The Insect Circulatory and Respiratory Systems

• What are some of the main roles of the human circulatory system?

Lecture Goals

• Understand the ‘open’ circulatory system in insects.
• Recognize the lack of integration between the circulatory and respiratory systems in insects.
• Understand the tracheal system of gas exchange.

The Insect Circulatory System

• Does an insect have blood?
• Does an insect have a heart?
• Does an insect have blood vessels?
• How can insects circulate their blood throughout their body?
The Insect Circulatory System

• What is the color of insect blood?
• Does the insect have blood cells?
• Does the insect have lymph?

• How can insects have lymph and blood together without vessels?

Insects have an “open” circulatory system.
– The hemocoel (body cavity) is filled with hemolymph (blood) that bathes the organs.
– Does this mean that blood does not circulate?

Insect Circulatory Organs

• Multichambered ‘heart’ = dorsal blood vessel
  – Chambers vary across lineages: cockroaches have 13, house flies have 3.
  – Each chamber has a pair of ostia: inlet valves that draw hemolymph into the heart.
Insect Circulatory Organs

- **Dorsal diaphragm** is a horizontal membrane in the abdomen that separates hemocoel into two regions.
  - Above is the pericardial sinus: hemolymph enters the heart.
  - Blood pumped anteriorly via peristaltic action to the head.
  - Below is abdominal hemocoel, blood flows posteriorly there.

Insect Circulatory Organs

- The leg muscles need to eat, too.
- Are divided by a septum.
- Insects have local **pulsatile** organs at the bases of appendages that pump hemolymph.

Insect Circulatory System

- Is the insect circulatory system active or passive?
- How is circulation achieved?
- What is being circulated?
Hemolymph

- Largely a colorless liquid that bathes tissues
  - (separated from cells by basement membrane; what purpose does this serve?)
  - Makes up 15-30% of total body weight and 15-70% of total body volume.
- More than nine cell types, all nucleate hemocytes
- Function of many still unknown.
- Most common are plasmatocytes: phagocytic on bacteria and other foreign microorganisms.

Functions of the hemolymph

- Transport of nutrients, wastes, hormones.
- Water storage
- Lubrication of internal organs
- Heat exchange
- Hydraulics

Functions of the hemolymph

- Immune reaction
- Phagocytosis
  - Plasmatocytes phagocyte bacteria, other foreign particles.
- Immunity proteins
  - Still poorly understood
- Encapsulation
Functions of the hemolymph

- Immune reaction
- Phagocytosis
- Immunity proteins
- Encapsulation
  - Lamellocytes encase parasitic wasp eggs that bind to the surface of cells and cannot be phagocytosed

Functions of the hemolymph

- Clots and wound repair.
  - Less risk of bleeding because of weak blood pressure.
  - Coagulocytes and prohemocytes seal wound.
- Which major function of the vertebrate circulatory system is not part of the insect circulatory system?
- Hint: Think about why insect blood is usually clear...

The insect respiratory system

- How do insects get oxygen to tissues?
- Hemolymph does not bind oxygen (with some exceptions).
- Respiration is via direct ventilation of tissues via tracheal system.
Spiracles

- External openings
- Hypothetically one per segment;
- Normally occur on meso-, metathorax, and abdominal segments 1-8 (none in head, prothorax or genital segments)

Spiracles

- Have a chamber or pit = atrium.
- Protected by valve which can be opened or closed.
- What do these do?
- These lead to tracheae

Trachea

- Series of air-filled tubes; unique to insects
- Entirely separate from the circulatory system.
- Lined with cuticle
- Extensively branched – 39% of body volume of the June beetle
- Taenidia: spiral cuticular thickening running through trachea – Prevent tubes from collapsing under reduced pressure.
- **Tracheoles**: smallest diameter tubes.
  - <1 micron in diameter
  - No cell in an insect is more than 1 cell away from a tracheole.
  - In flight muscles where O₂ consumption is high, tracheoles extend between muscle fibers.
  - Tips of tracheoles are fluid-filled at rest, but air-filled during activity (for maximum gas diffusion)
  - In the 5th instar silkworm, each spiracle gives rise to 103,000 tracheoles (~1.5 million altogether).

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**Ventilation in Insects**

Two types: **passive** and active

- Occlusor muscle influenced by CO₂ level
- Spiracle opens and air comes in.
- Air passes through atrium.

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**Ventilation in Insects**

Two types: **passive** and active

- Air passes trachea, reaches tracheoles.
- Air exchange in tracheole.
- Muscle takes O₂.
Ventilation in Insects
Two types: passive and active

- Only type of ventilation in smaller insects.
- Based on simple diffusion, not active pumping.
- Continuous O\textsubscript{2} uptake and CO\textsubscript{2} storage causes 'suction'.
- CO\textsubscript{2} is expelled in cyclical bursts—every 20 min. in termites, every 6 hr in moth pupae.
- In between CO\textsubscript{2} is stored in the hemolymph as bicarbonate.
- This creates negative pressure and air is sucked into the trachea.
- When CO\textsubscript{2} concentration in the trachea >6.5%, spiracles relax and CO\textsubscript{2} is expelled.

Ventilation in Insects
Two types: passive and active

- Large insects must physically move air in and out of the tracheal system.
- Close forward spiracles and force air out of rear ones via blood pressure, muscle contraction.
- Creates negative pressure (vacuum) up front when rear spiracles closed.

Ventilation in Insects
Two types: passive and active

- Tracheal air sacs (flying insects) can increase tidal flow and reduce density of the insect.
Arrangements of the Spiracles (modifications)

• Mosquito larvae: only abdominal segment 9 spiracle functional.
• No spiracles:
  – mayfly, damselfly nymphs use abdominal ‘tracheal gills’
  – Dragonfly uses gills in a modified hindgut.

Adaptations in other aquatic insects

• Giant water bugs (Belastomatidae) and water scorpions (Nepidae): breathe through a pair of ‘siphons’ at the posterior end of the abdomen.
• Diving beetles (Dytiscidae): trap an air bubble between the elytra and the abdominal terga: spiracles have moved (evolutionarily) to the dorsal surface of the abdomen.
• Waterboatmen (Corixidae): hairs on the abdomen hold a thin, continuous air bubble in place, giving the abdomen a silvery appearance.

Atracheate insects

• All gas exchange takes place through the integument.
• Examples are Collembola (springtails) and some parasitic hymenopterous larvae.
Additional functions of the tracheal system

- Suspend internal organs (especially during movement).
- Air pressure needed for ecdysis.
- Thermoregulation—insulating layer of trachea around flight muscles.
- Pathway for development of nervous system.
- Weight reduction—hollow structures.
- Sound perception—tympanum is modified from tracheal system.
- Defense—spittlebug froth, defensive secretions from some grasshoppers & moths.

Lecture Summary

- Insects have numerous ways of gaining nutrients; gut is partitioned into processing, digestion, reabsorption/excretion.
- The circulatory system is open and largely involved in nutrient delivery and the immune response.
- The tracheal respiratory system is separated from the circulatory system and functions to deliver oxygen directly to tissues.