Lessons From Bird Respiration

Presented by: Jennifer She, Tharindu Fernando, Ashutosh Sharma

For CAPS 422 on October 20th, 2015

What lessons can we learn from bird respiration?

- Why do birds need to be more efficient?
- What does avian respiratory anatomy look like?
- How does air circulate in the avian respiratory system?
- How is gas exchange more efficient in birds?
- How is diffusion made more efficient in birds?

The struggles of a bird…

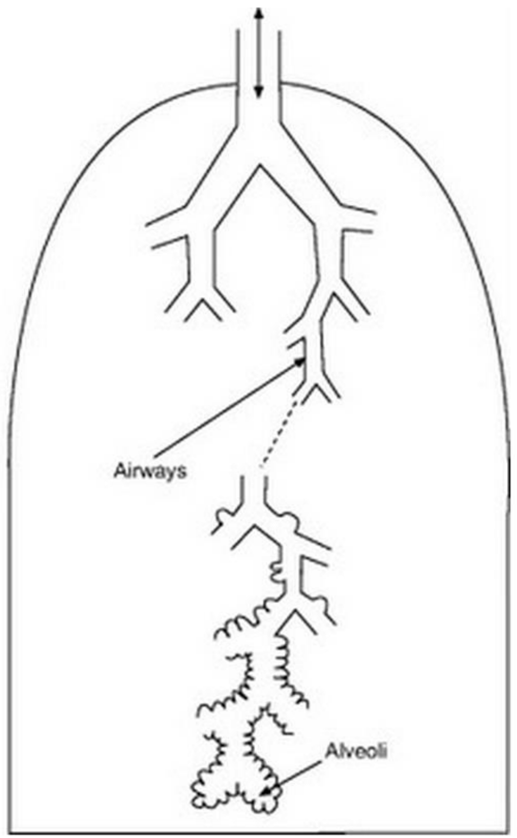
- Birds use up much more energy than we do
  - Basal metabolic rate of a young 70 kg white man: ~25 kcal/kg/day
  - For a swan: ~47 kcal/kg/day
  - For a hummingbird: >1500 kcal/kg/day
- Oxygen (PO_2) is also limited at high altitudes*

Because of this, birds would do well to have highly efficient respiratory systems to compensate.

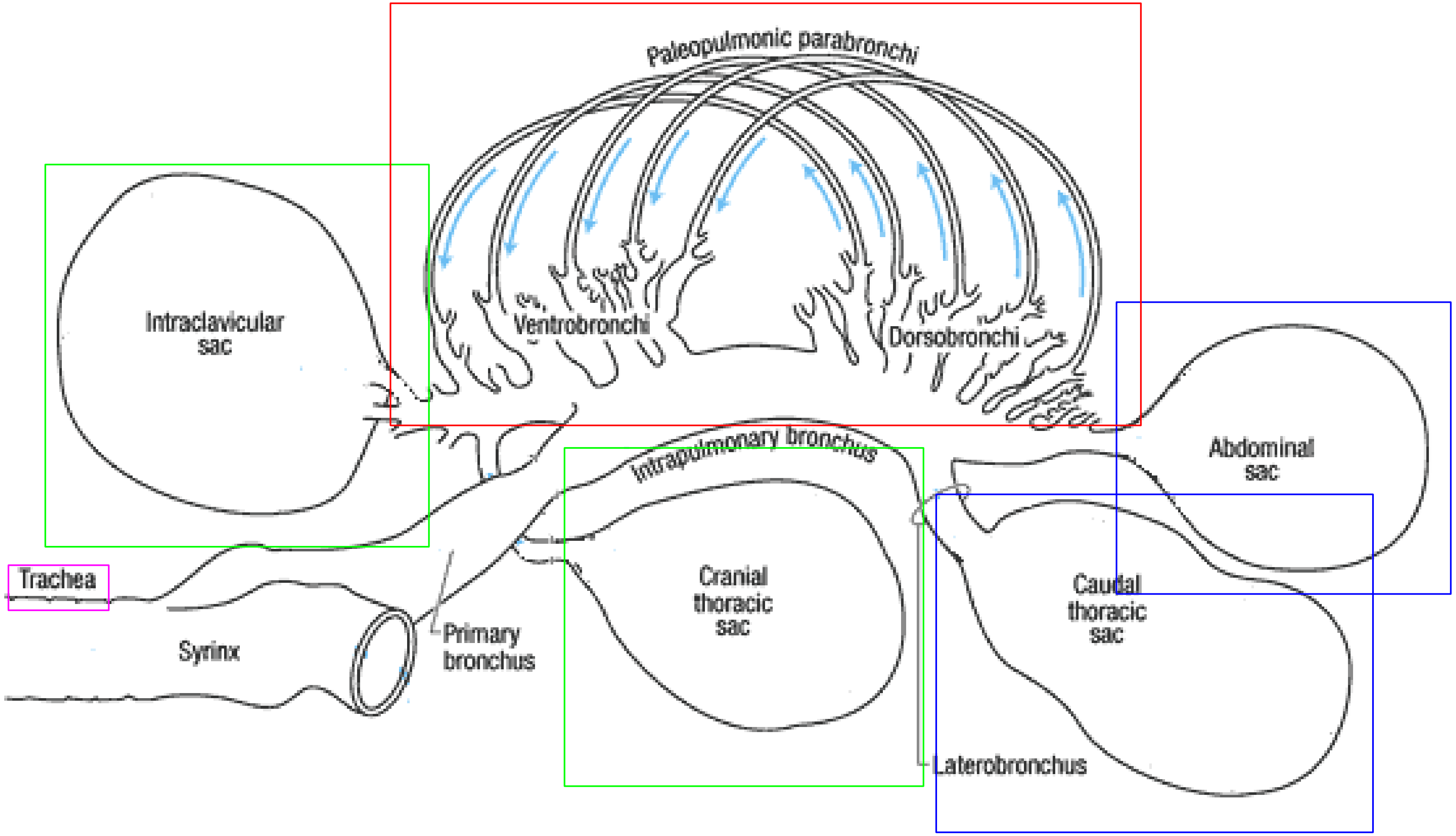
*In this presentation, we will focus primarily on adaptations in the bird respiratory system that occur at high altitudes.

A special species of murderous birds.

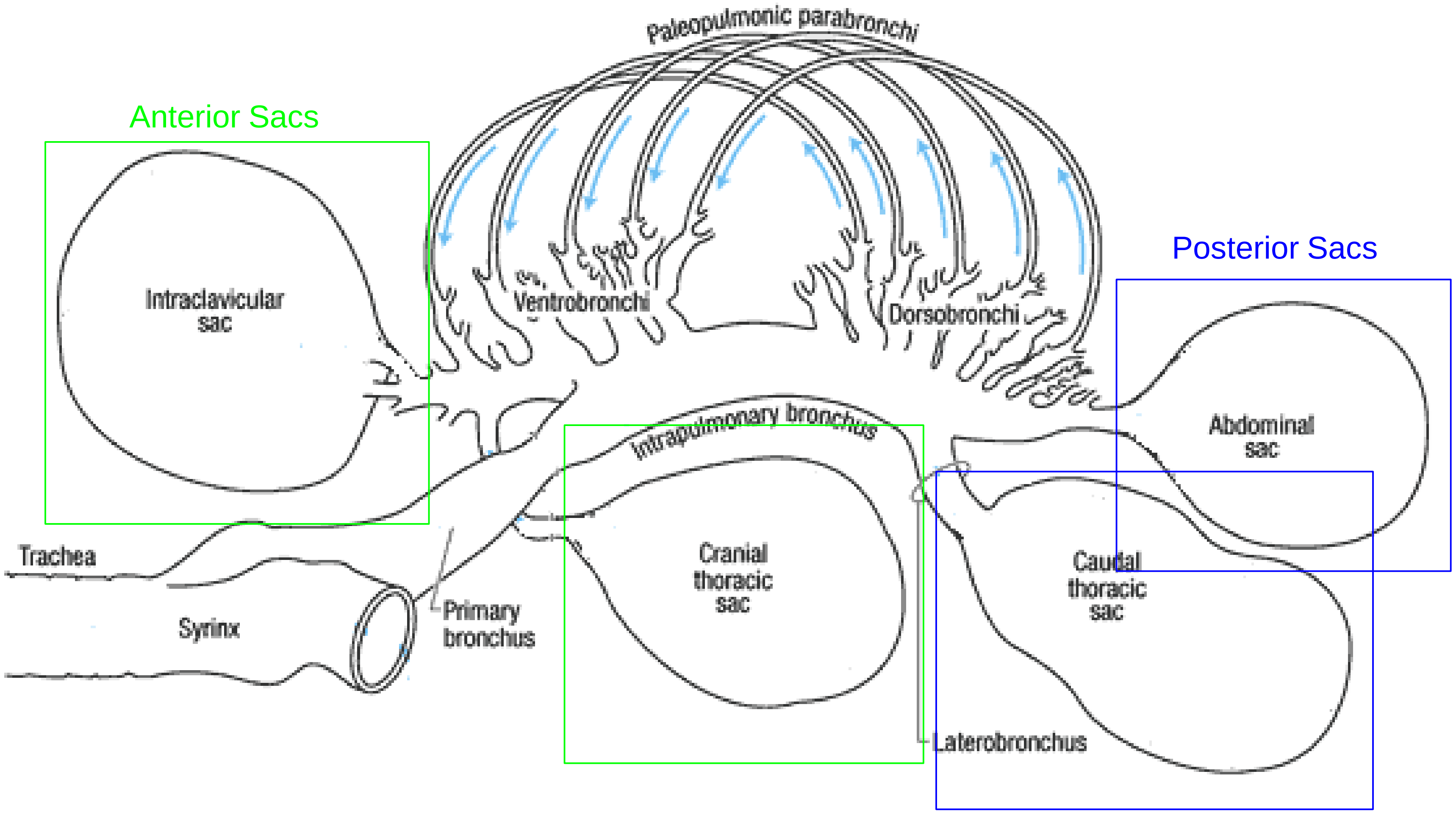
Bird vs. Human – Anatomy



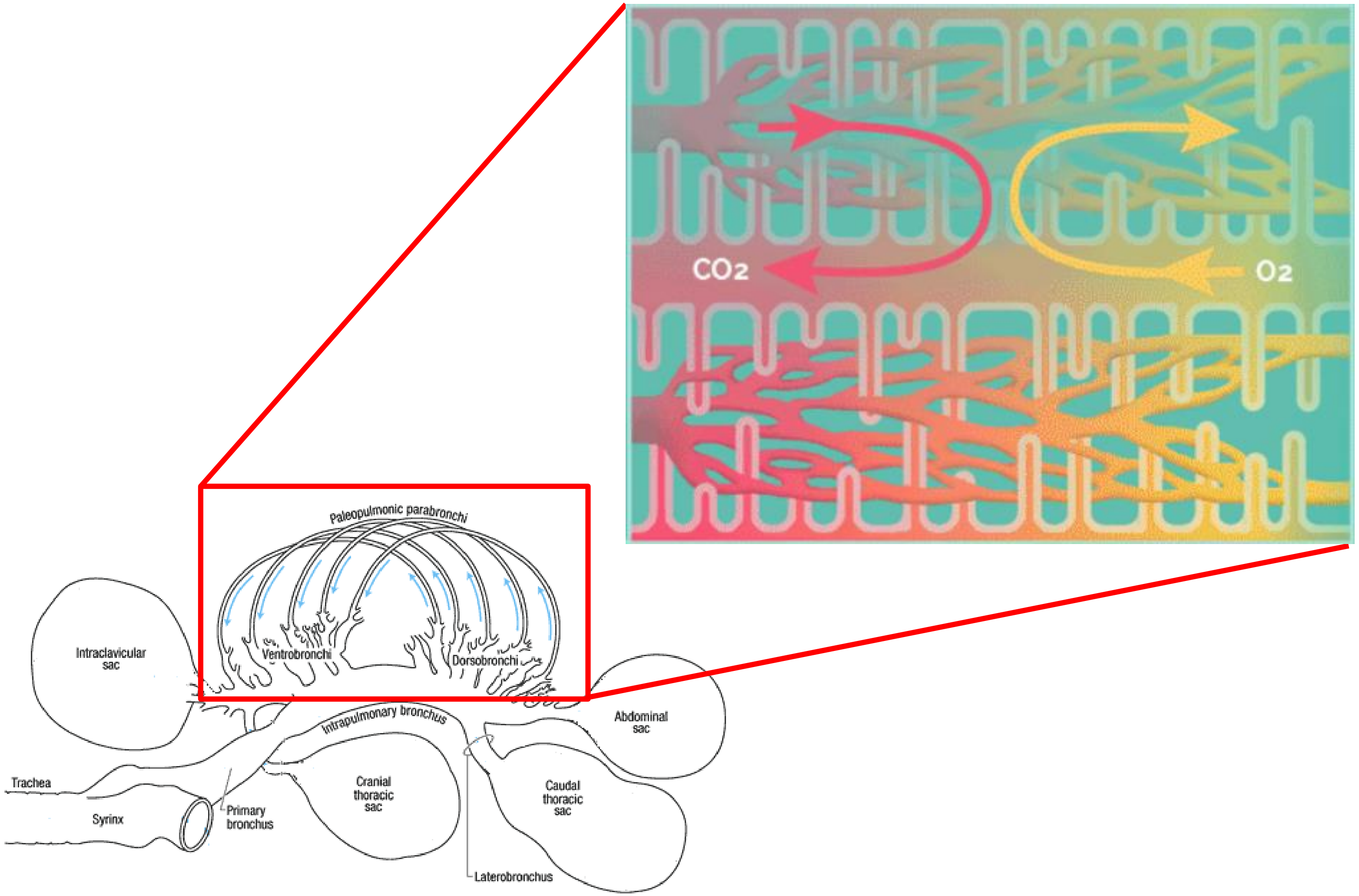
Bird vs. Human – Anatomy



Bird Anatomy - Air Sacs

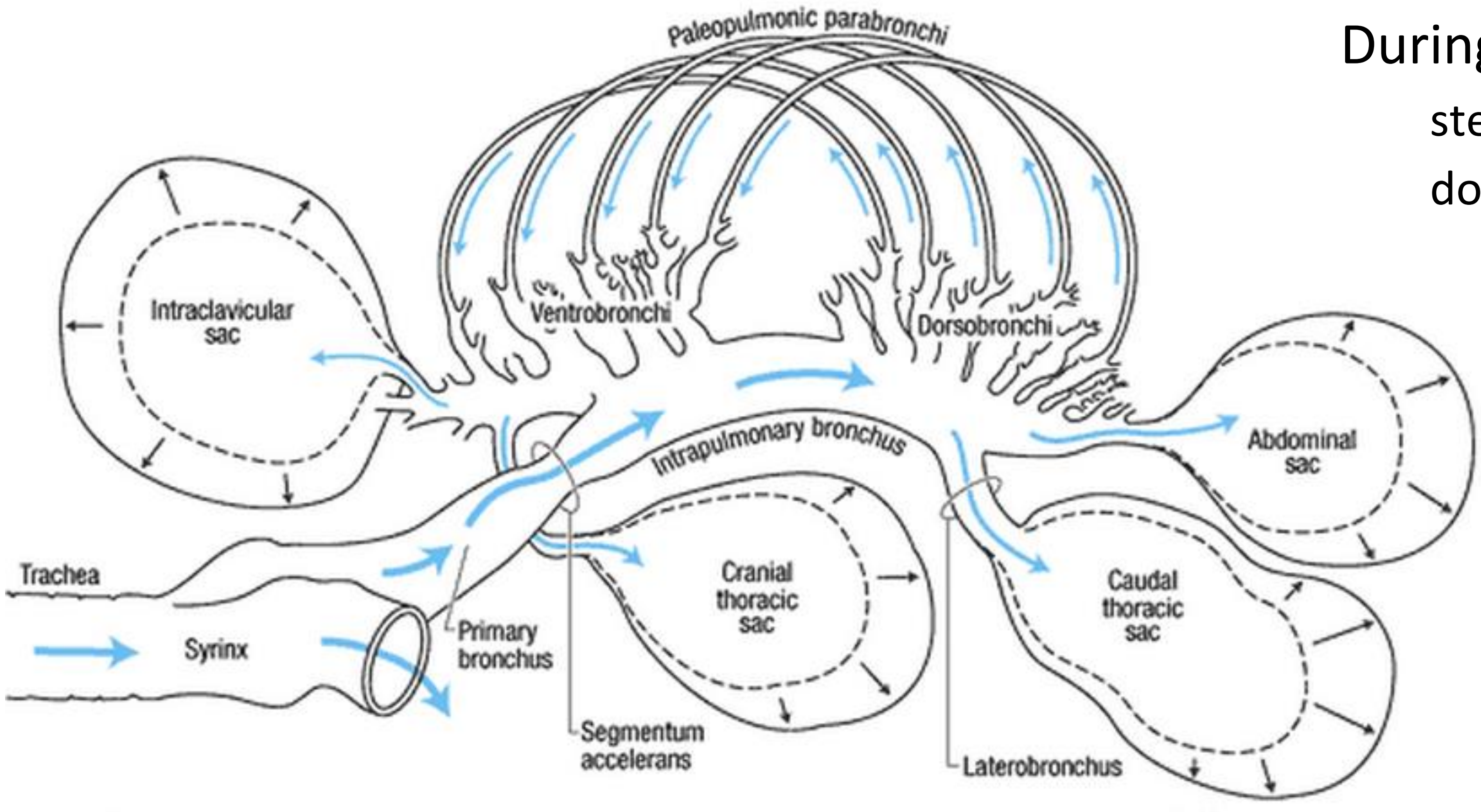


Bird Anatomy - Parabronchi



- No alveoli
- Parabronchi with atria that project radially

Inspiration

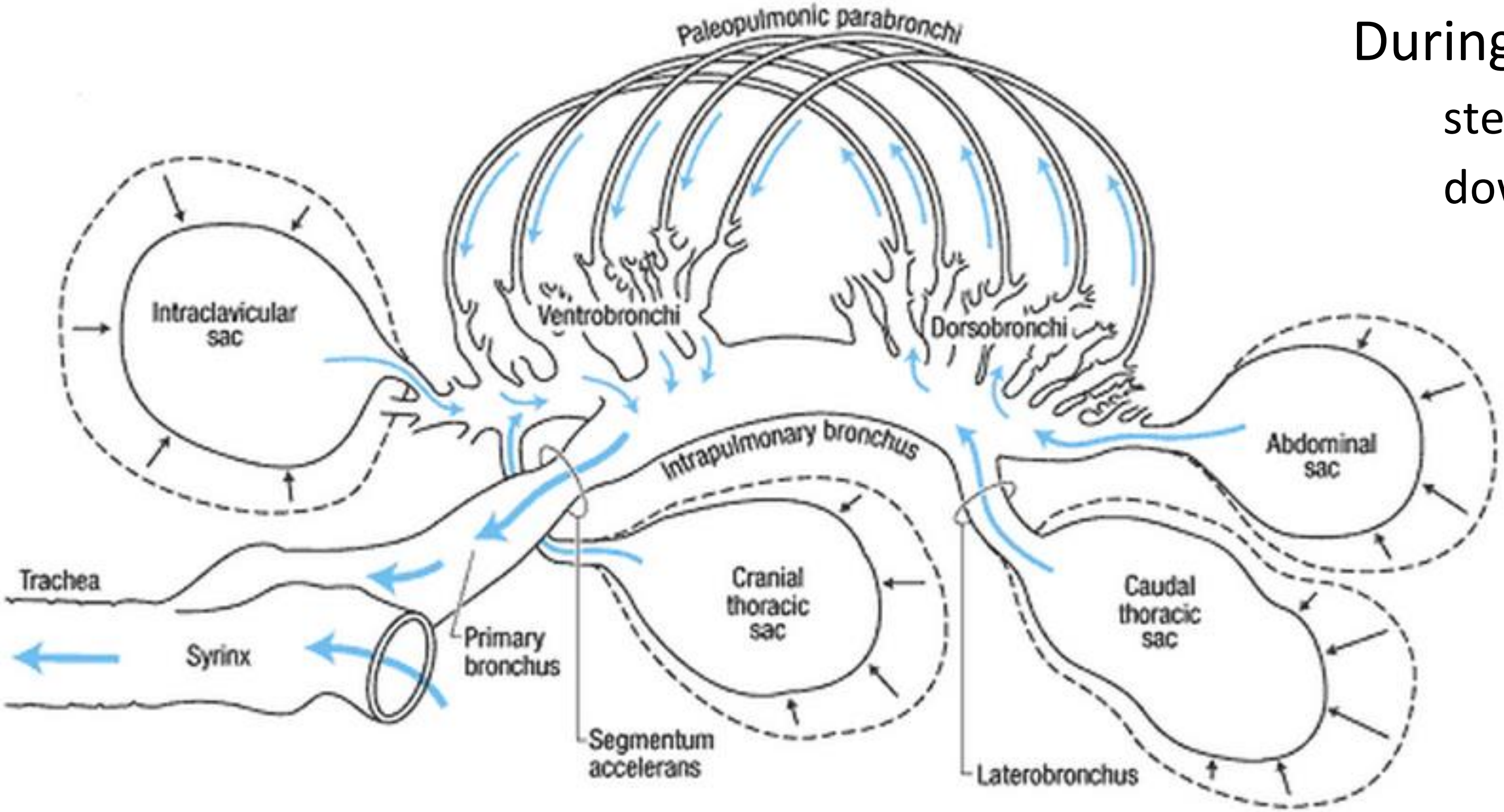


During inspiration:

sternum moves forward and downward; ribs move cranially

- expands the **both** posterior and anterior air sacs -> **lowers the pressure**!
- air from the bronchi flows into the posterior air sacs
- air from the lungs moves into the anterior air sacs
- this happens **simultaneously**!

Expiration

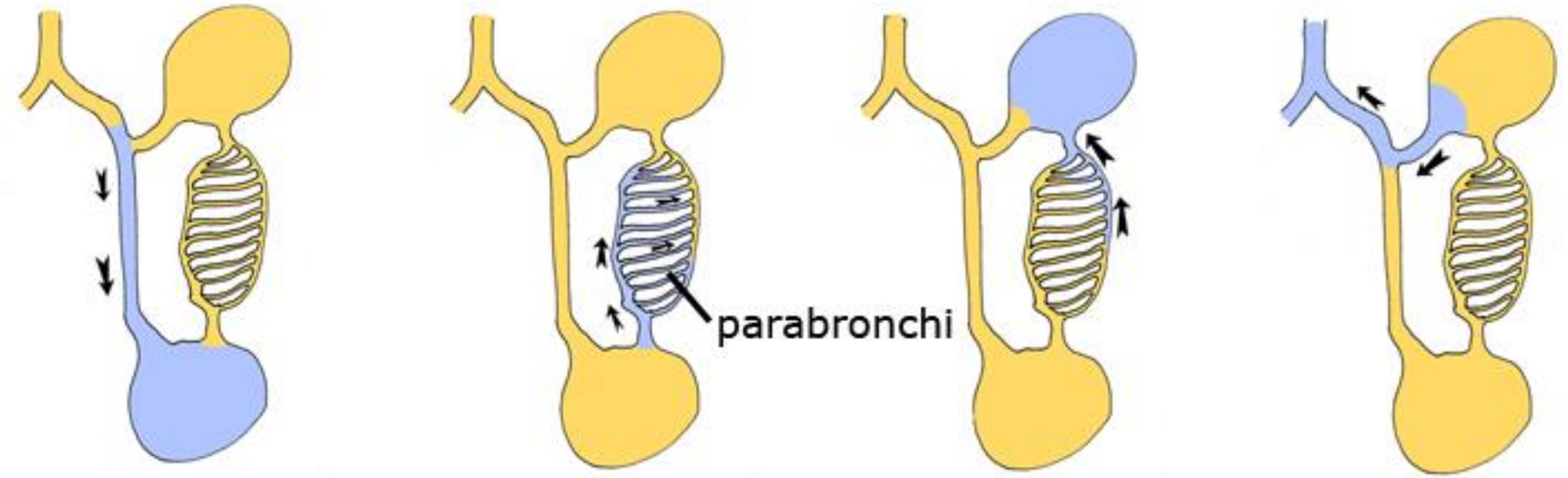


During expiration:

sternum moves backwards and downward; ribs move caudally

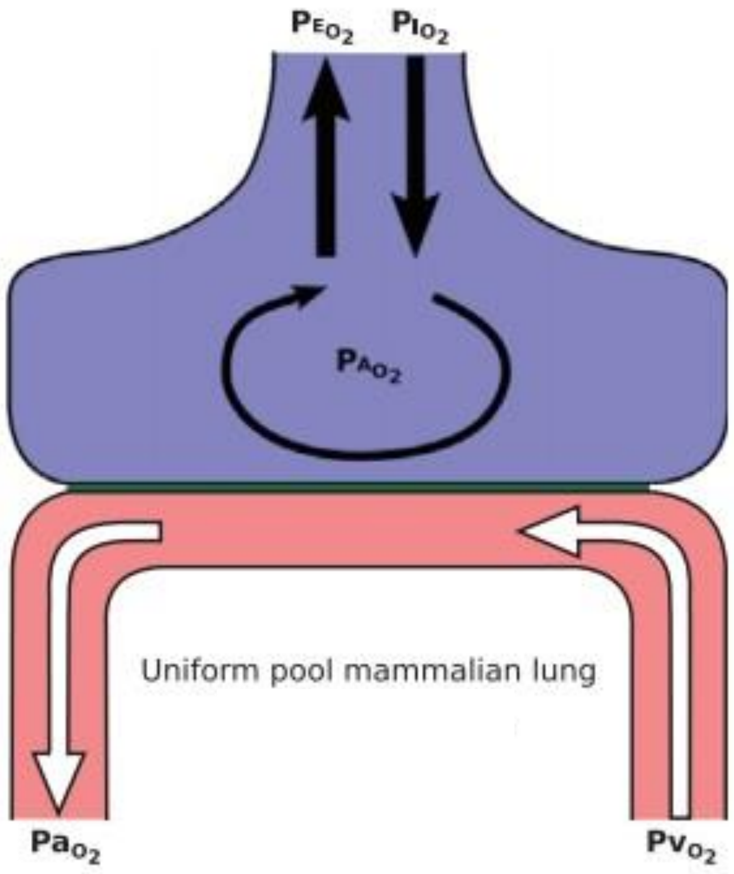
- contracts **both** posterior and anterior air sacs -> **increasing the pressure**!
- air from the posterior sacs flows into the lungs
- air from the anterior air sacs moves out the trachea
- this happens **simultaneously**!

Unidirectional Flow



(Kuss, 2012)

Uniform Pool Model in Humans



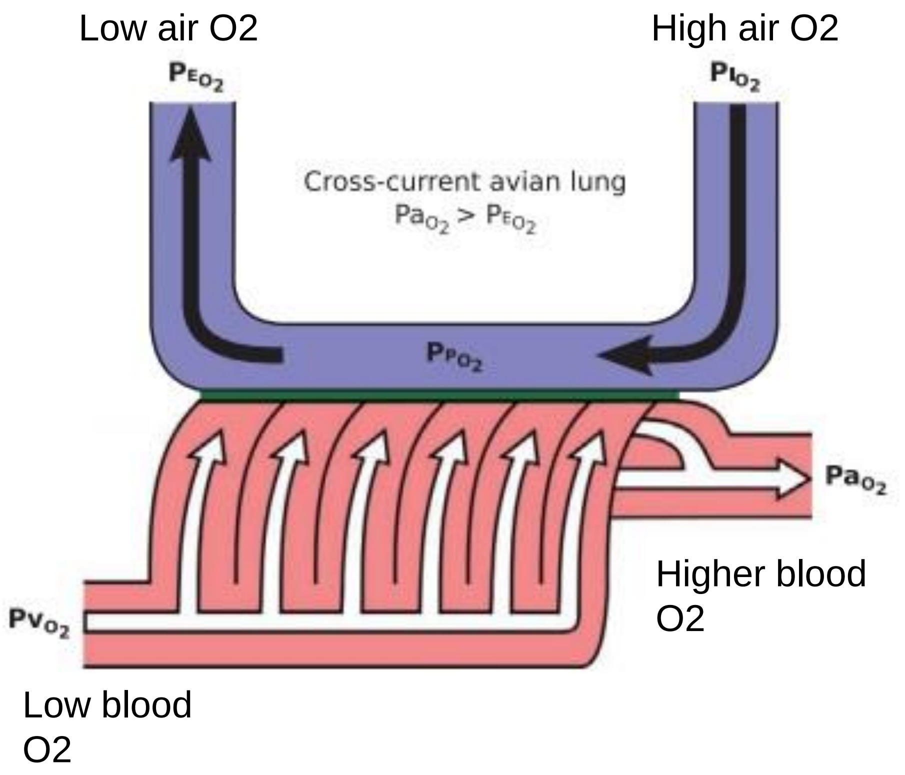
Higher blood O2

Low blood O2

- Air simply pools in the alveoli
- Capillary in contact with same pool of air
- Blood and air oxygen can only equilibrate
- Arterial blood oxygen is at most only equal to air oxygen levels

(Scott. G. R., 2011)

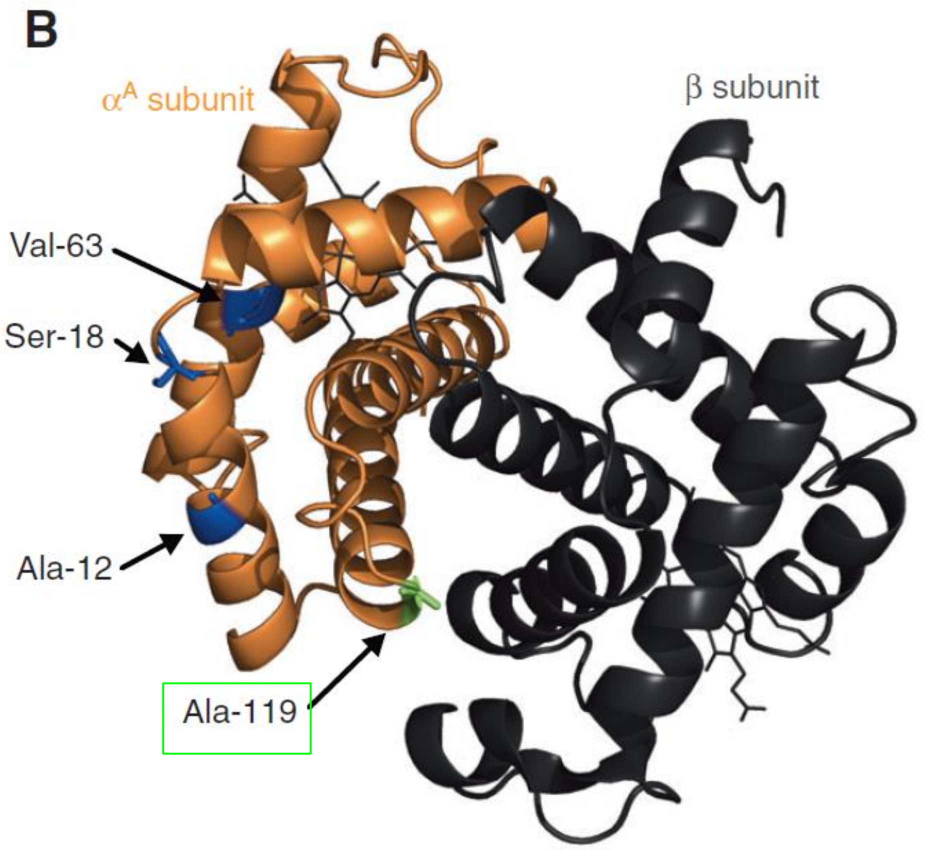
Cross-Current Exchange in Birds



- Blood capillaries are positioned perpendicular to air capillaries
- Constant diffusion of air into capillaries
- Blood pools from multiple capillaries into 1 final endpoint
- $Pa_{O2} > PE_{O2}$

(Scott. G. R., 2011)

Principles of Diffusion



Difference shown in green (Pro to Ala)

Avian haemoglobin has a difference in the alpha-A subunit

- Increases affinity for Oxygen
- Allows birds to make better use of the low Oxygen at higher altitudes

(Scott, 2011)

Principles of Diffusion

Fick's Law of Diffusion:

$$\dot{V}_{gas} \propto \frac{\boxed{A} * D * [\Delta P]}{T}$$

Rate of gas exchange proportional to A

- Birds have larger surface area of capillaries
- More Oxygen transferred per unit time compared to mammals

(Maina *et al*., 2010)

Principles of Diffusion

Fick's Law of Diffusion:

$$\dot{V}_{gas} \; \alpha \; \frac{A * D * [\Delta P]}{\boxed{T}}$$

Rate of gas exchange proportional to 1/T

- Thickness of blood-gas barrier is smaller than in mammals
- Thinnest among all terrestrial vertebrates
- Quicker diffusion of oxygen across capillaries

(Maina *et al*., 2010)

Principles of Diffusion

Fick's Law of Diffusion:

$$\dot{V}_{gas} \; \alpha \; \frac{A * D * [\Delta P]}{\boxed{T}}$$

On a more microscopic level… mitochondria

- In active muscle fibres of some birds (e.g. bar-headed geese), mitochondria are located closer to capillaries
- This decreases the intracellular distance that O_2 must travel by diffusion

(Scott *et al.*, 2009)

Key Points

- Unidirectional flow → no mixing
- Hemoglobin has higher affinity for Oxygen
- More surface area + thin blood-gas barrier + small distance to mitochondria (Fick's principle)
- Cross-current exchange

- **What can we learn from bird respiration?**
  - **All of the above increase efficiency!**

That’s all, folks!

Thanks for listening :)

References

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