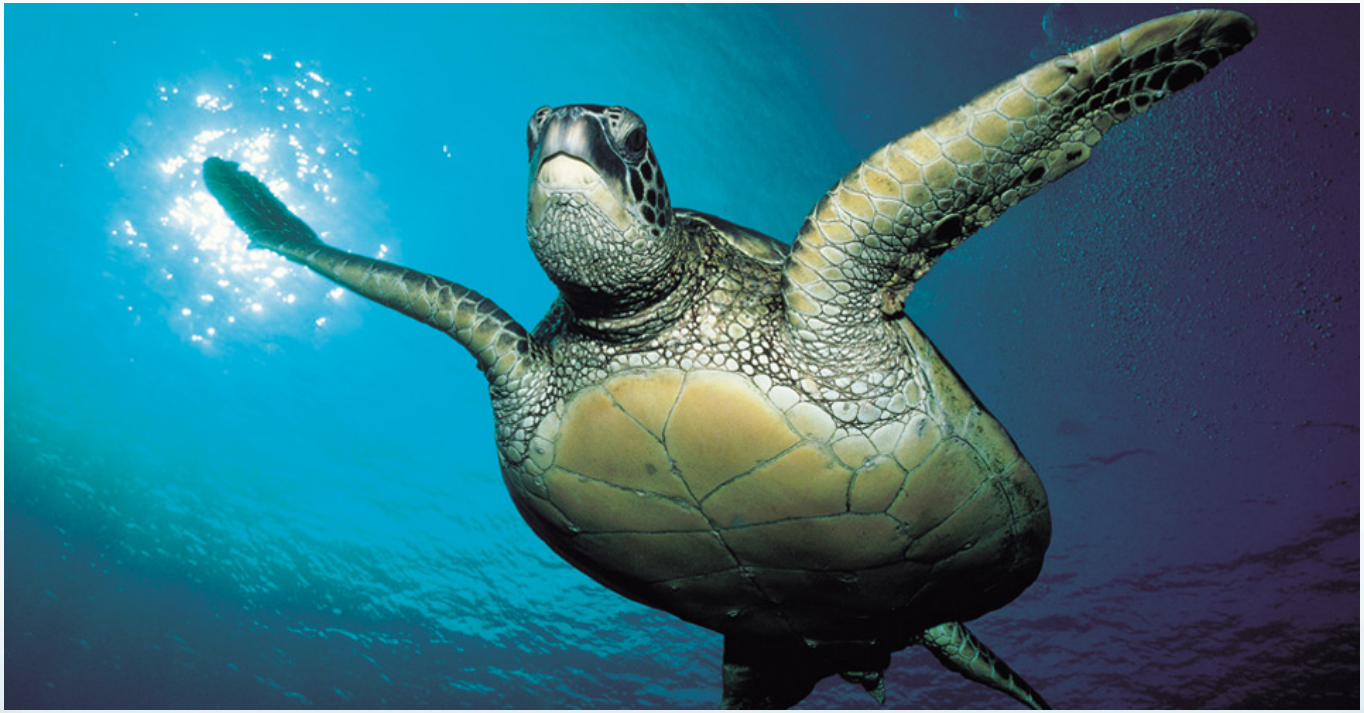
Turtle Respiratory Physiology



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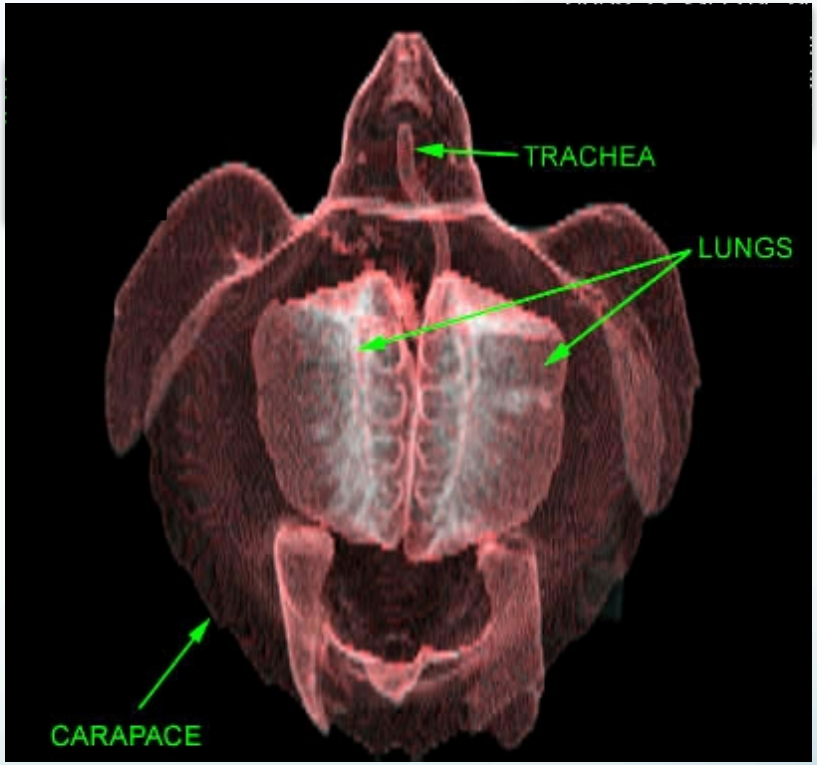
- Our presentation will focus largely on sea turtle respiratory physiology
- There are seven species of sea turtles and they breath using their lungs
- Some other species of turtles perform accessory underwater respiration through gas exchange in the cloaca and oral cavity[1]

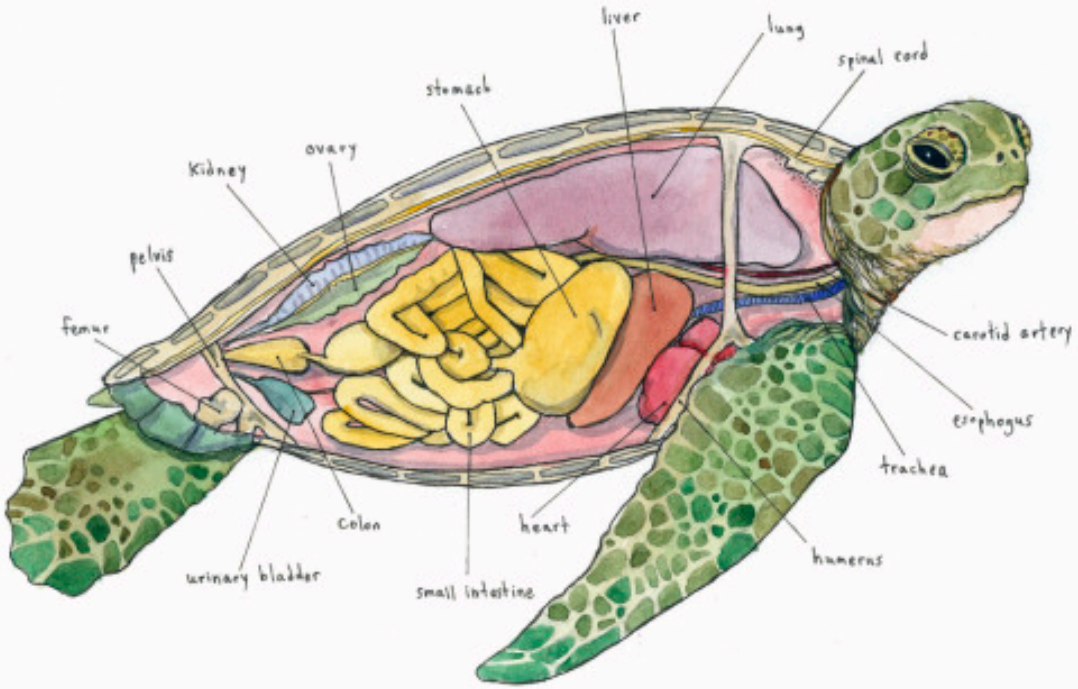
Presentation Overview

- Anatomy of the respiratory system
- Ventilation of the lungs
- Adaptations to the marine environment
- Diving
- Control of breathing
- Accessory modes of respiration

Anatomy of the Respiratory System

- The airway begins at the glottis[2]
- The trachea extends from the glottis and bifurcates into two bronchi that enter the anterior part of the lungs[2]
- The bronchi extend along the length of the lungs; smaller airways branch off the bronchi leading to the internal lobules[2]





- The lungs are attached dorsally to the shell and vertebral column; ventrally they are attached to the stomach and liver and posteriorly they are attached to the peritoneum that overlies the kidneys and adrenal glands[2]

Histology of the Lungs

- The lung tissue is highly elastic allowing for a large tidal volume[2]
- In order to prevent the lungs from collapsing under high pressures, smooth muscle and structural fibers infiltrate the lungs to enhance their mechanical stability; this is also characteristic of diving mammals[3]

Ventilation of the Lungs

- Turtles are negative pressure breathers
- The rib cage and spine are fused to the turtle's rigid shell; therefore the chest cavity can't be expanded using trunk muscles associated with the ribs[4]
- Turtles do not use their diaphragm to breath either[2]
- Instead abdominal muscles and muscles of the pelvic and pectoral girdles relax and contract to change the pleural pressure of the lungs[2]
- Expansion of the posterior limb pockets also helps to expand the lungs leading to inspiration[5]

Lungs Adapted to Marine Environment and Diving

- 85% of life span under water, varies by species.
- Prolonged dives lasting 15 – 30 min on a single breath.
- Able to survive submersion for several hours!
- Although adaptations exist, lungs are the only source of O_2 / CO_2 exchange
- Must be able to tolerate $\downarrow SaO_2$ and $\uparrow CO_2$ as well as the pH changes

How do they do it ?

Expected Changes In Humans

CO_2 accumulation (0 – 10min)

- as aerobic metabolism continues and CO_2 accumulates in the blood and in stagnant alveolar gas

P_AO_2 and subsequent P_aO_2 drop (3-10min)

- P_aO_2 of roughly 30-40mmHg is the danger zone

Tissue hypoxemia, lactic acid production (5 – 10min)

- ↓ pH

Hypoxia – Hypoxemia – Cerebral Hypoxia – ‘‘Black Out’’ – Death

Diving Adaptation

The Green Sea Turtle (*Chelonia mydas)*

Structurally reinforced airways

- routinely dives to 300m about 30 atm of pressure!
- prevent collapse at depth, up to a point
- rapid expiration with minimal flow limitations when surfacing
- (10 – 12L/sec)!
- Lungs as store oxygen

Deep Diver Adaptations

The Leatherback Sea Turtle (*Dermochelys coriacea*)

Ability to maintain tissue oxygenation while submerged requires ways of storing oxygen.

- High Hemoglobin (Hg) concentration relative to other reptiles
- Hematocrit values similar to humans 35 – 40%
- Myoglobin stores in muscle tissue allow for demanding aerobic activity while oxygen reserves are at a premium (chasing jellyfish)
- Lungs are relatively smaller and though to completely collapse during deeper dives

Blood Chemistry Regulation

Loggerhead Sea Turtle (Caretta caretta)

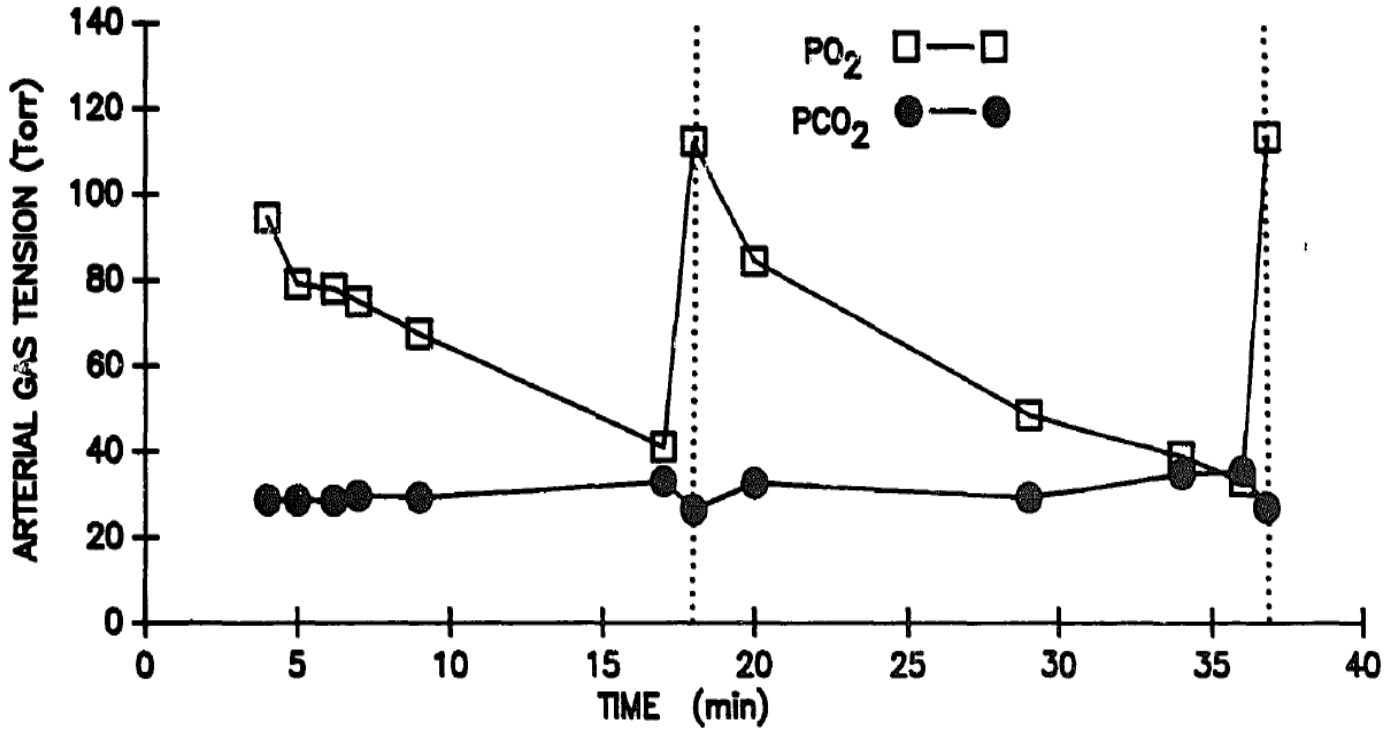


Fig. 5. Course of blood gases occurring in a sequence of voluntary dives in a loggerhead sea turtle. Vertical dashed lines indicate ventilation.

Lutcavage ME & Lutz PL (1991). Voluntary driving metabolism and ventilation in the loggerhead sea turtle. *J Exp Mar Biol Ecol* **147**(2), 287-296.

Blood Chemistry Regulation

Routine dives do not result in significant hypercapnia ($\uparrow CO_2$)

- Though to be buffered by HCO_3^-
- Basic blood proteins

Gradual decline of O_2

Prolonged submersion = $\uparrow CO_2$ $\downarrow$ pH and presence of lactate

- Obvious limit to aerobic activity
- Turtles spend time on the surface to recover and normalize blood gas

Control of Breathing

- Temperature/Metabolism
- Exercise
- Breathing rhythm
- Response to hypoxia

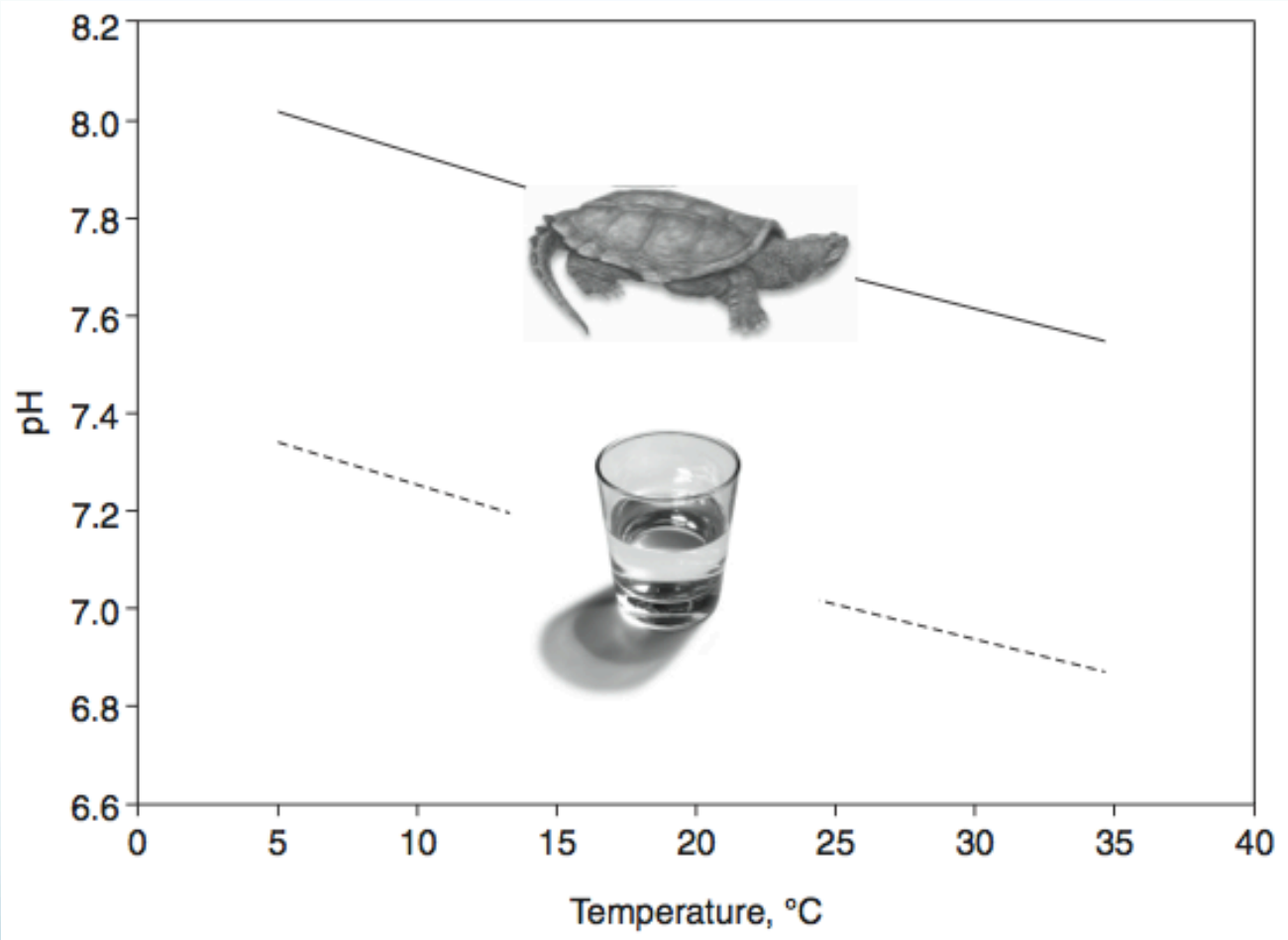
Temperature/Metabolism

- As temperature increases, metabolism increases
  - 30°C 4x metabolism of 10°C[4]
- But ventilation stays the same[4]
- What happens to O_2, CO_2, pH?
  - Lower O_2, higher CO_2, lower pH

Temperature/Metabolism

- O_2: turtles only requires 10% O_2 to survive, even at 30°C[4]
  - 21% O_2 in atm
- How does the range of temperature affect protein structure/function?
  - Denature?
- Turtles adjust pH to maintain protein function[2]
  - At 37°C, pH 7.4[4]
  - At 20°C, pH 7.7[4]
  - At 10°C, pH 8[4]

Temperature/Metabolism



Exercise

- Turtles don't hyperventilate in response to temperature-induced increase in metabolism[4]
- Humans hyperventilate in response to exercise
- Do turtles hyperventilate when they exercise?
  - Yes: at the same temperature, they maintain a constant pH[4]

Breathing rhythm

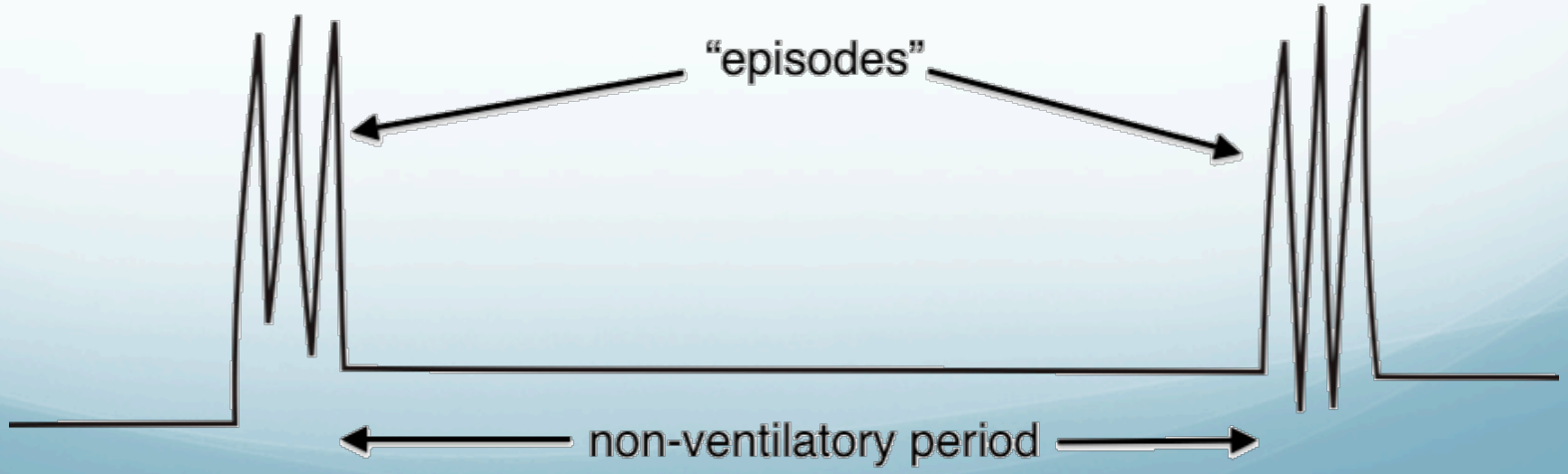
- Sea turtles pause their activity to breathe
  - At sea: periods of diving
  - On land: pauses during activities[4]
    - Shared muscles for breathing and locomotion[4]
  - In lab: intermittent breathing[10]
  - Innately programmed to breathe this way[10]

Control of breathing rhythm

- Central structures generate rhythm, afferent inputs modify
  - Central neurons mimic rhythm of ventilation[10]
  - Central chemoreceptors[11]
  - Artificial ventilation → no effort to breathe[13]
  - Hypoxia after period of diving → surface to breathe[14]

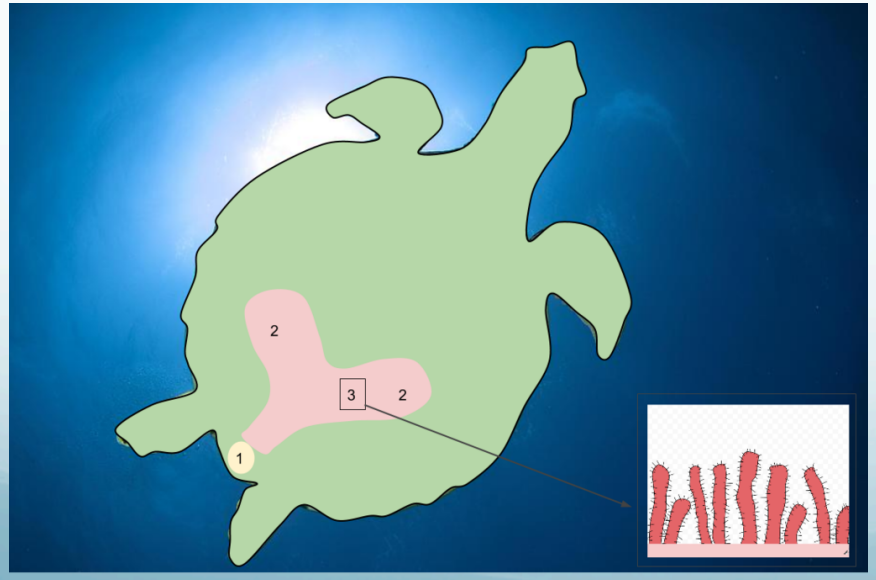
Hypoxia's effect on rhythm

- Increase frequency[15]
- Increase tidal volume[15]
- Increase inspiratory and expiratory duration[15]
- Decrease non-ventilatory period[16]



Cloacal Underwater Respiration

- Turtles pump water into their cloacal orifice[1]
- The water travels along a pair of internal channels (cloacal bursae) which are lined with long fimbriae[1]
- These fimbriae are the site of gas exchange[1]



(1)Cloacal orifice
(2)Cloacal bursae
(3)Location of fimbriae

Pharyngeal Underwater Respiration

- There are rhythmic movements of the hyoid apparatus that help to draw water in and out of the mouth and pharynx[1]
- Gas exchange takes place at the pharyngeal mucosa which is well vascularized and contains numerous villiform processes that increase the surface area for gas exchange[12]
- Accessory methods are important during long dives and hibernation
- During hibernation metabolic activity is very low and calcium carbonate from the shell is used as a long term pH buffer during

Summary of Presentation

- Turtles must ventilate their lungs using muscles other than the intercostals and diaphragm
- Different physiological adaptations are based on specific environmental conditions
- Ventilation changes according to temperature and metabolic demands
- Similar to humans, central nervous system structures control breathing rhythm
- Accessory modes of respiration are important during long dives and hibernation

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