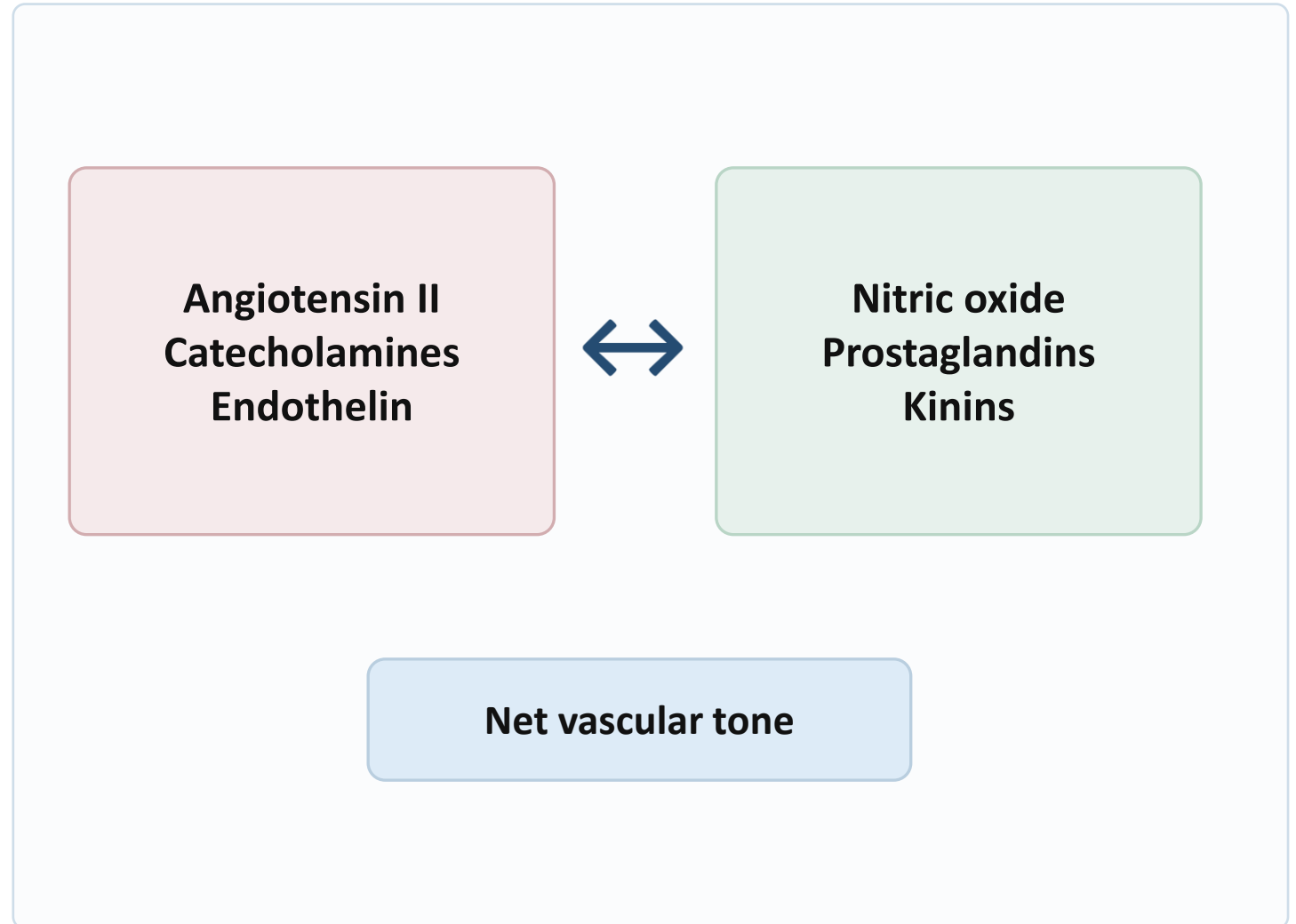
Prostaglandins

Nitric oxide (NO)

Vasodilation → resistance ↓

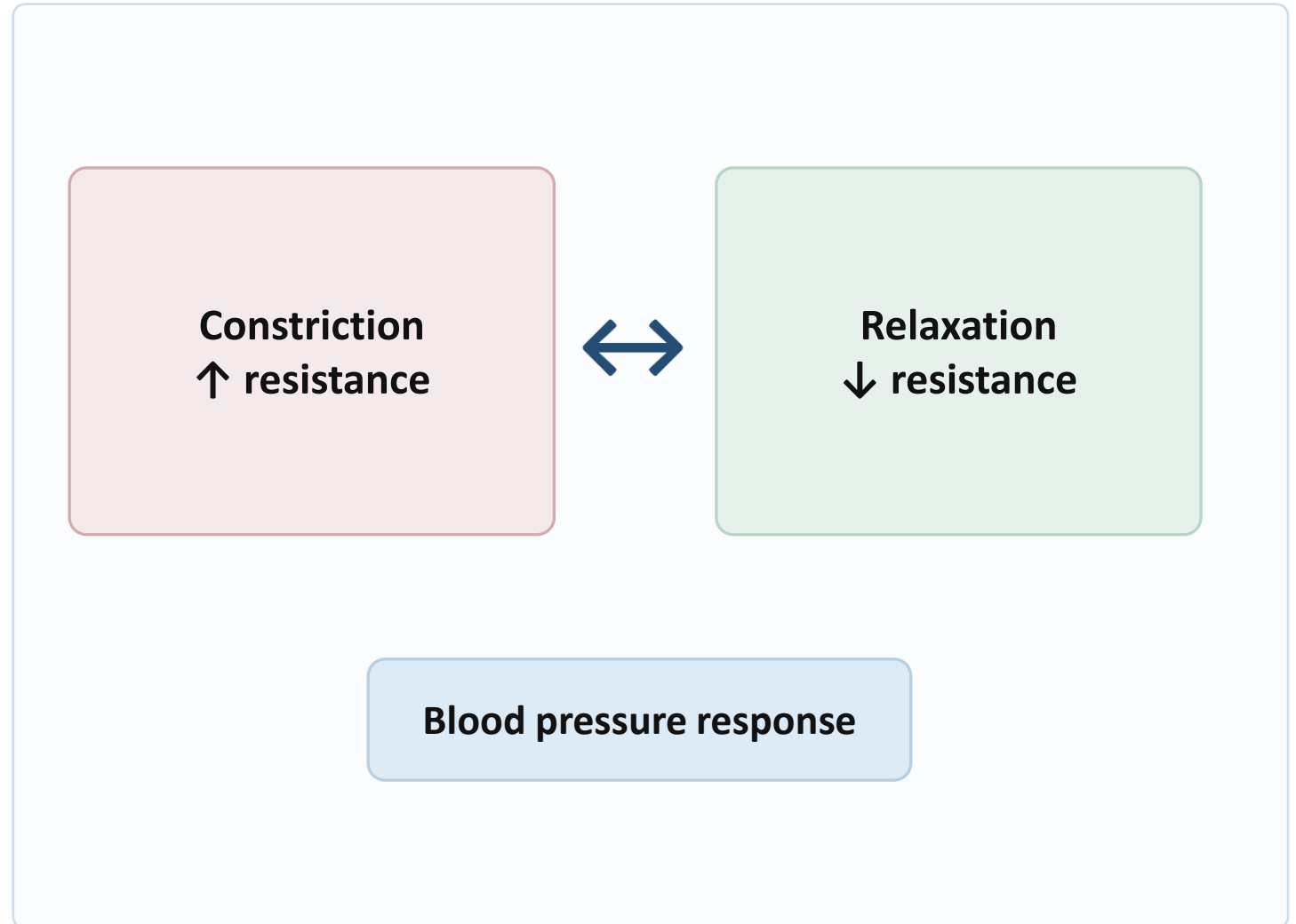
Nitric oxide and vascular homeostasis

- Nitric oxide contributes to the relaxing side of vasomotor balance.
- Renal NO is one of the factors that offset pressor mechanisms.
- Vascular tone reflects the net effect—not one mediator in isolation.



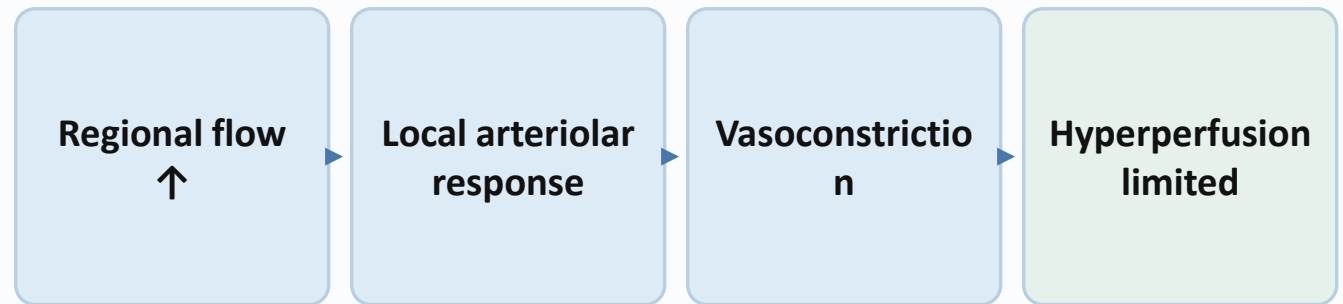
Vascular tone is a balance of opposing signals

- Constrictors and dilators act simultaneously on resistance vessels.
- Relative predominance of either side changes peripheral resistance.
- Systemic pressure follows the integrated net vascular response.



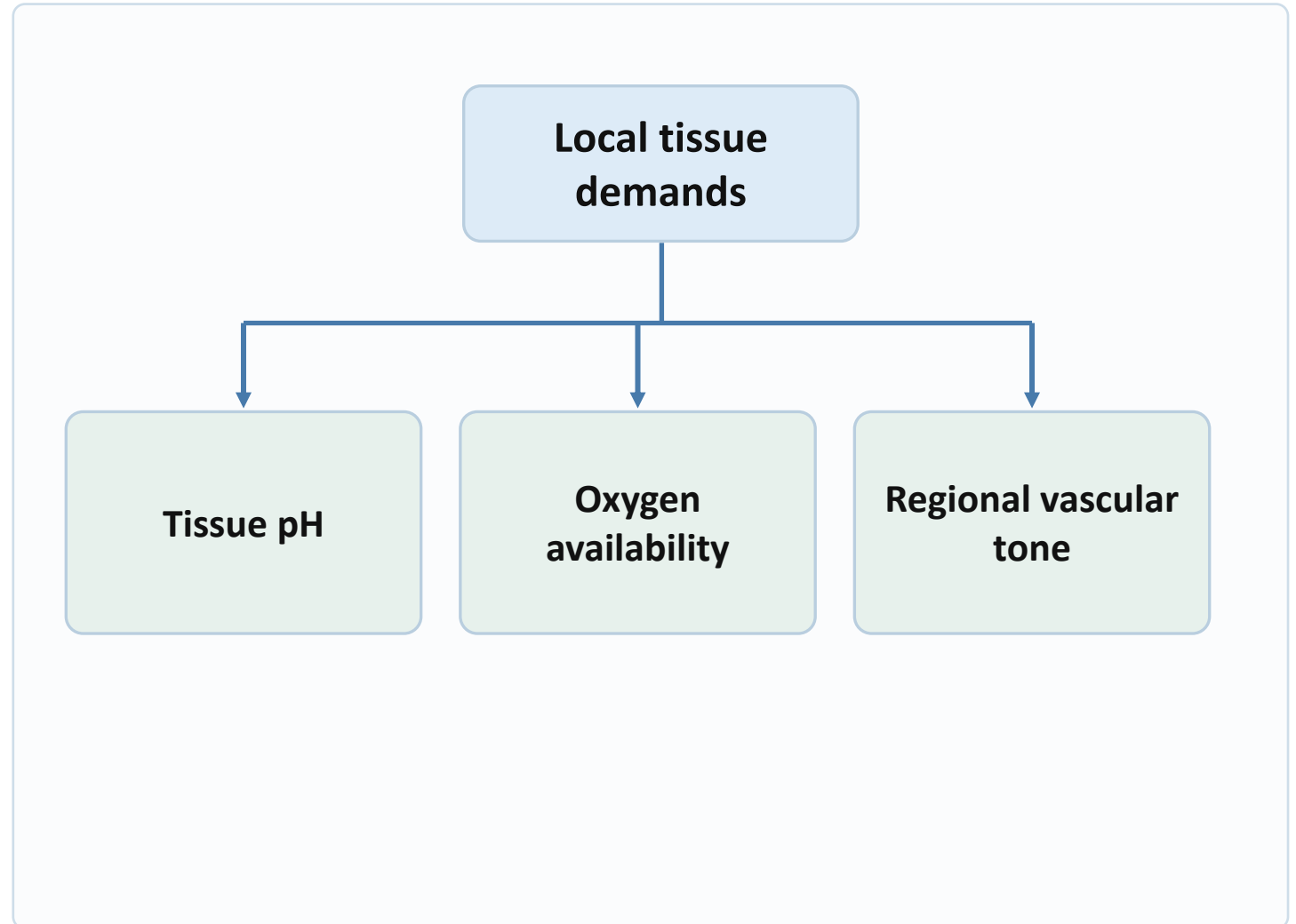
Autoregulation protects against hyperperfusion

- Resistance vessels respond to changes in delivered blood flow.
- Increased flow can induce local vasoconstriction.
- The local response restrains excess tissue perfusion.



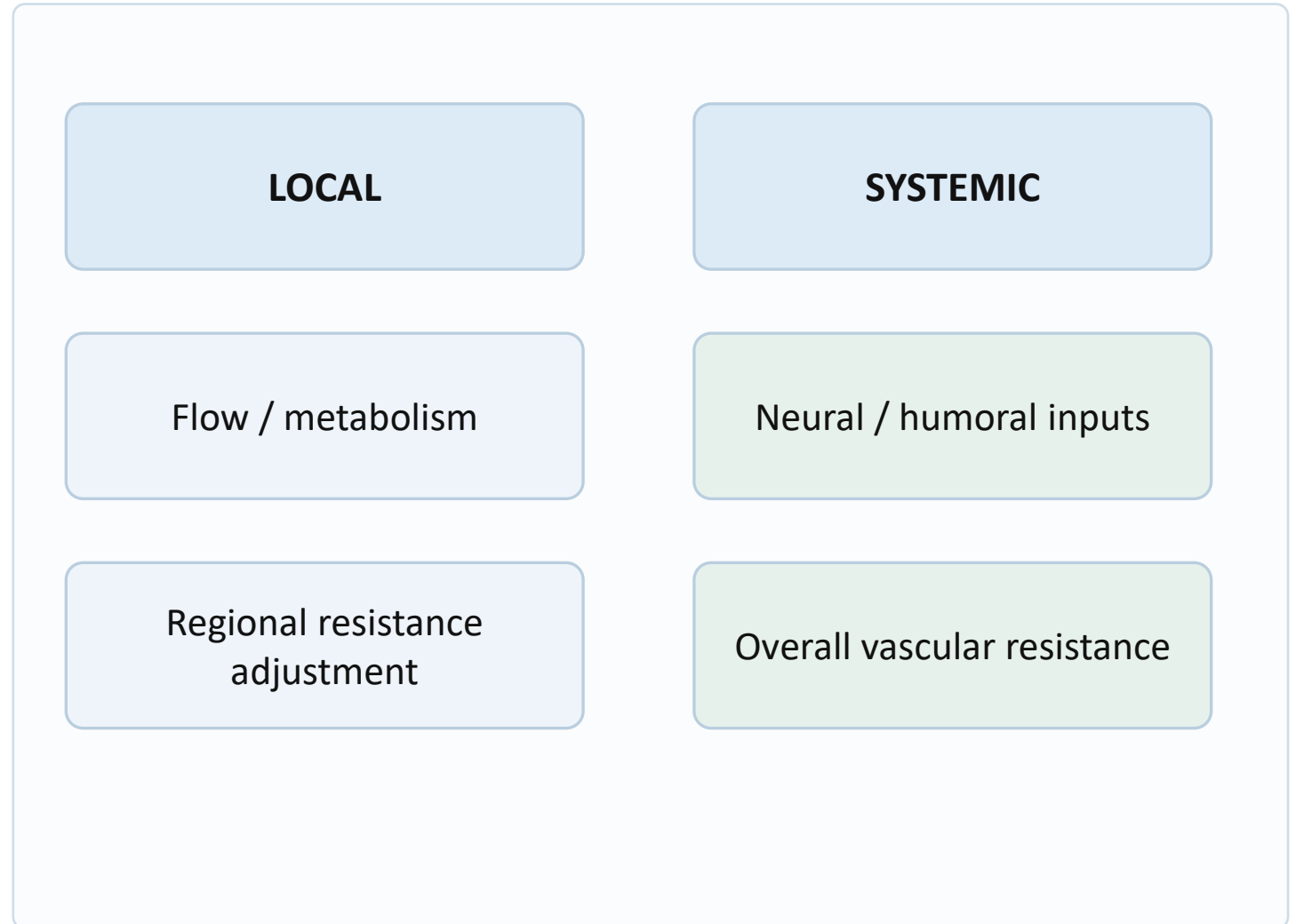
Local pH and hypoxia fine-tune perfusion

- Changes in tissue pH contribute to local regulation of vascular tone.
- Hypoxia signals altered local metabolic conditions.
- These mechanisms help match perfusion to regional demand.



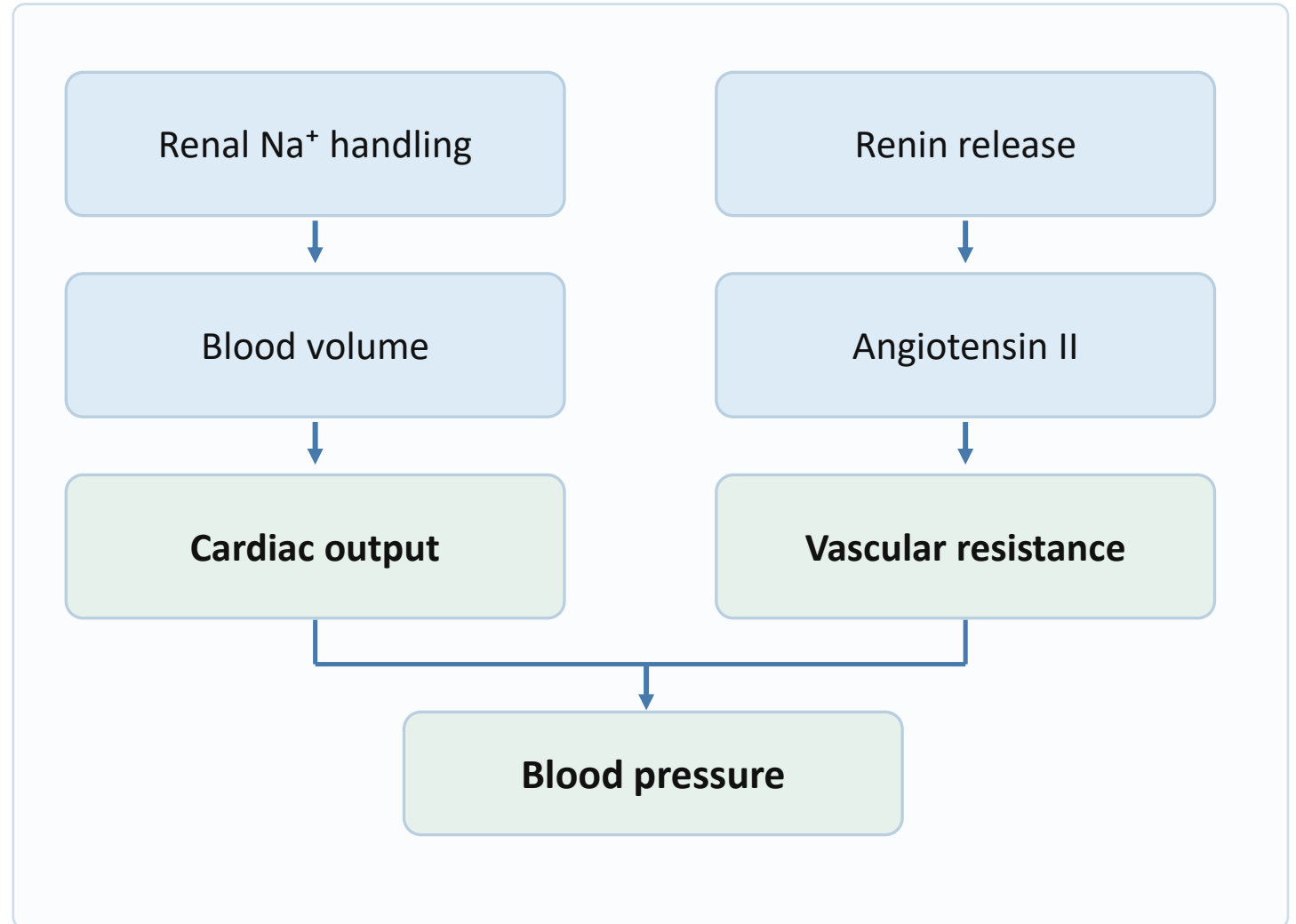
Local autoregulation is not the whole systemic response

- Local vascular feedback protects individual tissue beds.
- Neural and hormonal responses also alter systemic resistance.
- Systemic pressure represents the combined behavior of many beds.



Kidney: Long-term control of circulating volume

- The kidneys regulate net sodium excretion and reabsorption.
- Sodium balance governs the blood-volume component of pressure.
- Renal signals also modify arteriolar vascular tone.



Filtered sodium: A large daily physiologic load

- Roughly 170 L of plasma filtration per day.
- The filtered salt load is approximately 23 moles daily.
- Maintaining balance requires reabsorption of nearly all filtered sodium.

170 L

Plasma filtered /
day

23 mol

Salt in filtered
plasma / day

~99.5%

Reabsorbed at cited
intake

Most filtered sodium is reclaimed routinely

- About 98% of filtered sodium is reabsorbed by constitutively active transporters.
- This bulk transport precedes the regulated fine-adjustment step.
- A small residual fraction can still determine net excretion.

Filtered sodium handling

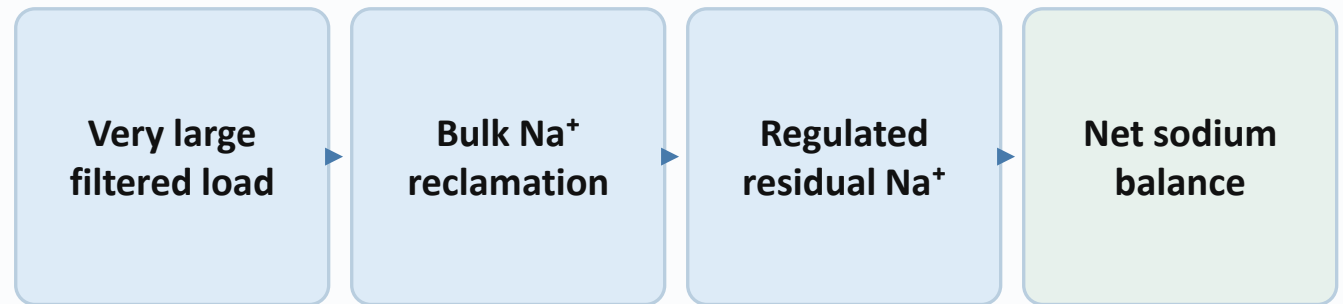


~98% constitutive reabsorption

Small remaining fraction
Subject to regulated uptake

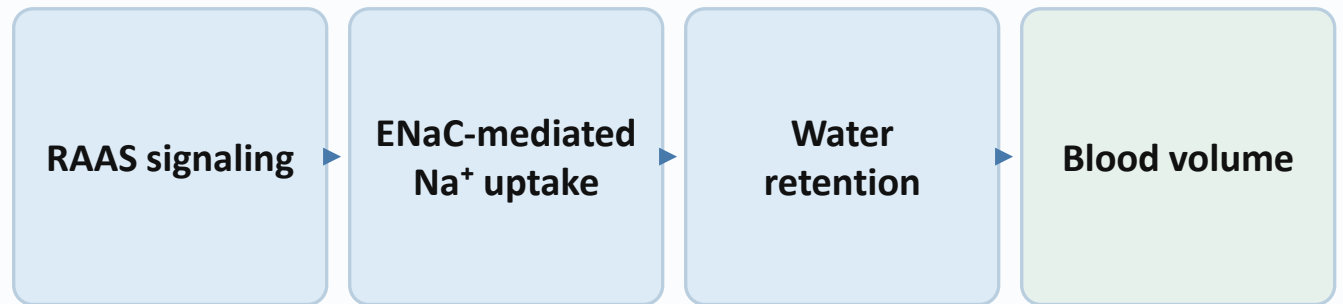
Small distal adjustments determine net sodium balance

- Most filtered sodium is already reabsorbed before final control.
- Regulation of the remaining fraction can alter net daily retention.
- A small fractional change matters because the filtered load is enormous.



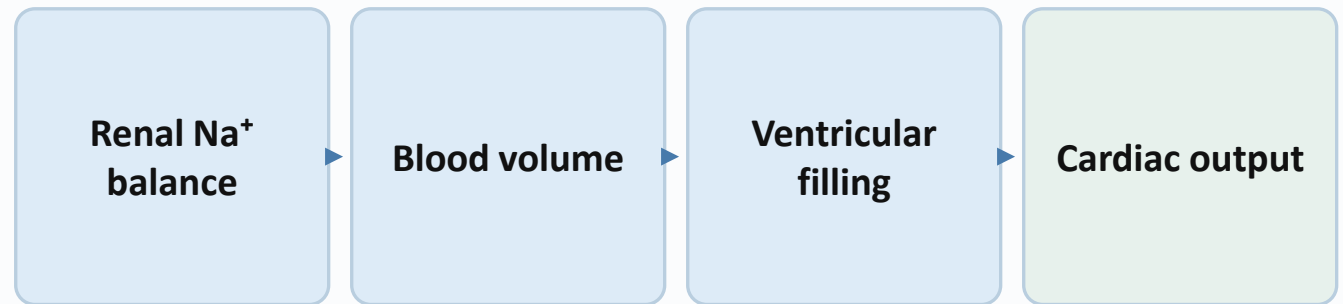
ENaC is a regulated sodium-reabsorptive pathway

- The epithelial sodium channel (ENaC) participates in distal sodium reabsorption.
- Its activity is tightly connected to the renin–angiotensin–aldosterone system.
- Distal channel regulation couples hormonal signals to volume homeostasis.



Sodium balance connects the kidney to the heart

- Greater net sodium retention promotes water retention.
- Expanded circulating volume influences filling pressure.
- Stroke volume and cardiac output then transmit this change to pressure.



Three organ systems generate circulating regulators

- Kidney releases renin in response to hemodynamic or tubular signals.
- Adrenal cortex releases aldosterone downstream of angiotensin II.
- Myocardium releases natriuretic peptides during volume-related signaling.

Kidney → renin

**Adrenal →
aldosterone**

**Heart → ANP /
BNP**

Regulation of vascular tone and Na⁺ balance

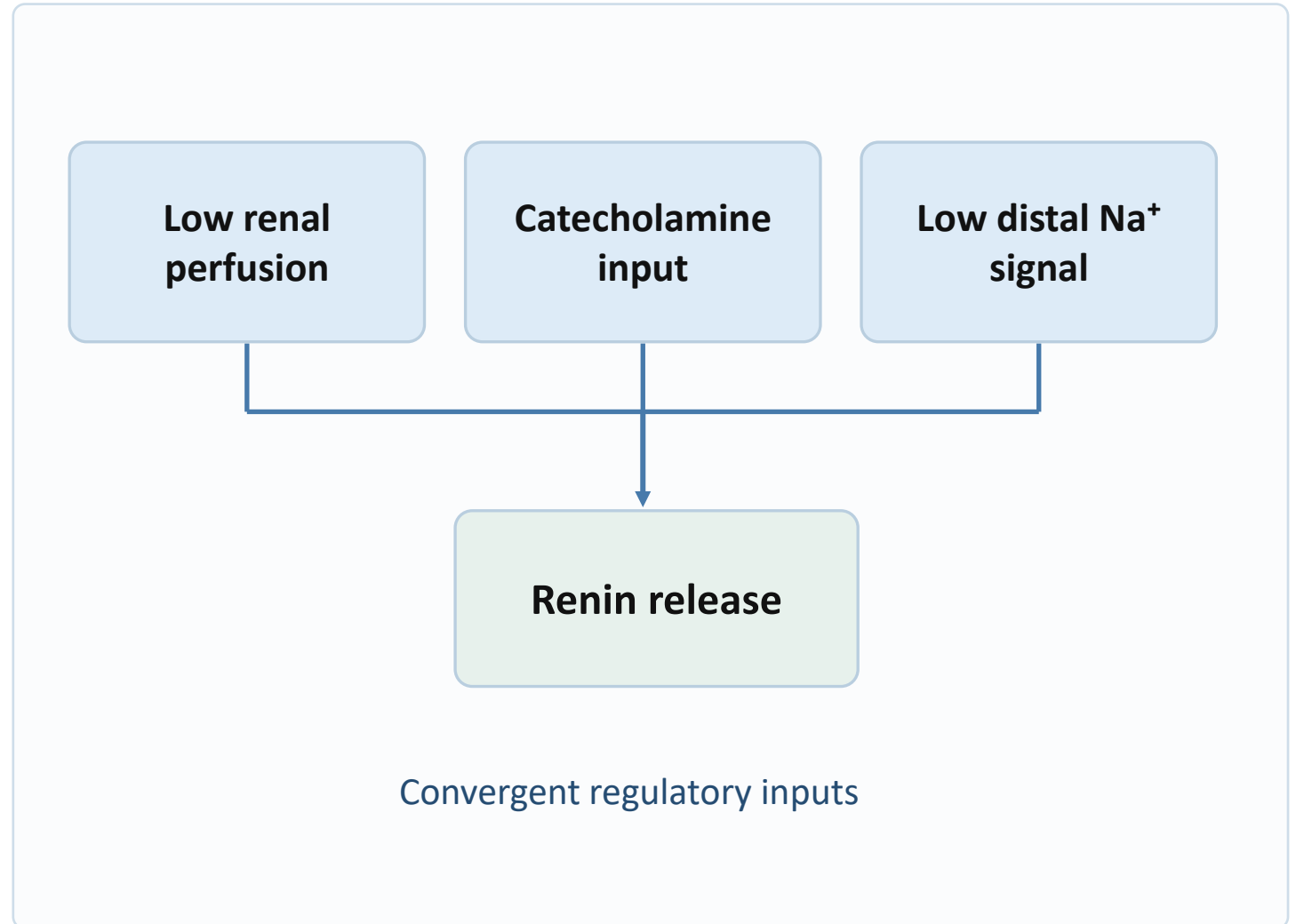
The juxtaglomerular apparatus senses pressure

- Renin is made by juxtaglomerular cells near afferent glomerular arterioles.
- These specialized cells detect changes in renal perfusion pressure.
- Reduced afferent pressure is a potent stimulus for renin secretion.



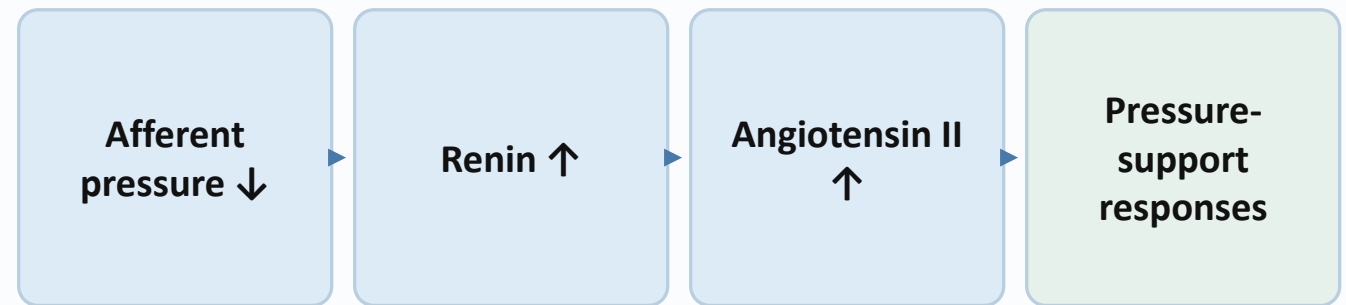
Three signals promote renin secretion

- Reduced afferent arteriolar blood pressure.
- Elevated circulating catecholamine stimulation.
- Low sodium delivery detected in the distal nephron.



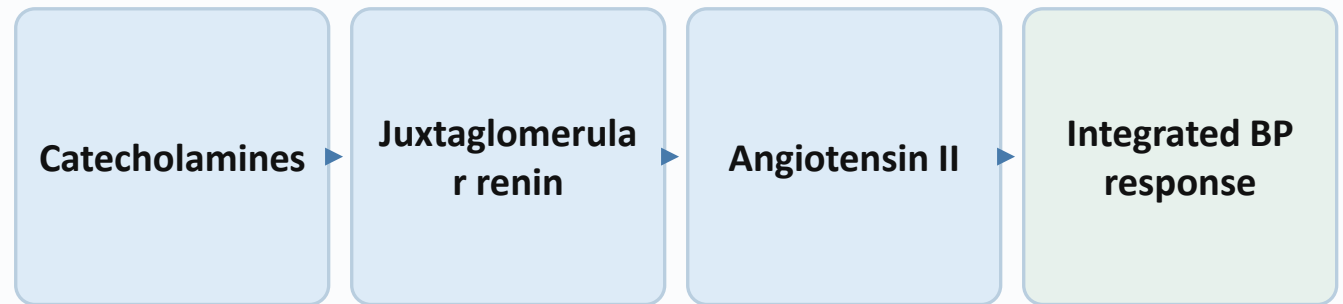
Reduced renal perfusion activates renin

- The kidney can experience low perfusion despite systemic pressure elsewhere.
- Low afferent arteriolar pressure triggers juxtaglomerular renin secretion.
- RAAS activation then promotes both vasoconstriction and volume retention.



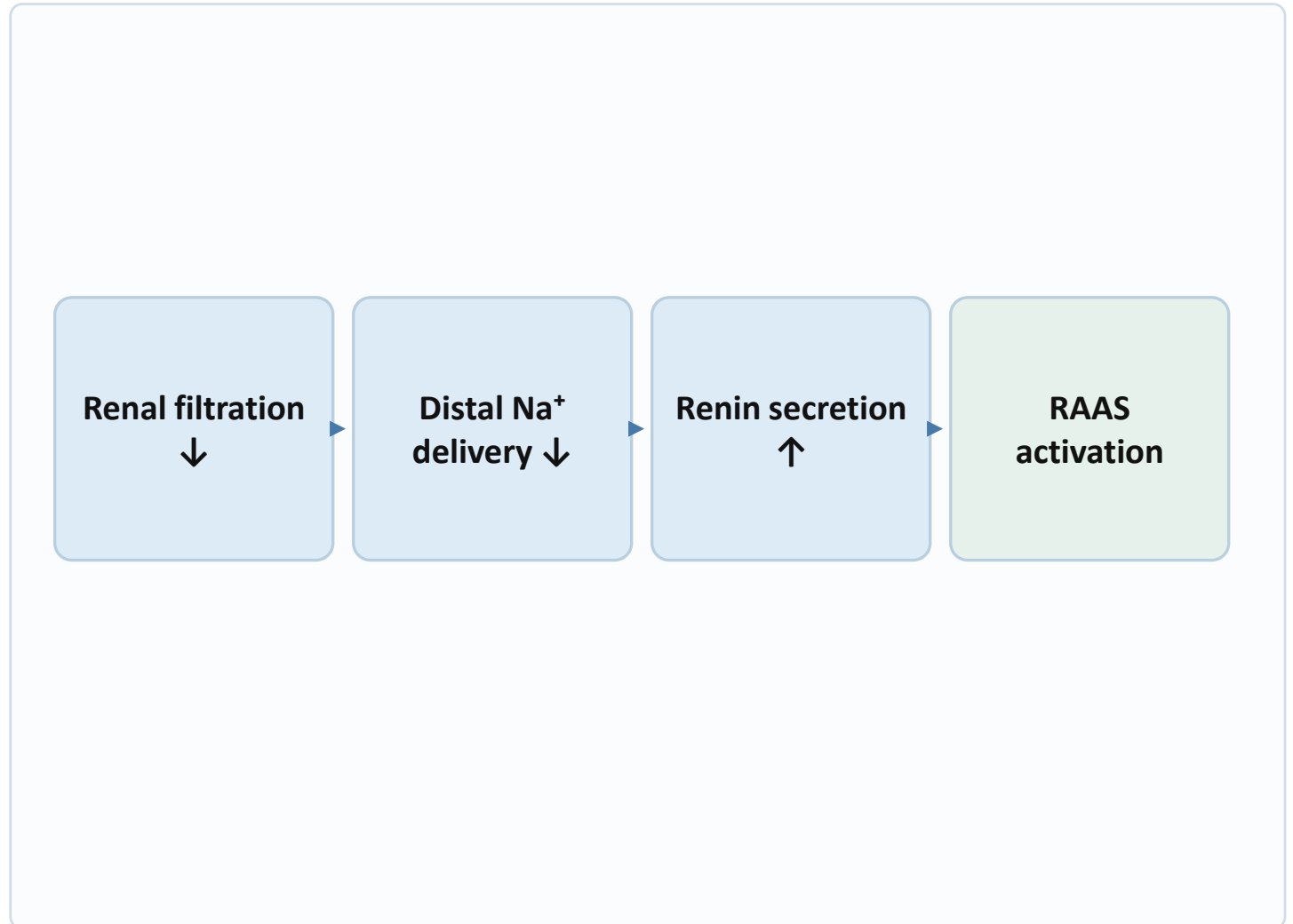
Catecholamines provide a renin-release signal

- Elevated catecholaminergic input stimulates renin release.
- Neural effects therefore intersect with endocrine regulation.
- The downstream renin pathway amplifies control beyond direct vascular tone.



Low distal sodium delivery stimulates renin

- Reduced filtration can change sodium reaching the distal nephron.
- Increased proximal reabsorption also lowers distal delivery.
- The low distal sodium signal promotes renin secretion.



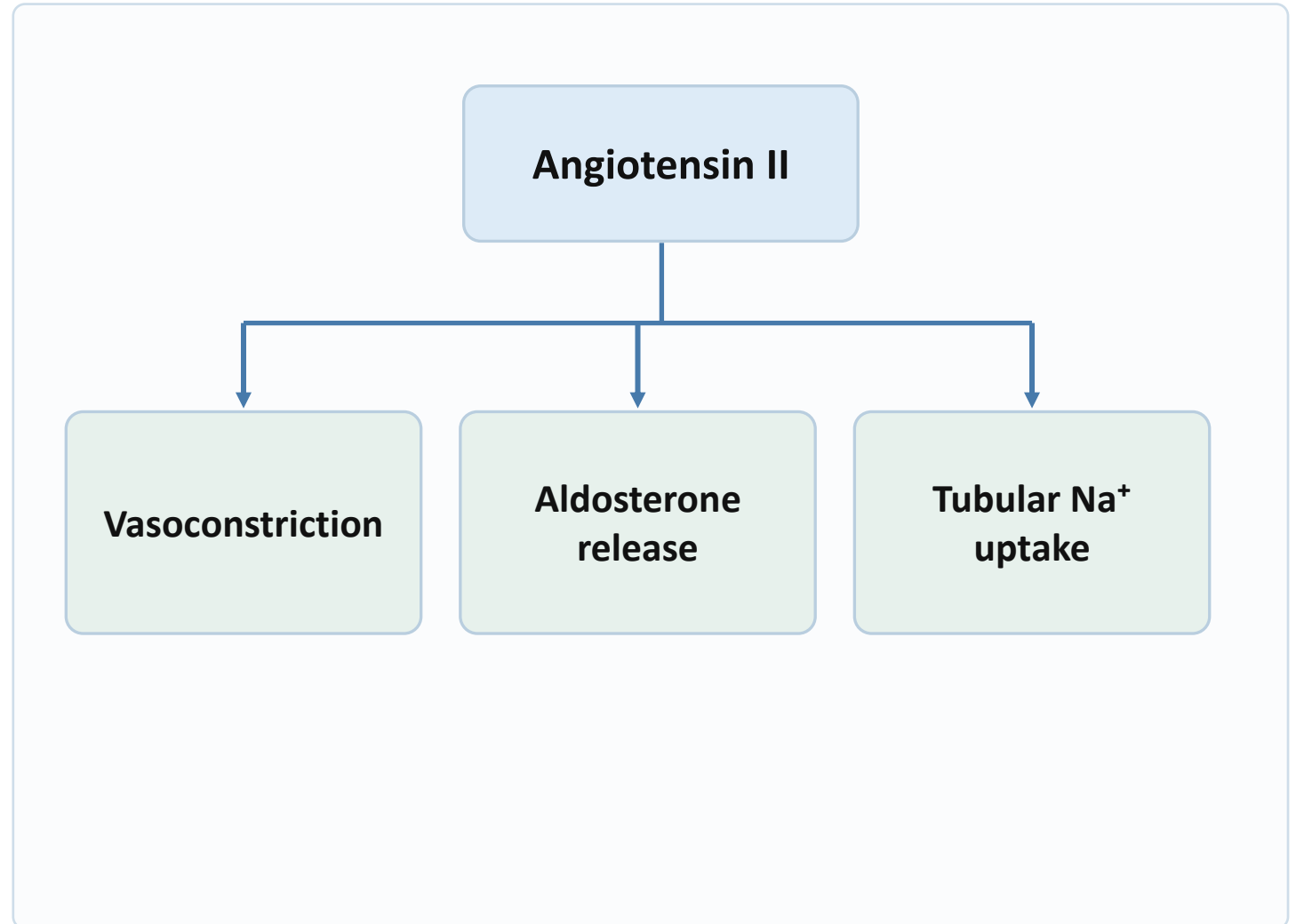
Renin initiates the angiotensin cascade

- Renin cleaves circulating angiotensinogen to angiotensin I.
- Angiotensin-converting enzyme converts angiotensin I to angiotensin II.
- Vascular endothelium is a major source of ACE.



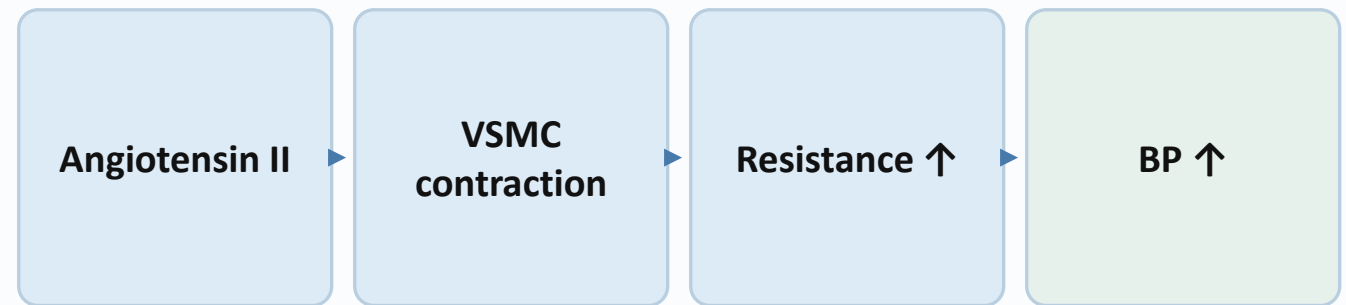
Angiotensin II coordinates three pressor responses

- It directly contracts vascular smooth muscle.
- It stimulates adrenal secretion of aldosterone.
- It also increases renal tubular sodium reabsorption.



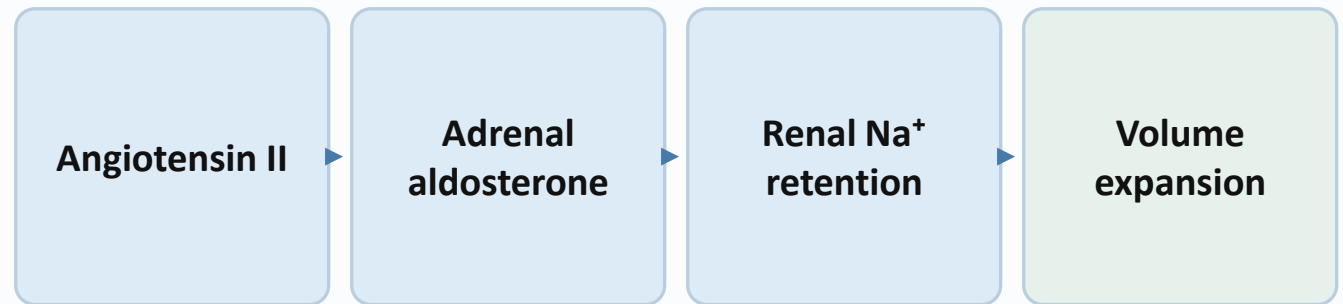
The vascular branch raises resistance

- Angiotensin II induces vascular contraction.
- Arteriolar narrowing increases peripheral resistance.
- Pressure rises through the resistance arm of the BP equation.



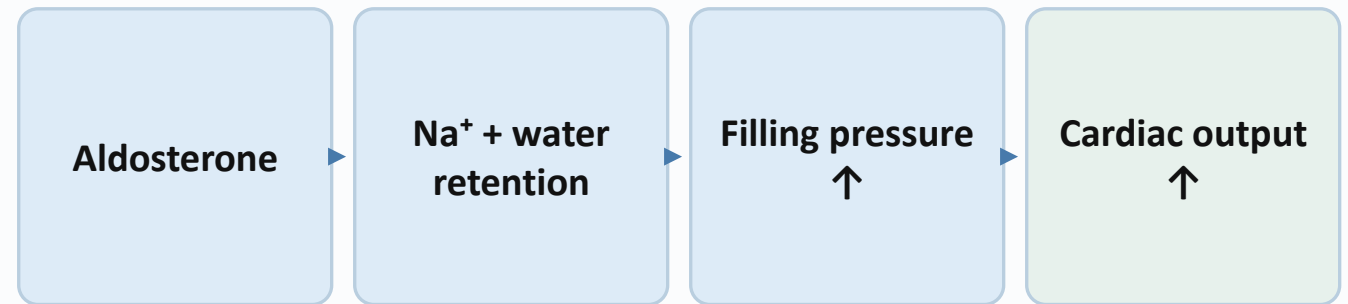
The adrenal branch releases aldosterone

- Angiotensin II stimulates aldosterone secretion from the adrenal gland.
- Aldosterone enhances sodium reabsorption in the distal nephron.
- Water retention follows sodium, expanding blood volume.



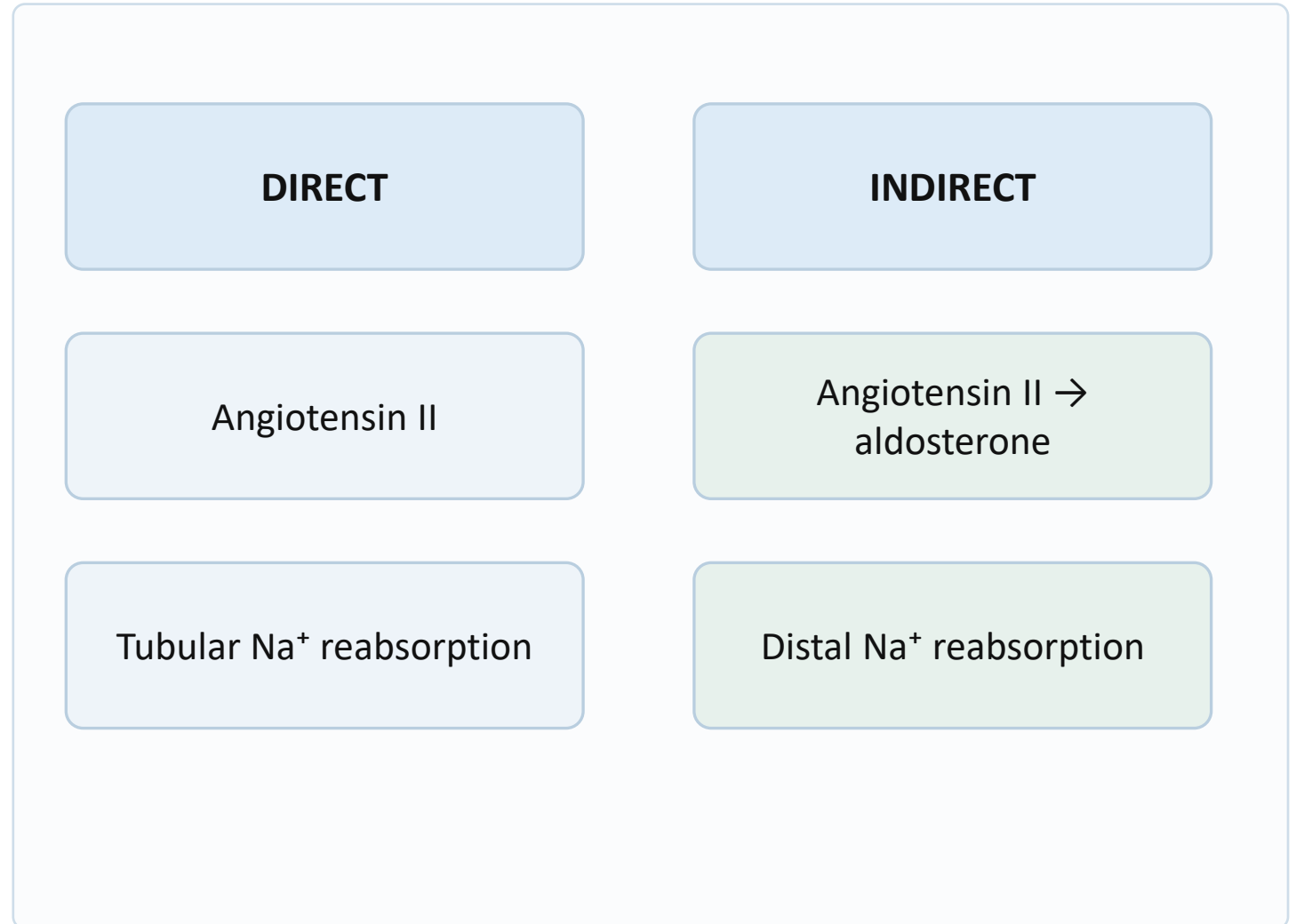
Aldosterone acts through blood-volume regulation

- The major pressure effect described is increased sodium and water resorption.
- Blood-volume expansion raises cardiac filling pressure.
- Changes in stroke volume and cardiac output contribute to higher pressure.



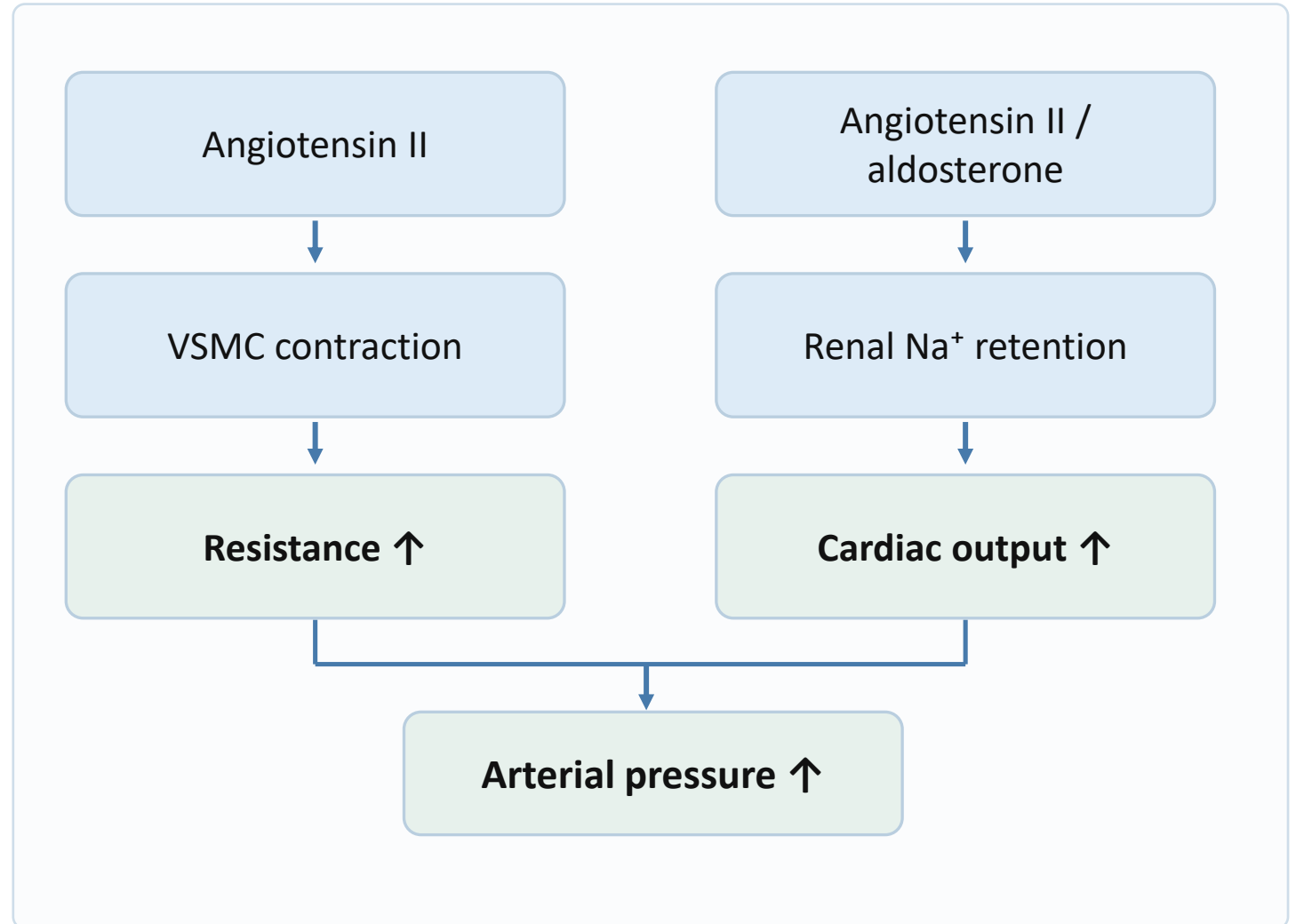
Angiotensin II also acts directly on renal tubules

- The source identifies increased tubular sodium reabsorption as a direct action.
- This complements the indirect, aldosterone-mediated pathway.
- Both mechanisms favor water retention and support circulating volume.



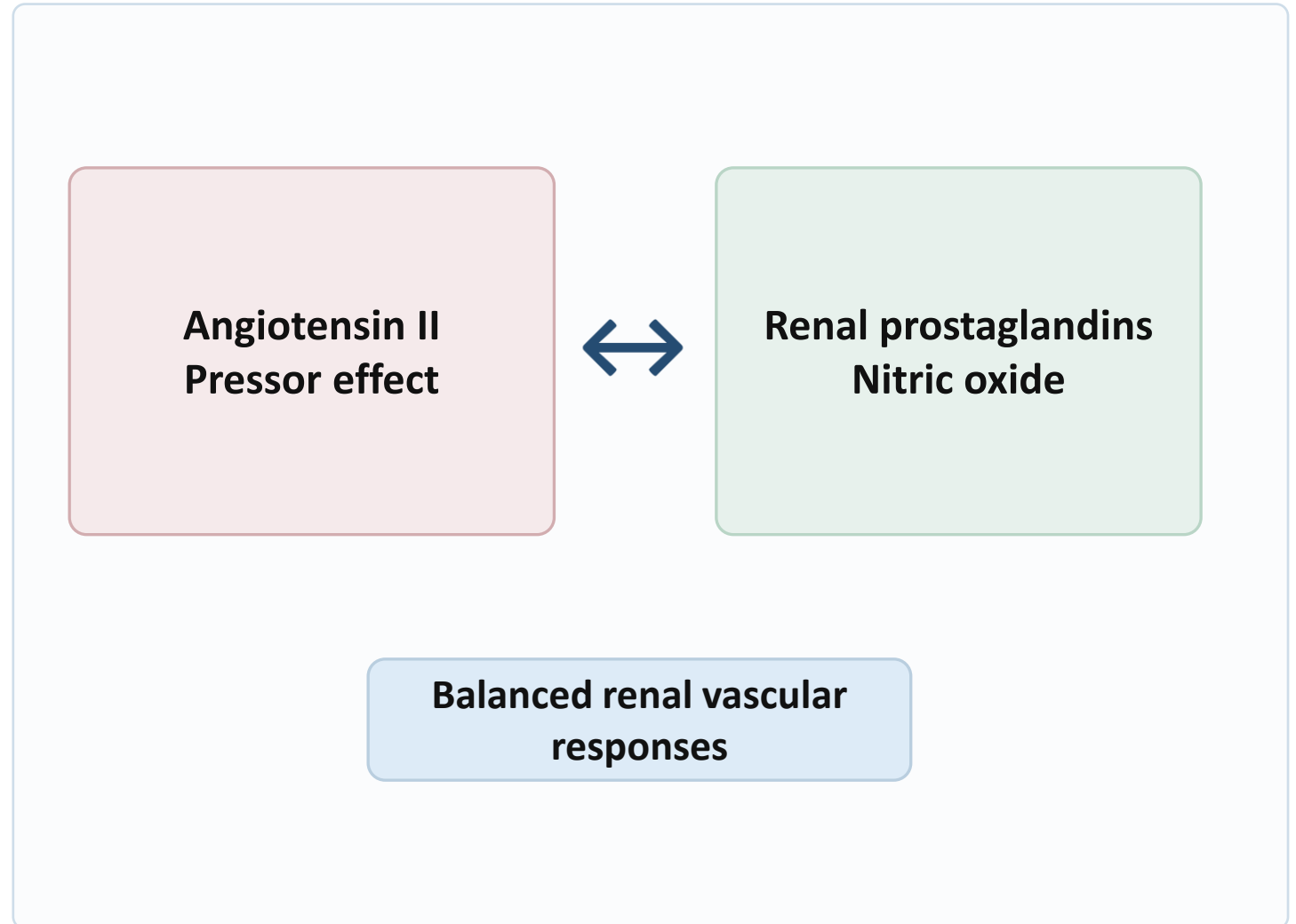
One hormonal cascade influences both BP determinants

- Direct vasoconstriction raises peripheral resistance.
- Renal sodium retention expands blood volume and cardiac output.
- This dual action explains the strong pressor potential of RAAS.



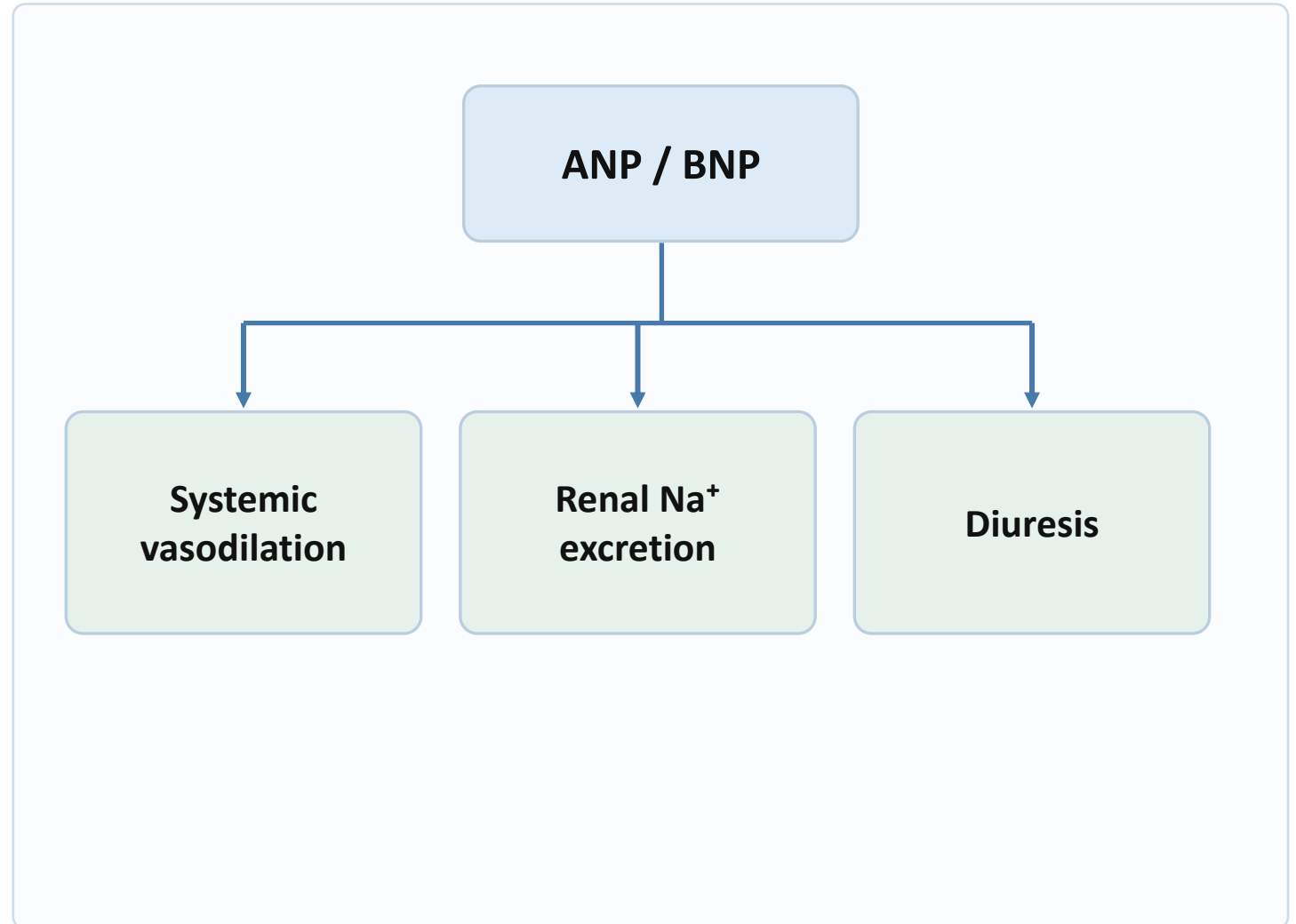
The kidney also releases vasodilating mediators

- Renal prostaglandins are vascular relaxing factors.
- Renal nitric oxide also counters pressor activity.
- These actions provide local opposition to angiotensin-mediated vasoconstriction.



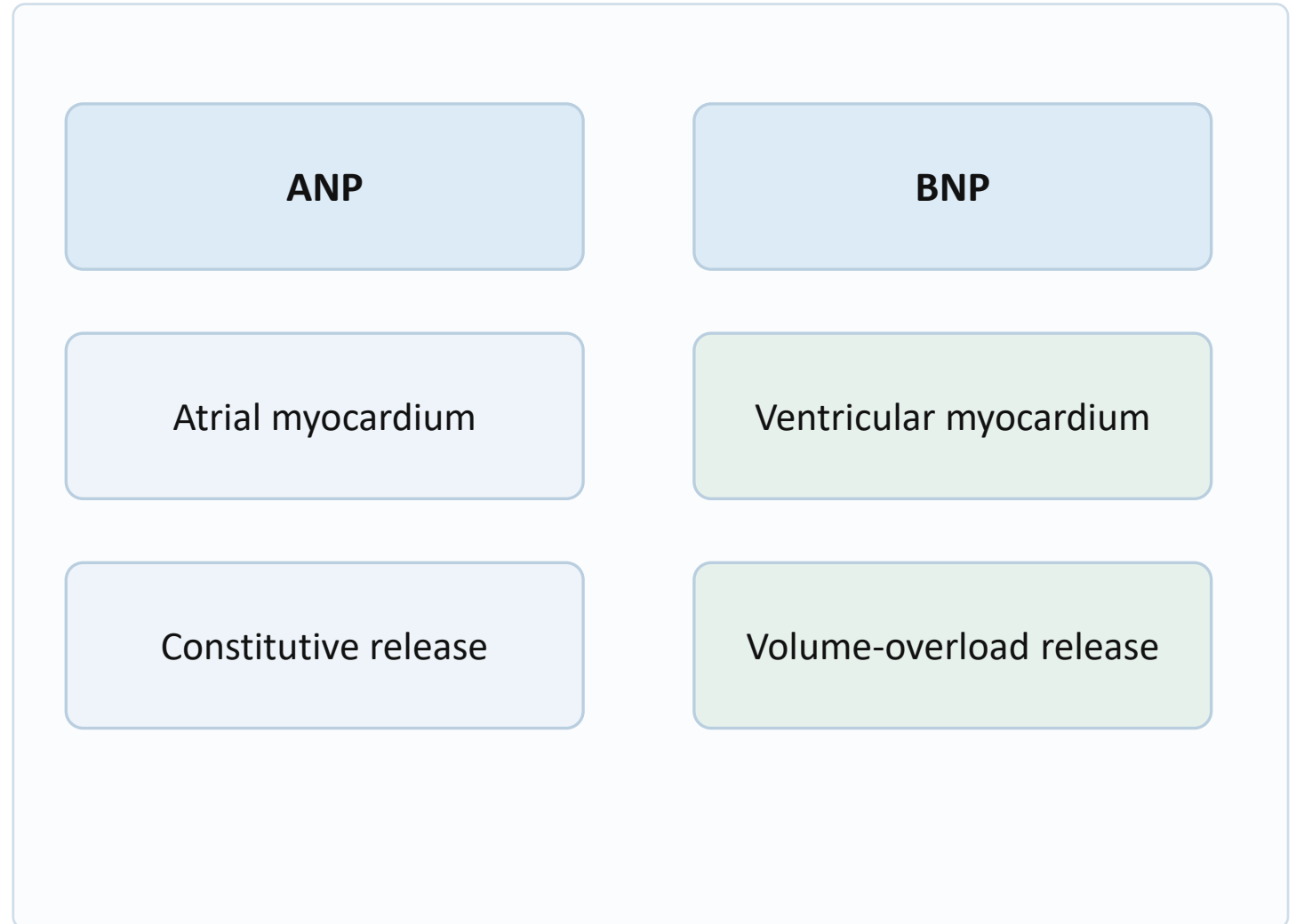
Natriuretic peptides counter volume expansion

- The heart participates in pressure and volume regulation as an endocrine organ.
- Atrial natriuretic peptide (ANP) and B-type natriuretic peptide (BNP) lower pressure.
- Their actions include vasodilation and enhanced sodium elimination.



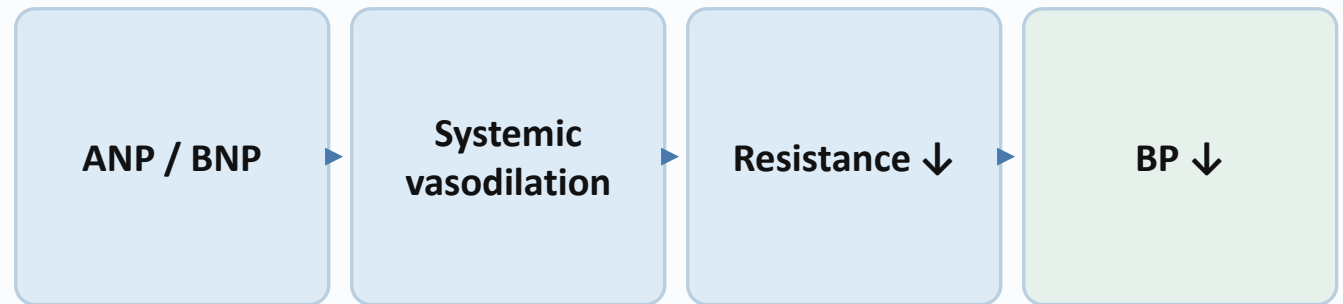
ANP and BNP arise from distinct cardiac sources

- ANP is released from atrial myocardium, including constitutive secretion.
- BNP is released from ventricular myocardium in volume-overload states.
- Both peptides participate in volume-sensitive pressure homeostasis.



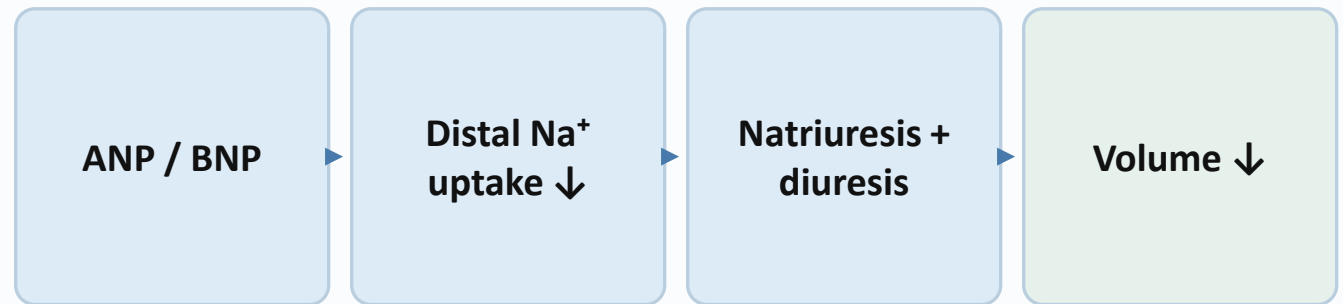
Natriuretic peptides reduce vascular resistance

- ANP and BNP promote systemic vasodilation.
- Relaxation of resistance vessels decreases the resistance component of pressure.
- This complements their independent renal effects.



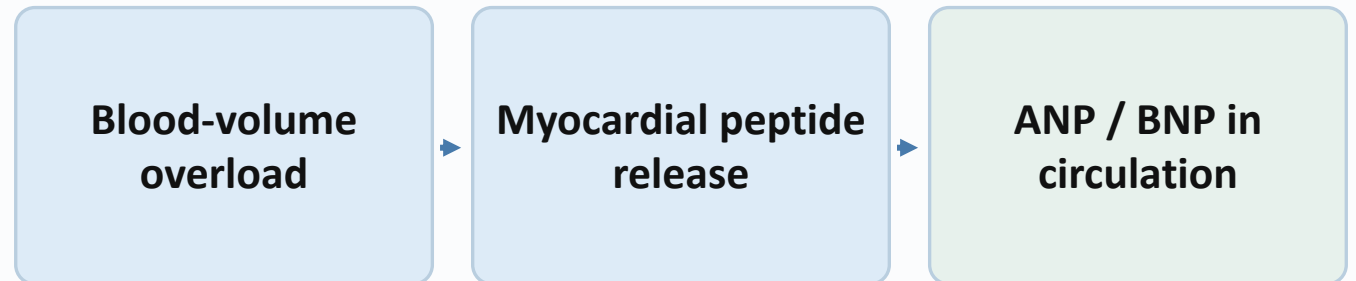
Natriuretic peptides increase renal salt excretion

- ANP and BNP inhibit sodium reabsorption in the distal renal tubules.
- More sodium is excreted, and urinary water loss increases.
- Reduced volume lowers the filling-related component of cardiac output.



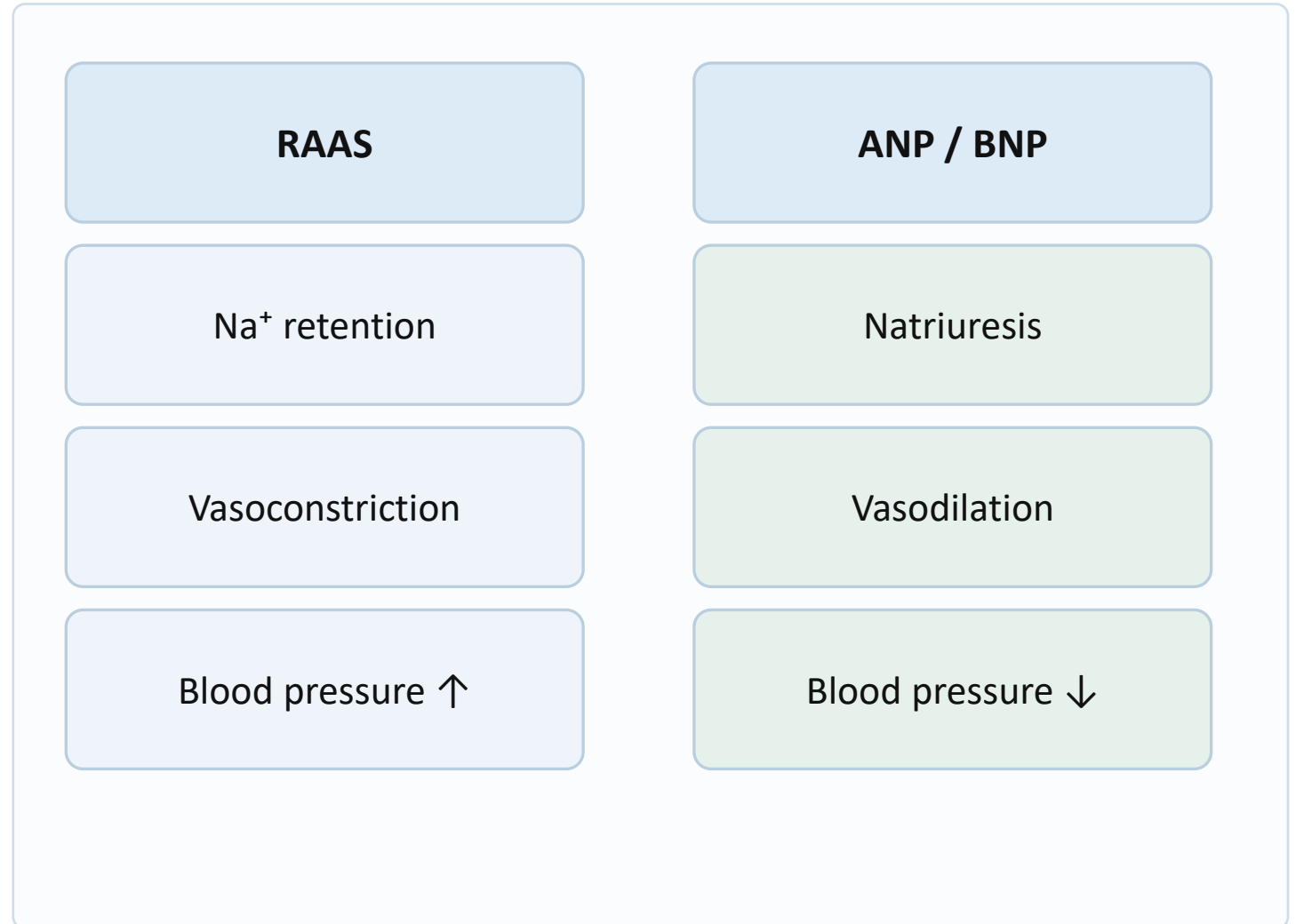
Elevated natriuretic peptides indicate volume stress

- Robbins relates raised circulating ANP or BNP to a hypervolemic state.
- Congestive heart failure is a typical associated setting.
- Interpret the observation as a physiologic signal, not a stand-alone diagnosis.



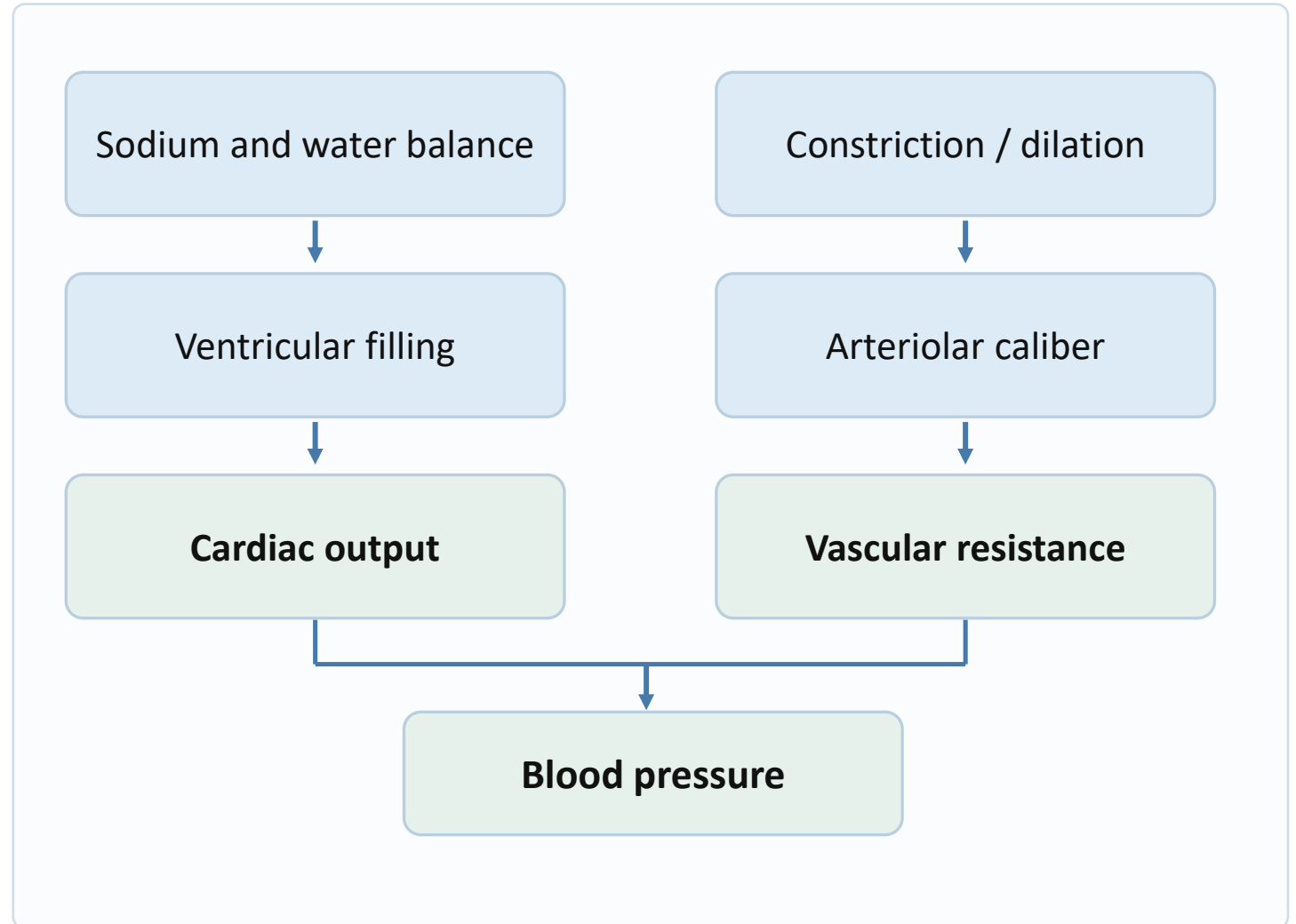
RAAS and natriuretic peptides oppose one another

- RAAS favors sodium retention and increases vascular tone.
- ANP and BNP favor sodium excretion and systemic relaxation.
- Blood pressure reflects their net effects alongside other inputs.



Pressure control integrates volume and tone

- Volume regulation primarily modifies filling and cardiac output.
- Vasomotor regulation modifies peripheral vascular resistance.
- Angiotensin II and natriuretic peptides can influence both components.



Hypertension: Essential versus secondary causes

- The source attributes about 90–95% of cases to essential hypertension.
- Secondary hypertension is linked to identifiable underlying mechanisms.
- Understanding normal physiology clarifies the mechanism of secondary forms.

ESSENTIAL

Multifactorial contributions

Genetic and environmental inputs

SECONDARY

Identifiable disease or exposure

Renal, endocrine, vascular, other

Renal causes of secondary hypertension

- Parenchymal examples include acute glomerulonephritis and chronic renal disease.
- Other examples include polycystic disease, renal vasculitis, and renin-producing tumors.
- Renal artery stenosis is a major perfusion-mediated example.

Parenchymal renal disease

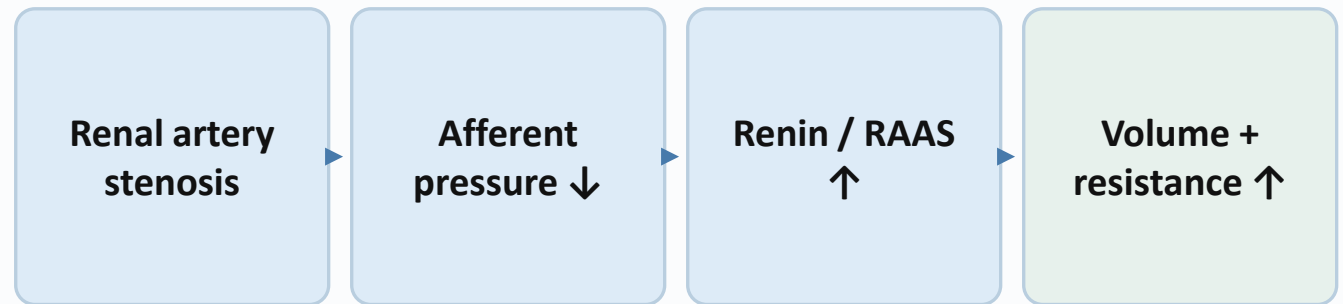
Renal artery stenosis

Renin-associated disease

Disturbed renal control of Na⁺ or RAAS

Renal artery stenosis activates the RAAS

- A narrowed renal artery reduces downstream glomerular perfusion pressure.
- Reduced afferent pressure stimulates renin secretion.
- Angiotensin II and aldosterone increase resistance and blood volume.



Endocrine causes alter humoral regulation

- The source lists primary aldosteronism and Cushing syndrome.
- It also includes pheochromocytoma, acromegaly, and hyperthyroidism.
- Hormonal exposures and pregnancy-related hypertension are additional categories.

**Adrenal hormone
excess**

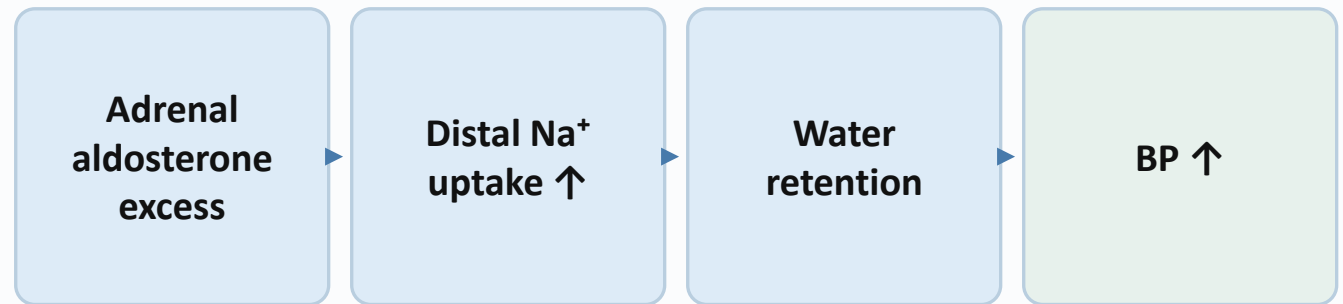
**Catecholamine
excess**

**Other endocrine
states**

**Hormonal disruption of vascular or volume
control**

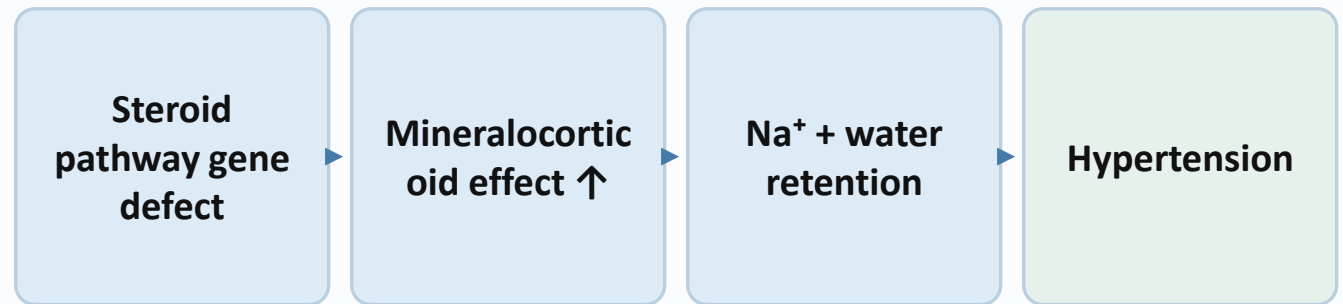
Primary aldosteronism favors sodium retention

- Primary aldosteronism is identified as a frequent secondary cause.
- Idiopathic cases and aldosterone-secreting adenomas.
- Excess aldosterone produces volume expansion through renal sodium uptake.



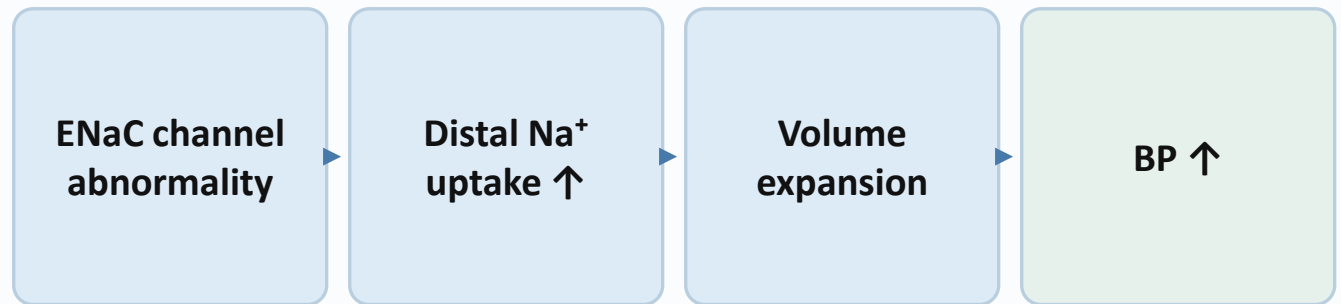
Inherited defects in adrenal steroid metabolism

- Monogenic disorders involving steroidogenic enzymes.
- These disorders can produce excess mineralocorticoid effects.
- The final common pathway is renal salt retention and volume-dependent pressure rise.



Liddle syndrome: Abnormal distal sodium uptake

- The source describes mutations affecting epithelial sodium channels (ENaC).
- Abnormally increased distal sodium reabsorption favors volume expansion.
- This illustrates hypertension from renal transport dysregulation.



Additional secondary causes span several systems

- Cardiovascular examples include coarctation of the aorta and aortic rigidity.
- Neurologic/related contributors listed include intracranial pressure, sleep apnea, and stress.
- Medication or hormonal exposures can alter vascular or sodium regulation.

Cardiovascular

**Neurologic /
stress-related**

**Drug or hormone
exposure**

Multiple pathways → elevated pressure

Distinguish mechanisms, not merely diagnoses

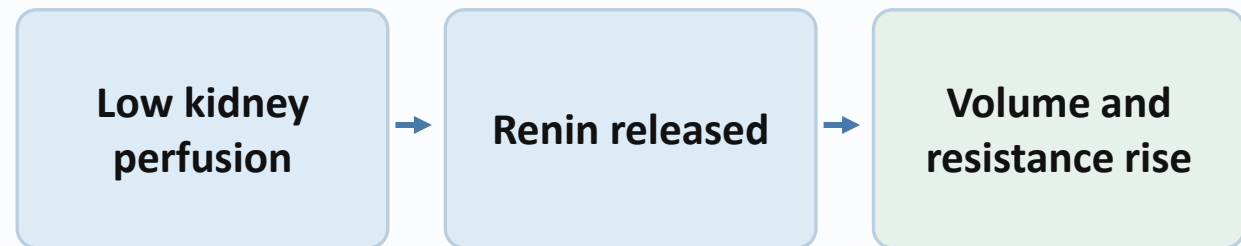
- Renal artery stenosis:
Inappropriate renin drive from low renal perfusion.
- Primary aldosteronism: Adrenal mineralocorticoid excess.
- ENaC-related disease: Increased distal sodium transport.

Mechanism	Primary disturbance	Pressure effect
Renovascular	Low renal perfusion	RAAS / volume + tone
Aldosterone excess	Adrenal steroid signal	Renal Na ⁺ retention
ENaC-related	Distal tubular transport	Renal Na ⁺ retention

Clinical reasoning: A poorly perfused kidney

- Scenario: A kidney receives reduced arterial pressure distal to a stenosis.
- Prediction: Renin rises despite pressure elevation elsewhere.
- Consequence: Angiotensin II and aldosterone sustain systemic hypertension.

Why can renal hypoperfusion cause systemic hypertension?



Clinical reasoning: Sodium retention without RAAS drive

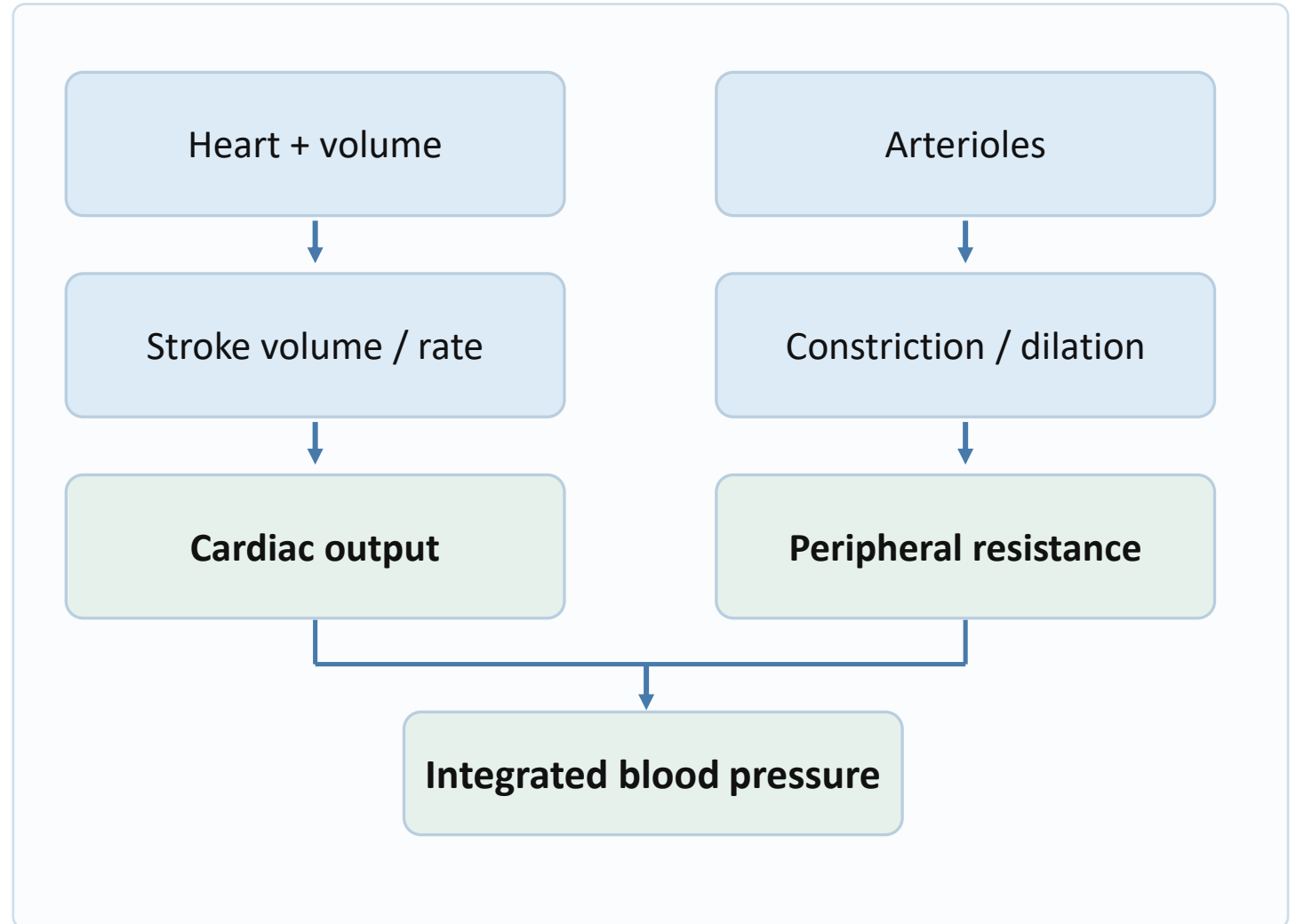
- Scenario: A distal tubular sodium channel is abnormally active.
- Prediction: Sodium and water retention increase circulating volume.
- Mechanistic lesson: Hypertension can originate at the renal transporter.

Which pressure determinant changes first?



High-yield physiologic synthesis

- Cardiac output links heart rate, contractility, filling, and blood volume.
- Arteriolar smooth muscle integrates constrictor and dilator signals.
- Renal sodium handling anchors blood-volume control.
- RAAS and natriuretic peptides connect organ-level sensors to both BP arms.



Pressure regulation: three diagnostic questions

- Is cardiac output changing through heart rate, contractility, or ventricular filling?
- Are arteriolar resistance vessels responding mainly to constrictor or dilator signals?
- Does the kidney favor sodium retention, or do natriuretic responses promote elimination?

