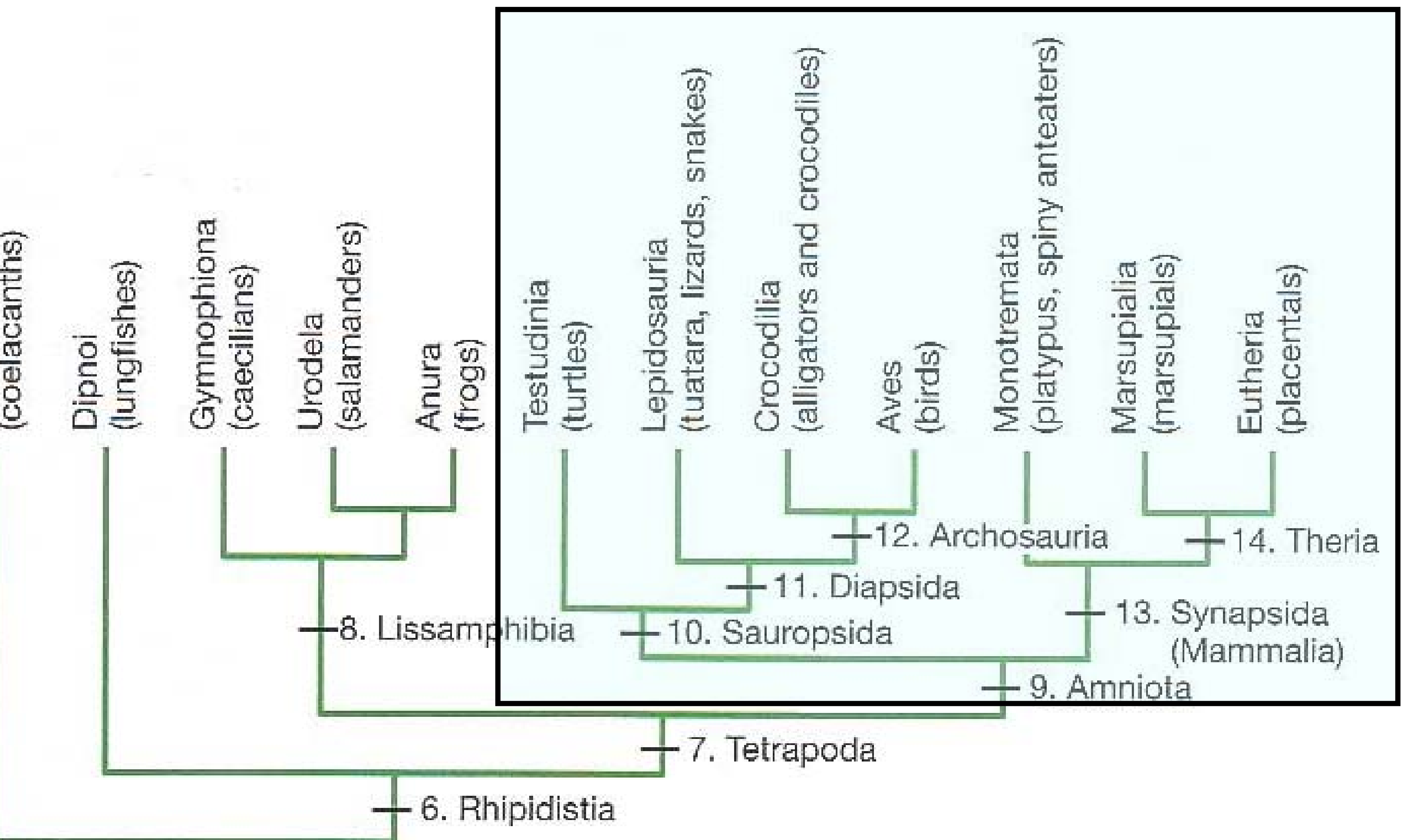
Sauropsida and Synapsida: Two major clades of amniotes

Readings: Chapter 11: 265-301

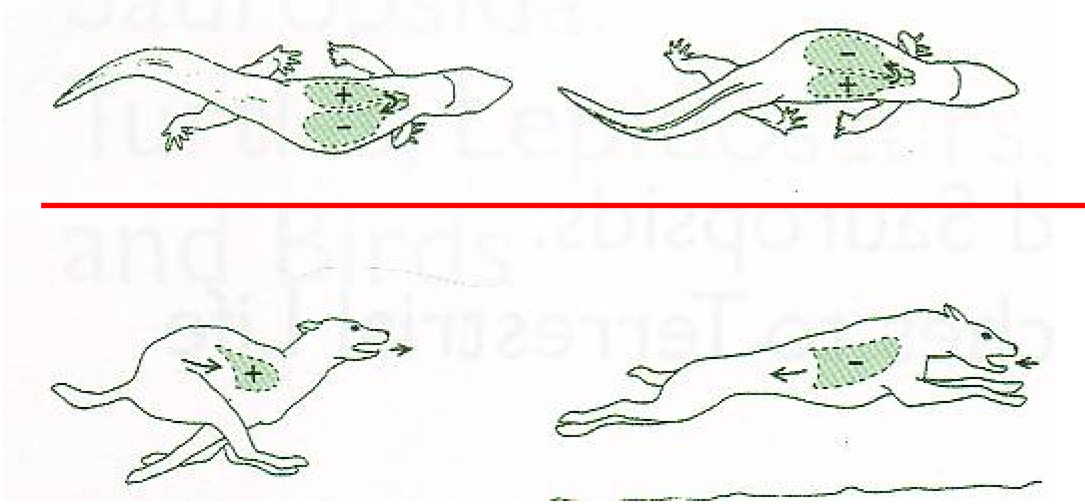


More than one way to succeed in terrestrial environment

- How did these 2 lineages take advantage of opportunities of terrestrial environment presented to amniotes?
- Both lineages developed:
  - Fast predators that chase prey;
  - Fast prey that run from predators;
  - Powered flight;
  - Parental care;
  - Social behavior;
  - Endothermy

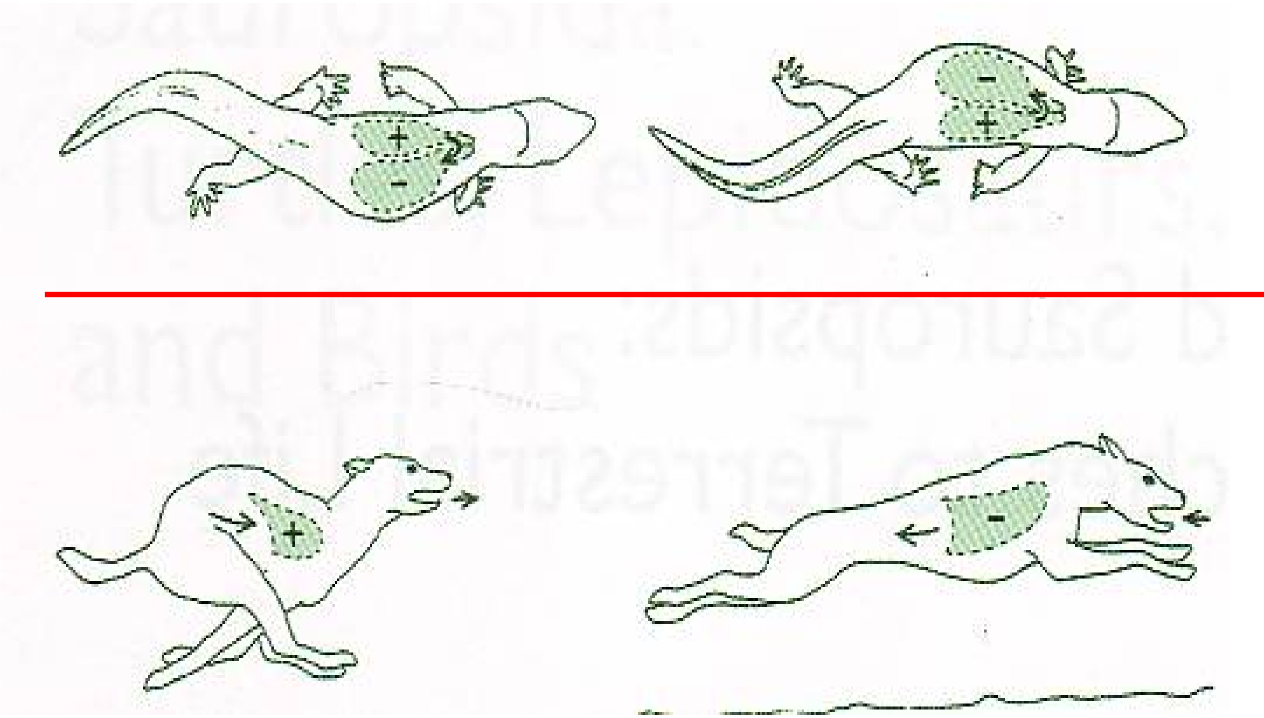
Sustaining locomotion on land

- Problem: muscles need oxygen.
- Lateral undulation is an ancestral mode of locommotion (fishes, early tetrapods, salamanders, lizards, crocs).
- Axial muscles have 2 functions, that are not compatible:
  - Bending body for locomotion
  - Compressing ribs for ventilation
  - Issue: bending compresses lungs on either side, but does not help air go in and out of body. It will move from lung-to-lung, and this exacerbates the problem.
- This limits vertebrates with the ancestral mode to short bursts of activity.
- In lizards, ventilation ceases during locomotion.



Sustaining locomotion on land

- Compare to a synapsid:
- As vertebral column bends, air pressure changes force air in and out of lungs, helping ventilate during high levels of activity.

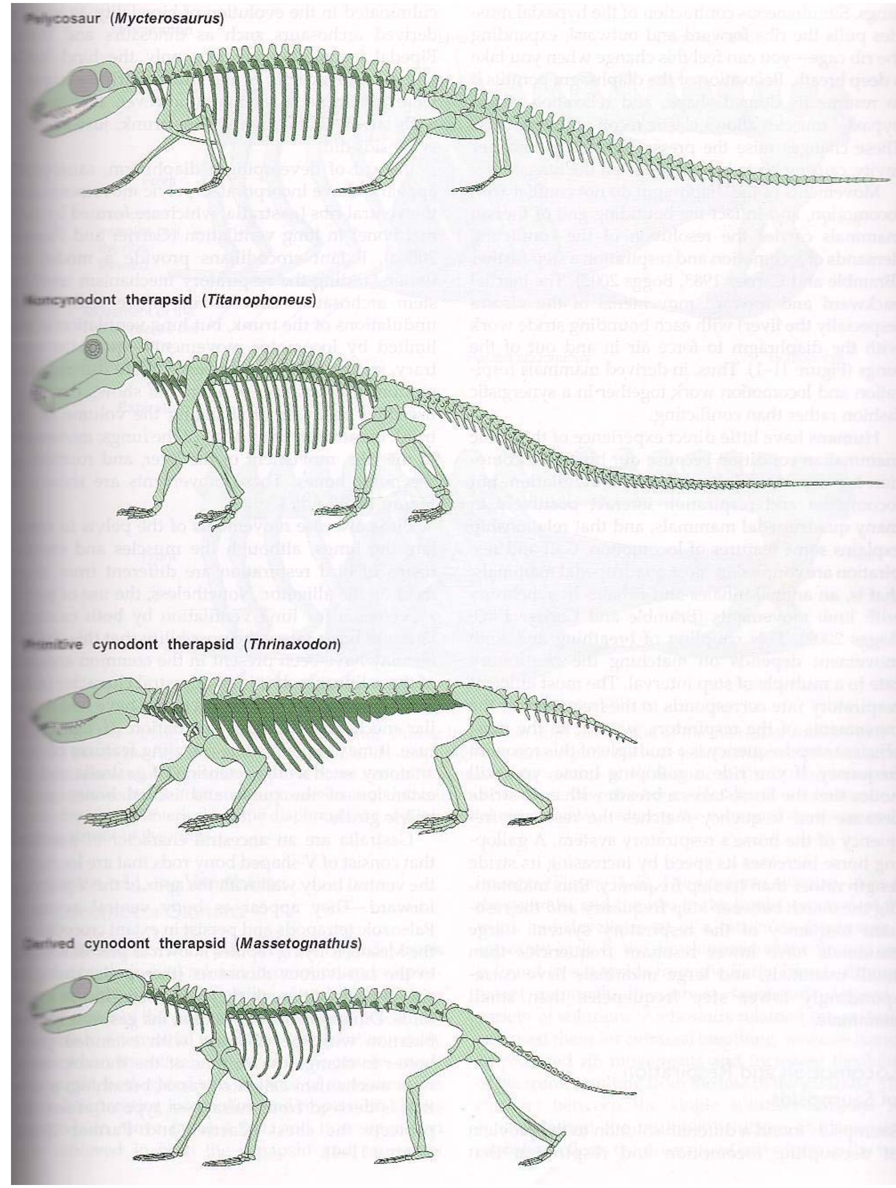


Synapsids developed muscular diaphragm

- Muscular diaphragm separates body cavity into 2 parts:
  - Pulmonary cavity
  - Abdominal cavity
- Convex anteriorly when relaxed, flattens when contracted.
- Simultaneous muscle contractions pull ribs forward and outward expanding rib cage.
- These movements do not interfere with locomotion, and locomotion actually move viscera which enhances function of diaphragm.

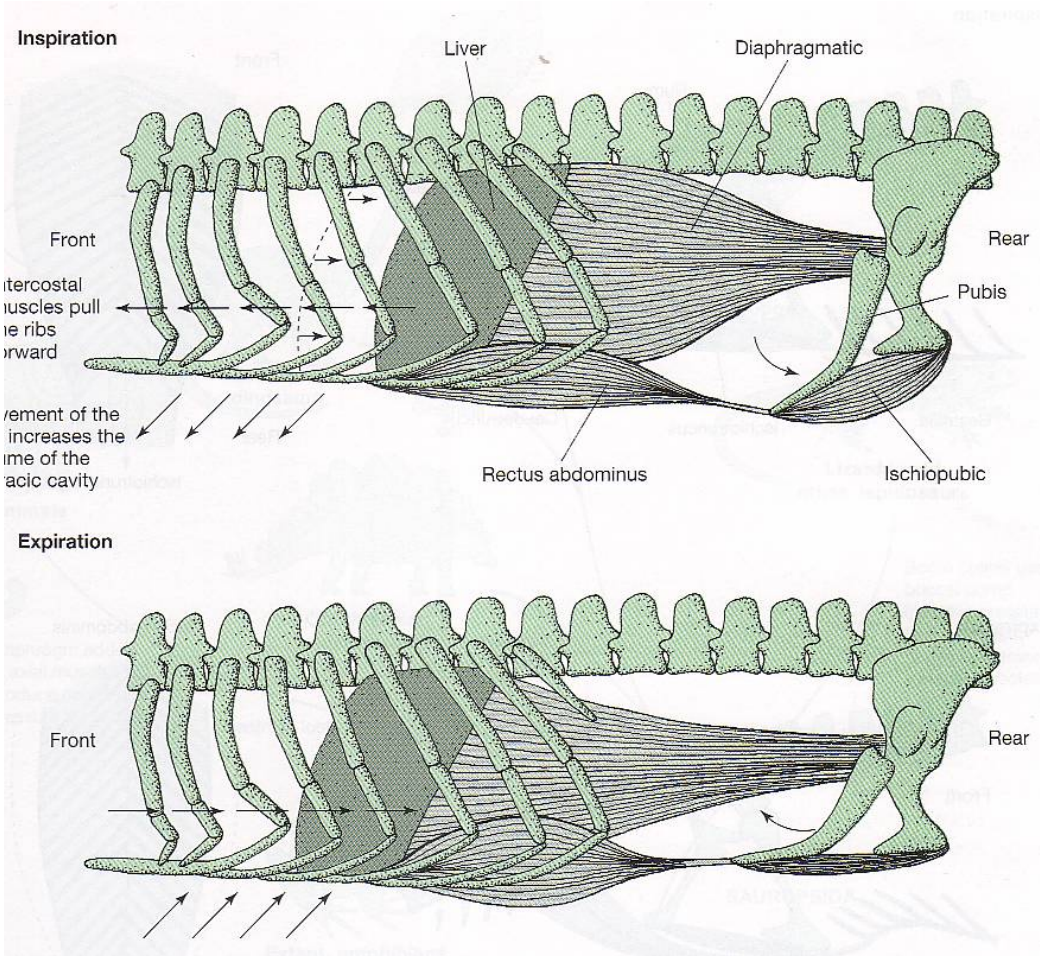
Ancestral to derived synapsids

- Evolutionary trend:
  - Shorter tail length;
  - Loss of ribs from posterior vertebrae;
  - Longer legs;
- The trend in these features robably coincided with development of diaphragm for respiration, and fore-aft movement of legs.



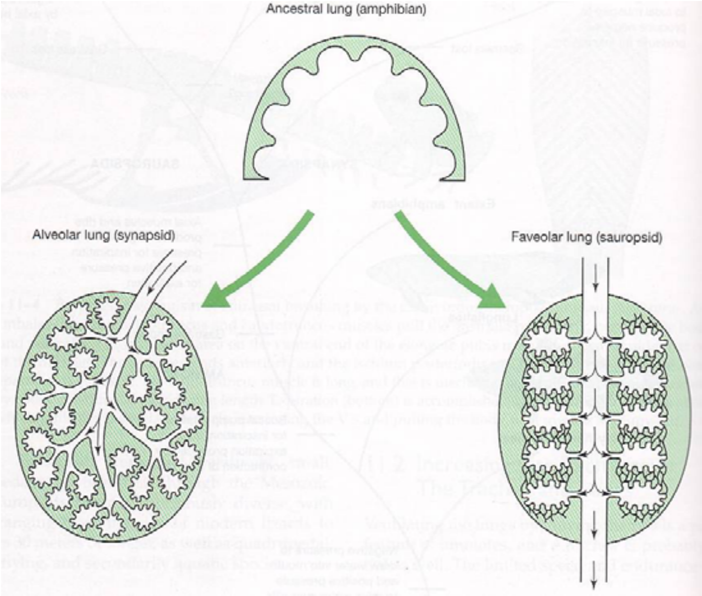
Gastralia and cuirassal breathing

- Abdominal rib cage
- Present in *Sphenodon*, Archosaurs (crocodilians), ancestral condition in Sauropsids;
- Gastralia and lung ventilation:
  - In *Alligator*, muscle contraction moves ribs forward;
  - Contraction of diaphragmatic muscle pulls liver back;
  - Ischiopubic muscle rotates pubic bones downward.
- These movements increase volume of thoracic cavity and pull air in. Relaxing the muscles pushes viscera forward forcing air out.



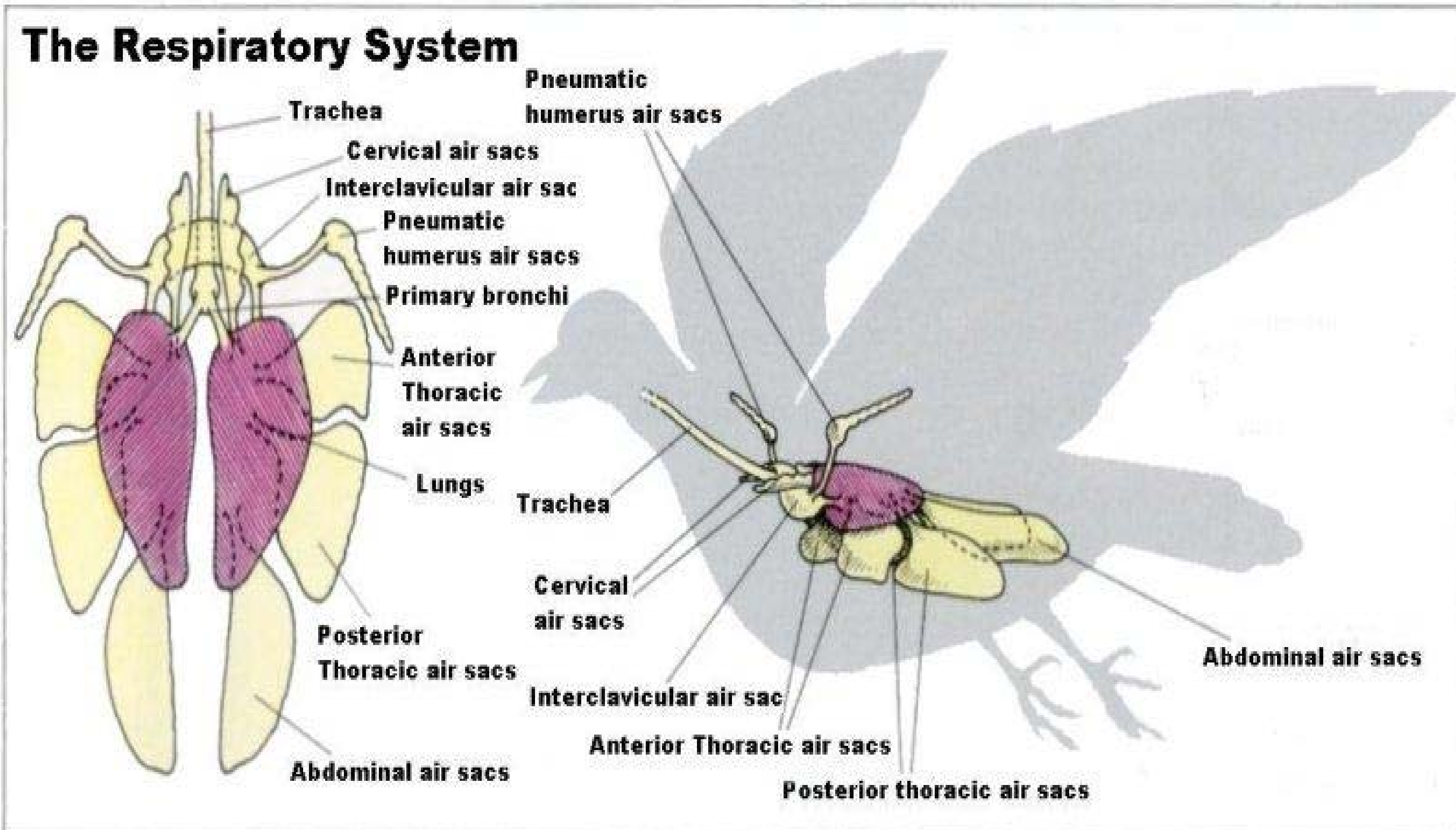
Lungs

- Ancestral lung was sac-like.
- Both sauropsids and synapsids achieved higher surface are of respiring surfaces in lungs:
  - Alveolar lungs developed in synapsid lineage
  - Faveolar lungs in Sauropsids.



Avian respiration

- Birds have one-way air flow.
- Unique among vertebrates



Bird breaths

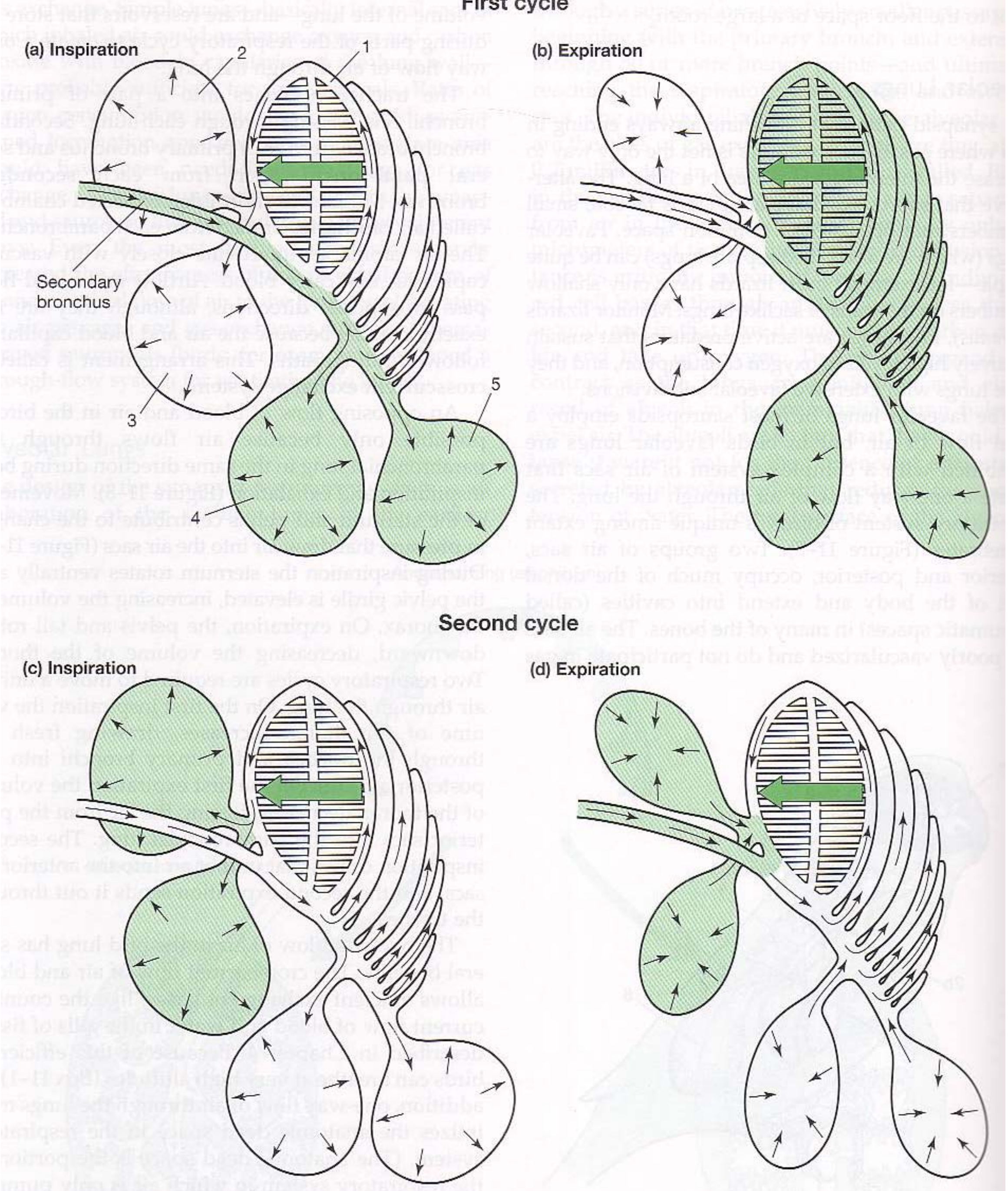
- 2 groups of air sacs, anterior and posterior
- Branch into pneumatic spaces in many bones.
- Air sacs do not participate in gas exchange with blood, but are large, 9x lung volume.
- Reduces anatomic dead space, the portion of respiratory system where air only goes back and forth, not replaced by fresh air.
  - In tidal breathing like ours, there is always some stale air in the lungs. In humans, it is 30% of lung volume.
- Flow-through system of birds reduces stale air, allowing for long necks.
  - Try to breathe through a long hose and you will see you can’t do it!

Bird breathing

- Trachea
  - Primary bronchi
    - Secondary bronchi
      - Parabronchi
        - » Air capillaries (millions)
- Crosscurrent exchange
  - Airflow and bloodflow in opposite directions
  - Possible because air goes through lung in only one direction during both inspiration and exhalation.
  - Helps breathing at high altitudes
- Sternum and pelvis movements help pull air into air sacs

2 cycles are needed to move a unit of air through the lung

- Fresh air from trachea into posterior air sacs
- Posterior sacs into lung
- 2nd inspiration draws air into anterior air sacs;
- Second expiration sends it out the trachea.



Nitrogenous waste

- Textbook Chapter 11
- Pages: 287-297

Kidneys of synapsids and sauropsids

  - Locomotion
  - Endurance
  - Thermoregulation
- All of these require energy, and we’ve seen how amniotes can develop relatively high energy lifestyles.
- Hi rates of energy intake go along with the lifestyle.
- A consequence of high energy intake is the corresponding production of large amounts of nitrogenous waste.

Ammonia, Urea, Uric acid

- Ammonia– NH_3
  - – Very toxic;
  - – Very soluble in water;
  - – Diffuses rapidly because it's a small molecule.
- Aquatic nonamniotes produce much ammonia.
- Terrestrial amniotes produce very little.

Ammonia, Urea, Uric acid

- Urea –$CO(NH_2)_2$
  - Ammonia is converted to urea;
  - Much less toxic than ammonia;
  - Urea is very soluble in water, even more than ammonia.
  - Thus, it can be accumulated in the body and released as concentrated urine.
  - Synthesis of urea is ancestral trait of amniotes and all gnathostomes.

Ammonia, Urea, Uric acid

- Uric acid –$C_5H_4O_3N_4$
  - Uric acid is not soluble
  - Combines with sodium and potassium and precipitates as sodium or potassium urate.

Two ways to save water

- Synapsids retain the ancestral condition and excrete urea.
  - Synapsid kidney is very efficient at producing concentrated urine.
- Sauropsids synthesize uric acid. The water used in synthesizing uric acid is recovered when it precipitates.

Mammalian Kidney

- Review and understand:
  - Nephron
    - Glomerlus
    - Loop of Henle – *derived character of mammals*
      - Where composition of urine is altered to be dilute or concentrated.
    - Proximal convoluted tubule
    - Distal convoluted tubule
  - Mammals can produce urine more concentrated than any nonamniote and more concentrated than almost all sauropsids.

TABLE 11.3 Maximum Urine Concentrations of Some Synapsids and Sauropsids

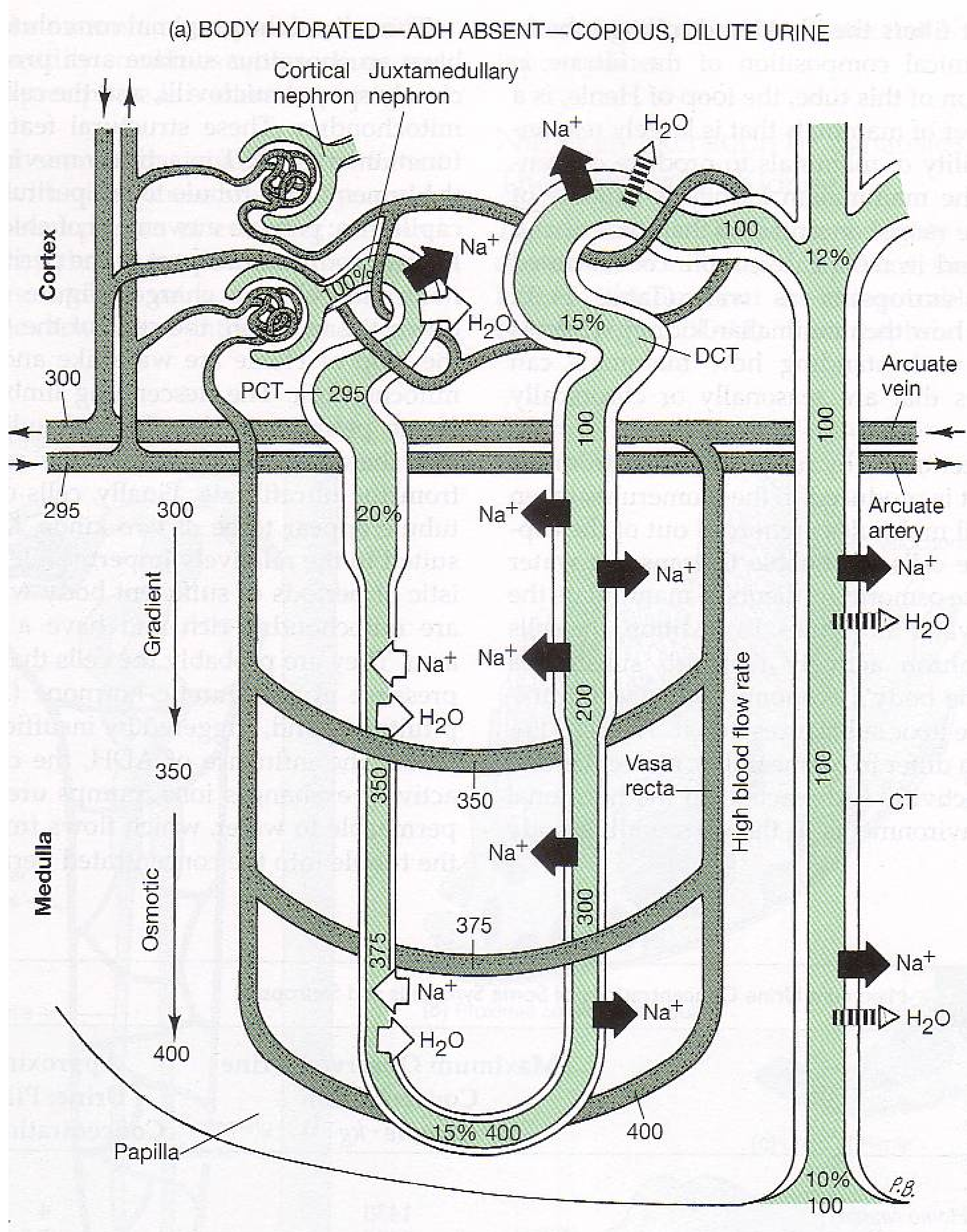
Species	Maximum Observed Urine Concentration ($mmole \cdot kg^{-1}$)	Approximate Urine: Plasma Concentration Ratio
Synapsids		
Human (*Homo sapiens*)	1430	4
Bottlenose porpoise (*Tursiops truncatus*)	2658	7.5
Hill kangaroo (*Macropus robustus*)	2730	7.5
Camel (*Camelus dromedarius*)	2800	8
White rat (*Rattus norvegicus*)	2900	8.9
Marsupial mouse (*Dasycercus eristicauda*)	3231	10
Cat (*Felis domesticus*)	3250	9.9
Desert woodrat (*Neotoma lepida*)	4250	12
Vampire bat (*Desmodus rotundus*)	6250	20
Kangaroo rat (*Dipodomys merriami*)	6382	18
Australian hopping mouse (*Notomys alexis*)	9370	22
Sauropsids		
American alligator (*Alligator missisippiensis*)	312	0.95
Desert iguana (*Dipsosaurus dorsalis*)	300	0.95
Desert tortoise (*Gopherus agassizii*)	622	1.8
Pelican (*Pelecanus erythrorhynchos*)	700	2
House sparrow (*Passer domesticus*)	826	2.4
House finch (*Carpodacus mexicanus*)	850	2.4
Savannah sparrow (*Passerculus sandvicensis*)	2000	5.8

When the body is hydrated

- Study fig 11-15:
- Glomerlus produces the ultrafiltrate, which contains water and small molecules like ammonia;
- Osmotic gradients cause water to move.
- Proximal convoluted tubule has cells with lots of surface area and mitochondria that are good for moving sodium out of the tubule.
- Water follows the sodium passively

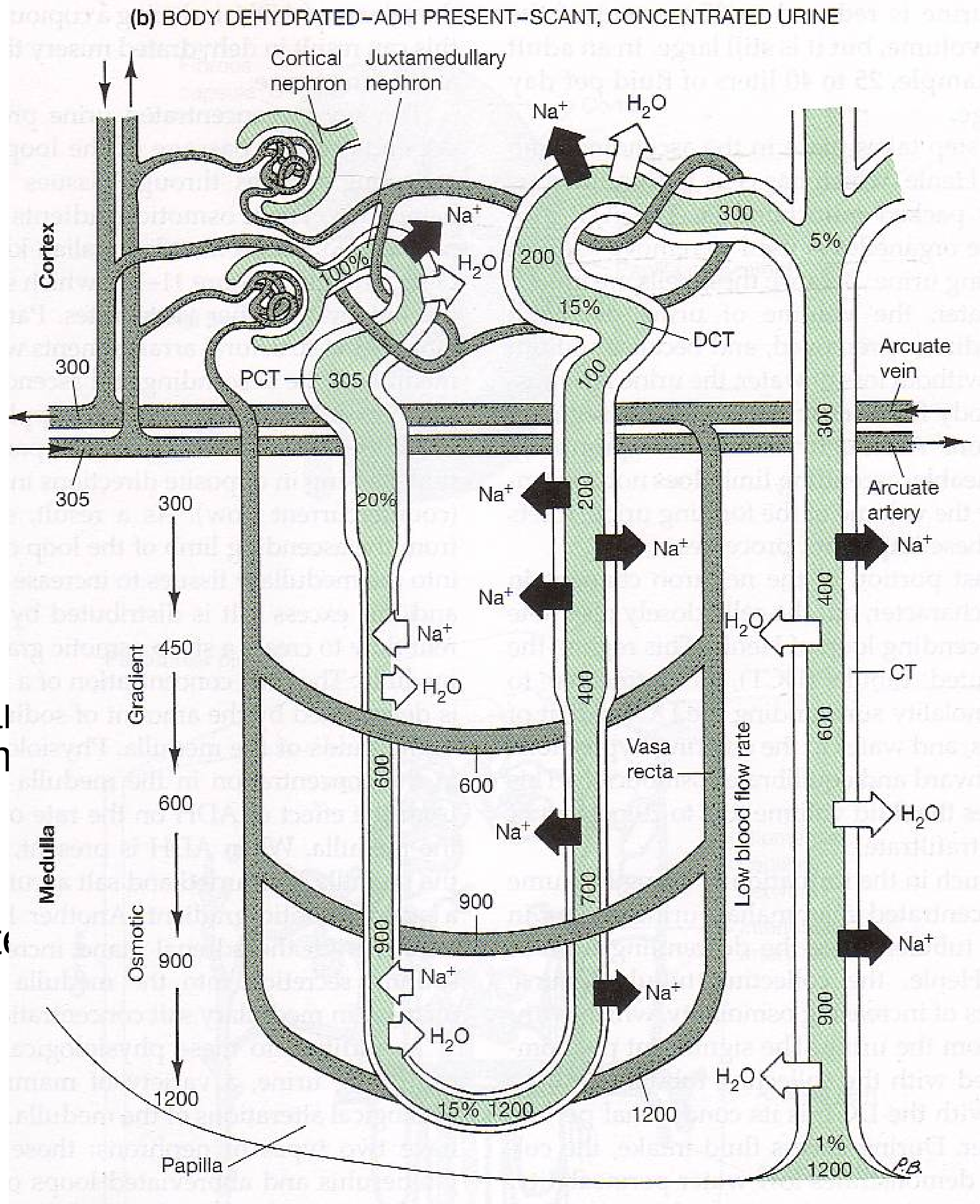
When hydrated

- In Loop of Henle:
- Descending part of loop, water comes out;
- Ascending part, sodium is removed from the ultrafiltrate.



When Dehydrated

- Pituitary gland (by your brain) secretes antidiuretic hormone (ADH).
  - Alcohol inhibits ADH, inducing copious urine flow.
- ADH levels go up when body is dehydrated.
- The collecting tubule (fa right) cells pump sodium out.
- The tubule becomes permeable and water flows from the ultrafiltrate into the concentrated fluids outside of the tubule.



- Why was Gatorade invented?
- What does it do, and how does it work?

Six steps of mammalian kidney function

- Glomerulus produces ultrafiltrate
  - Isosmolal with blood plasma, and similar.
  - Humans produce 170 liters (45 gallons) of ultrafiltrate per day. Excrete 1.5 l of urine, because kidney reabsorbs 99% of ultrafiltrate.
- Proximal convoluted tubule decreases amount of ultrafiltrate
  - Active transport of sodium out of PCT; 2/3 of salt and water are reabsorbed from ultrafiltrate.
  - Ultrafiltrate is still isosmolal with blood, but makeup is different than blood plasma.
- Descending loop of Henle – removes water
  - The loop descends through an increasing osmolal gradient and water moves out of the urine.
  - At this stage, volume of urine is 25% of the original ultrafiltrate. In a human it would be 25-40 liters at this stage.

Six steps of mammalian kidney function

- Ascending loop of Henle – sodium removed, but no water
    - The volume of urine stays the same;
    - Removal of sodium but not water makes the urine hyposmolal to body fluids.
- Distal convoluted tubule – permeable to water and water flows out.
    - Reduces volume to 5-20% of original glomerulus filtrate
- Collecting tubules – move through tissues of increasing osmolality, and more water moves out.
    - Permeability of the CT is conditional, so either copious urine or concentrated urine can be produced
- The mammalian kidney can thus get rid of excess fluids or conserve water when necessary.
- The structure of the overall kidney creates the osmotic gradients needed for the loop of Henle and DCT to work.
  - Medulla of kidney is built with parallel tubes with counter current flow.
  - Salts excreted during ascending loop contribute to making the osmotic gradient.
  - Some mammals have two kinds of nephrons, one set with shallow loops of Henle that don’t go deep into medulla and another that go deep into medulla. They control each set independently, further allowing fine-tuning of water balance.

Nitrogen excretion in Sauropsids

- Uricotelic -- means excrete uric acid
  - Turtles, birds, lizards, snakes, crocodilians– all sauropsids are uricotelic.
  - Except for freshwater turtles, uric acid accounts for 80-90% of urniary nitrogen in sauropsids.
- Strategy for water conservation when producing uric acid is totally different from when making concentrated urine as in synapsids.

Nitrogen excretion in Sauropsids

- Lepidosaur kidneys do not have loop of Henle;
- Urine from lepidosaur kidneys has about the same osmotic concentration as blood plasma;
- Bird kidneys have two types of nephrons:
  - Short loop nephrons
  - Long loop nephrons
    - These produce urine 2-3x more concentrated than blood plasma, but still much less concentrated than what mammals achieve.

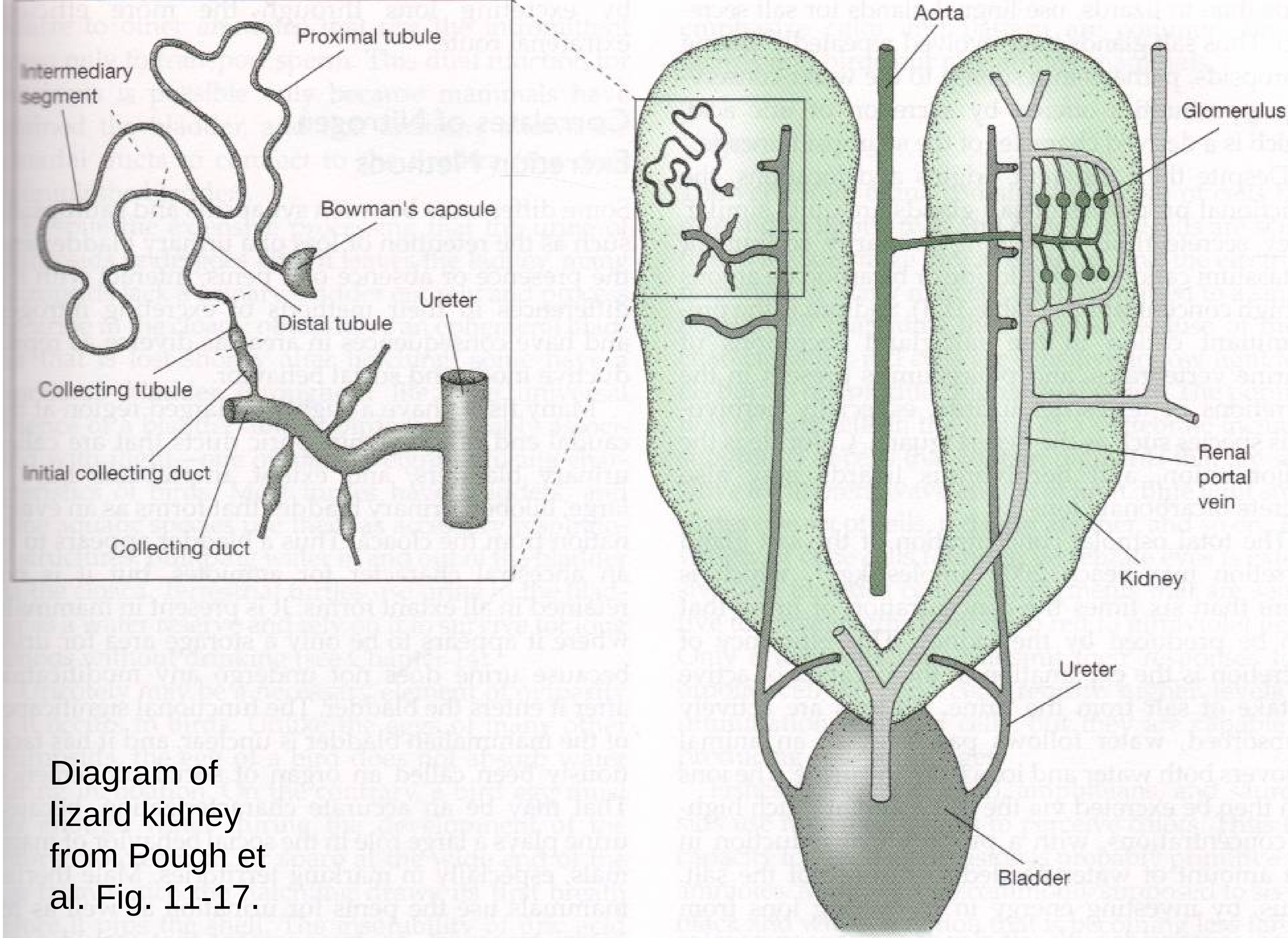


Diagram of lizard kidney from Pough et al. Fig. 11-17.

Nitrogen excretion in Sauropsids

- Low solubility of uric acid
  - Uric acid precipitates when it is in the cloaca or bladder.
  - Becomes a light-colored mass of sodium, potassium and ammonium salts of uric acid.
    - Bird poop.
  - When the uric acid precipates out of solution, the water is rebsorbed into the blood.
    - In many sauropsids, sodium and potassium are also reabsorbed.

Salt-excreting glands

- Many sauropsids also have salt-excreting glands that get rid of salt with less water than by making urine.
- Salt glands secrete fluid with high concentration of sodium and potassium ions.
- Salt glands work very well! The concentration of salt gland secretion is 6x concentration that can be produced by kidney.
  - Nasal salt glands in many lizards;
  - Lateral nasal gland in birds.
    - Marine birds, freshwater birds, shorebirds, raptors, upland game birds, ostrich, roadrunner.
  - Seasnakes- sublingual gland secretes a salty solution into the tongue sheath and it is expelled when the snake sticks out its tongue.
  - Crocodilians- salt-glands on tongue of some crocs, alligator, and caiman.
  - Seaturtles and diamondback terrapin – lacrimal glands are enlarged and secrete salt.
  - Terrestrial turtles do not have salt glands.

Bladders……

- Fishes and extant amphibians have urinary bladders, thus having a bladder is the ancestral state.
- Bladder is not retained in all amniotes
  - Mammals– storage of urine;
    - “organ of social convenience”
    - Only mammals use penis for urination and sperm transfer. This is only possible because presence of bladder allows gonadal ducts to connect to urethra.
  - Many sauropsids do not have a bladder and process urine in the cloaca.
    - Birds do not; probably saves weight.
  - Many others do have a bladder.
    - Most turtles do, and some aquatic turtles use it as respiratory surface.
    - Terrestrial turtles store dilute urine as water reserve.