Insect Morphology

- Head
- Mouthparts (part 1)
- Mouthparts (part 2)
- Thorax & Abdomen (part 1)
- Thorax and Abdomen (part 2)
- Cockroach dissection

Department of Biological Sciences
University of Alberta, Edmonton, Alberta, Canada

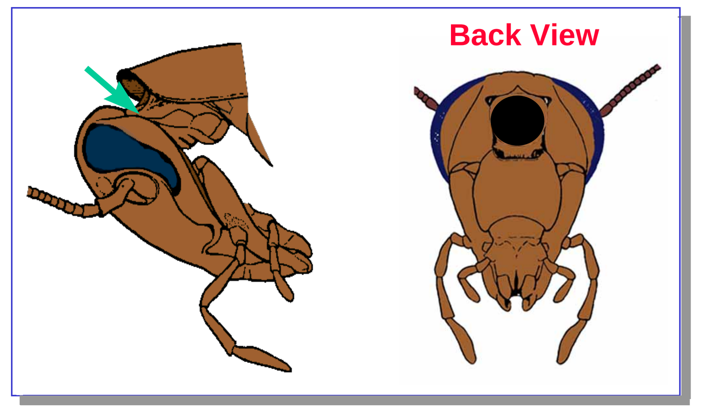
The Insect Head

Insects are strongly cephalized animals, that is, many of the important functions are moved anteriorly with a high degree of merging or condensing of segments, sensory structures and neural ganglia. This module illustrates the preceding statement. Additional information on the insect head can be found in the mouthpart module.
Six or seven segments are condensed to form the head capsule. This strong structure provides protection for the brain, support for eyes, ocelli, antennae and mouthparts. The strongest muscles in the head serve the mandibles in chewing insects and the sucking pump in piercing-sucking insects.
The hard exoskeleton that is a common feature of arthropods is particularly well illustrated in the head. The lesser appreciated internal cuticular support structures are also well represented by the cross-bracing tentorium.

Supported in part by
Academic Technologies for Learning
and Faculty of Science, University of Alberta

©
B.K.Mitchell and J.S.Scott
Department of Biological Sciences
University of Alberta

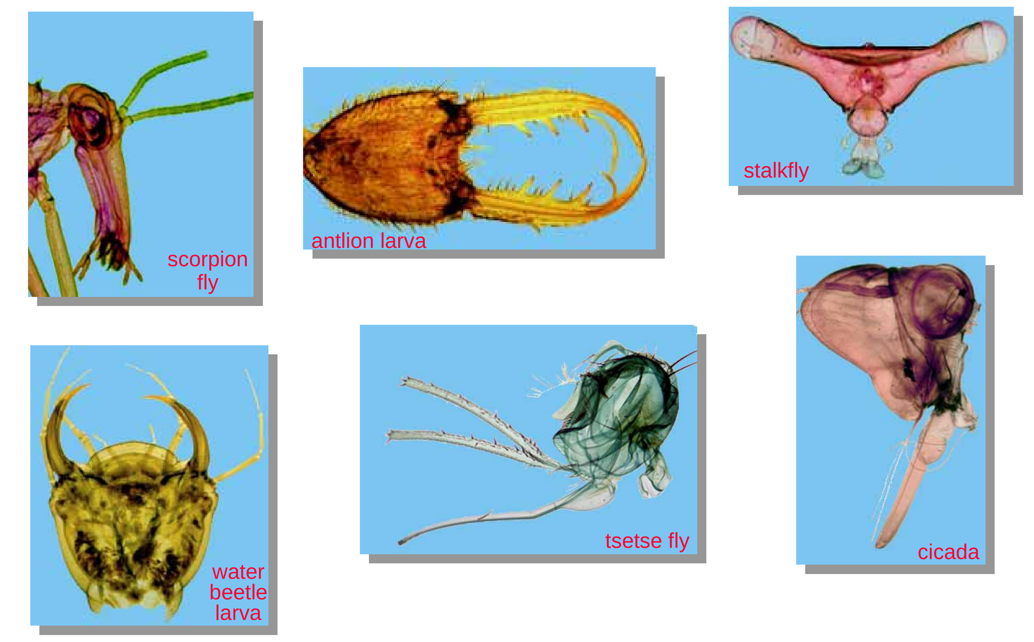
Grasshoppers and cockroaches (drawings) are often used to illustrate the most basic form of the insect head. The eye is often prominent and the mouthparts can seem strange to us. The evolutionary flexibility of the four mouthpart segmental appendages is the theme of the mouthpart segment of this series.



In cockroaches, the head is very flexibly attached to the thorax via an extensive neck membrane (arrow). The oesophagus, heart, tracheal system, and nervous system all pass through the foramen at the back of the head ●

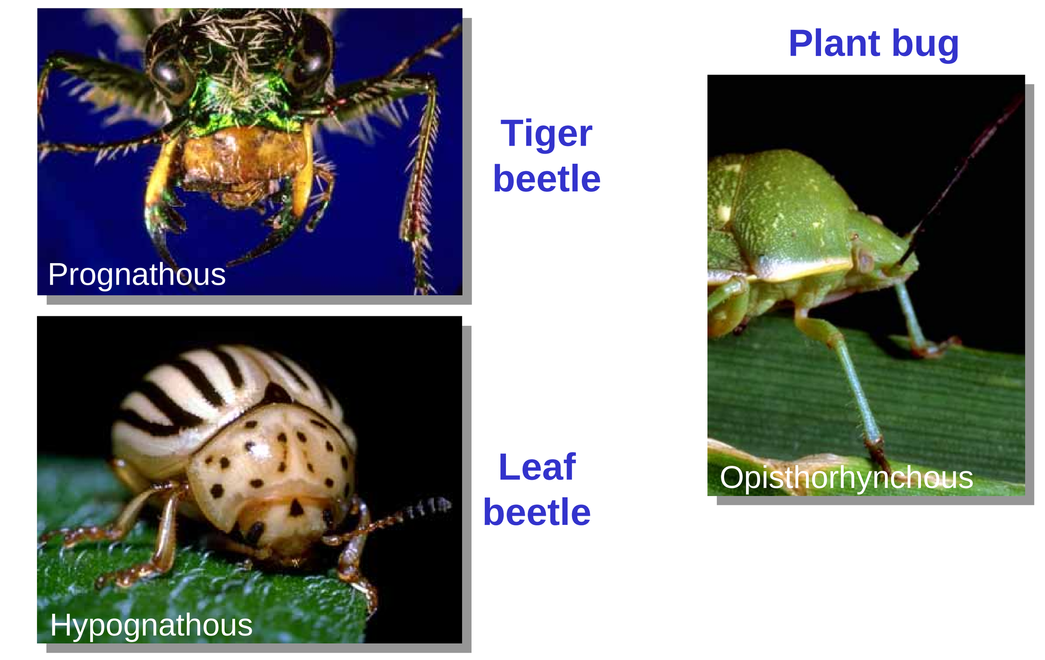
1

Insect heads take many shapes reflecting the characteristic feeding habits of the species concerned. For example, predaceous insects have forward directed mouthparts with a corresponding forward protrusion of the head. The predators in this collage of photos are probably obvious.

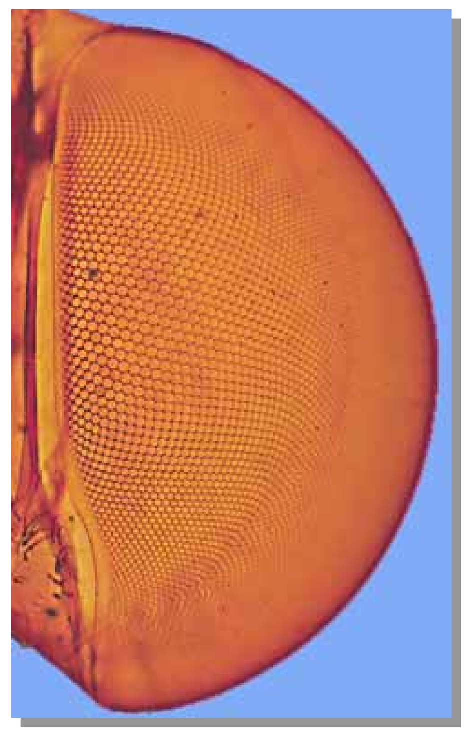


2

The three most prominent arrangements of the head have been given the names **Prognathous**, **Hypognathous** and **Opisthorhynchous**.

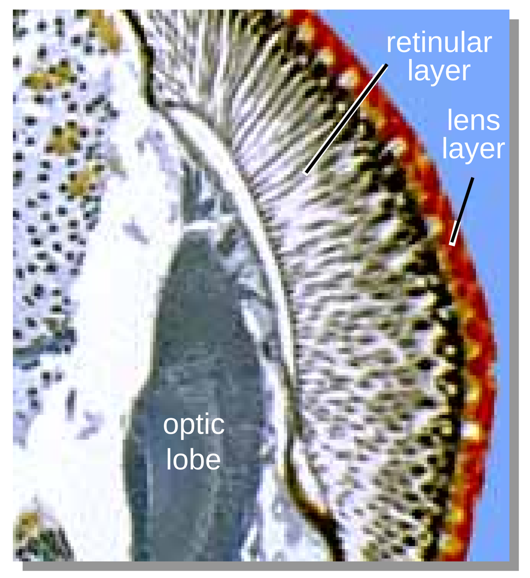


3



The compound eyes are often the most prominent structures on the insect head. Immatures and adults of hemimetabolous insects have them, as do adult hometabola. Insect compound eyes have thousands of more or less equivalent sensory cartridges called ommatidia. Each ommatidium has a hexagonal lens (hundreds in focus in this picture) and six to eight light-sensitive cells. Single homologous sensory cells from numerous adjacent ommatidia respond to light in their limited field of view and send the information to the same place in the optic lobe of the brain. The image formed in the insect brain is not as detailed as ours but insects can be exquisitely sensitive to movement in the visual field. They also can see in colour.

4

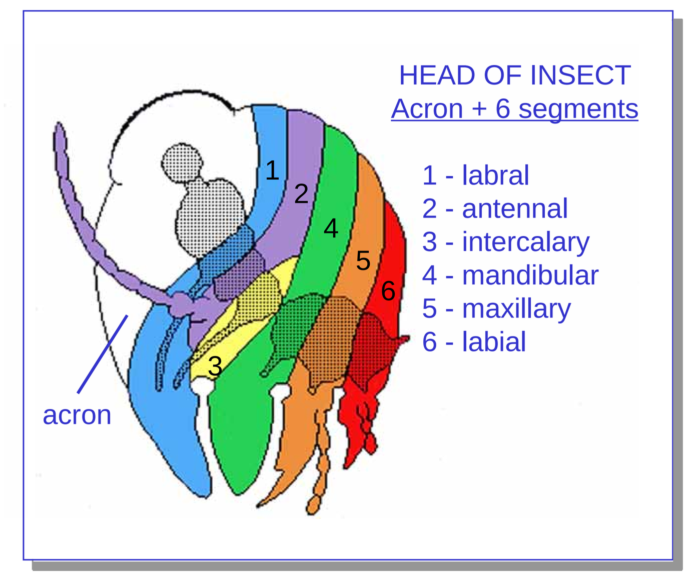


This section through a compound eye shows some of the features. The lens layer is in red, the retinular layer in black and gray and the first of three parts of the optic lobe in blue-gray.

The retinular layer contains the sensory cells (six to eight per ommatidium). The dark layer just under the lens layer contains pigments that help reduce light scattering during the day.

This is a dark adapted eye so the pigments are all at one end. This increases light scattering but it increases sensitivity.

5

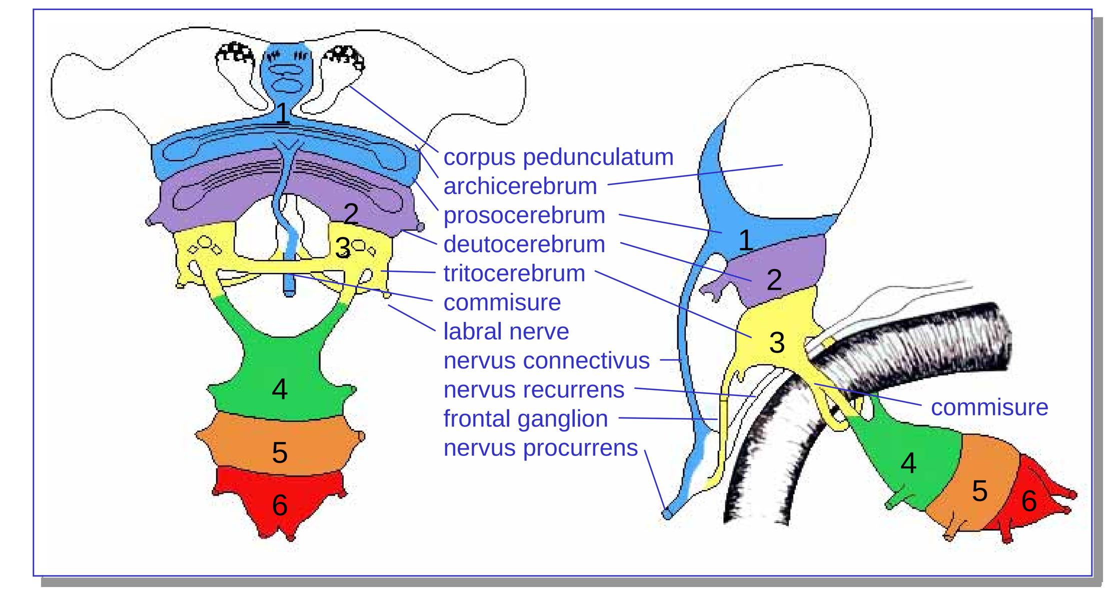


Jake Remple, a Canadian entomologist, summarized this interpretation of insect head segmentation based on a careful examination of developing embryos of the blister beetle *Lytta*.

The last three segments are easy to see at all stages of development (mandibular, maxillary and labial) because they bear obvious bi-lateral appendages.

The three anterior segments required developmental analysis to confirm their presence. The acron is homologous with the front part of the body of bi-laterally symmetrical animals such as the earthworm and is not considered a true segment because it lacks a pair of appendages.

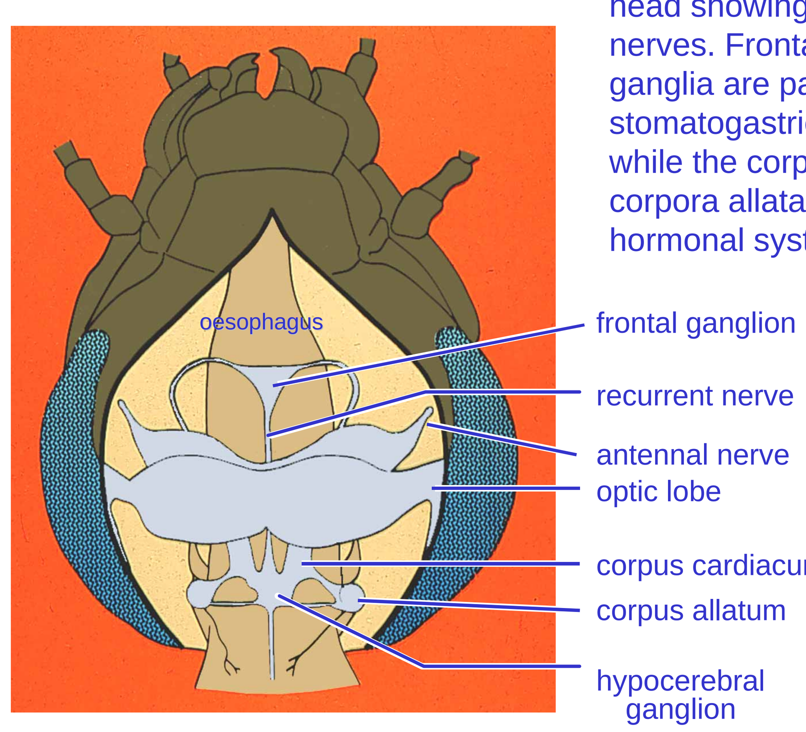
6



The largest structure in the head-neck region is the brain and sub-oesophageal ganglion complex. The oesophagus passes between these two major masses of nervous tissue. These are dorsal and lateral views respectively. The numbers correspond to the segmentation numbers of the previous slide.

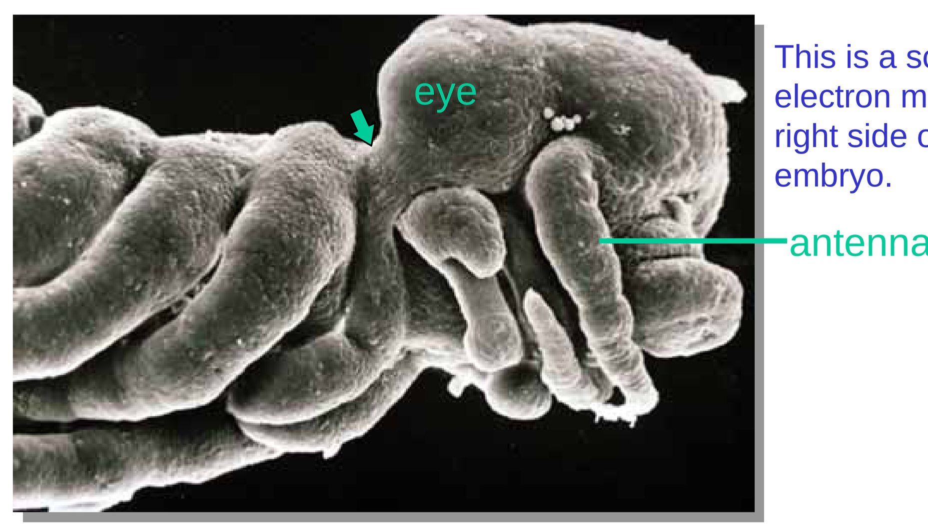
7

COCKROACH BRAIN - dorsal aspect



Drawing of dissected cockroach head showing brain and related nerves. Frontal and hypocerebral ganglia are part of the stomatogastric nervous system, while the corpora cardiaca and corpora allata are part of the hormonal system.

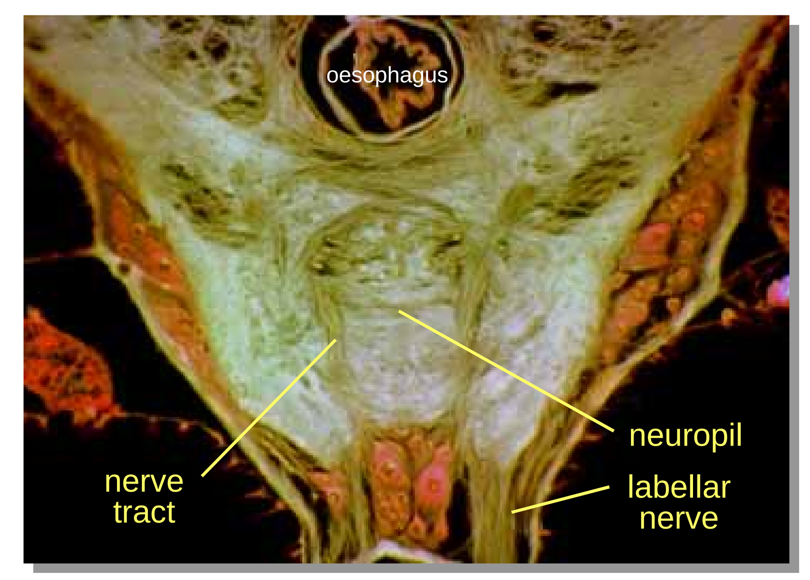
8



This is a scanning electron micrograph of the right side of a leafhopper embryo.

The green arrow marks the boundary between the head and thorax. Ventral is down and anterior is to the right.

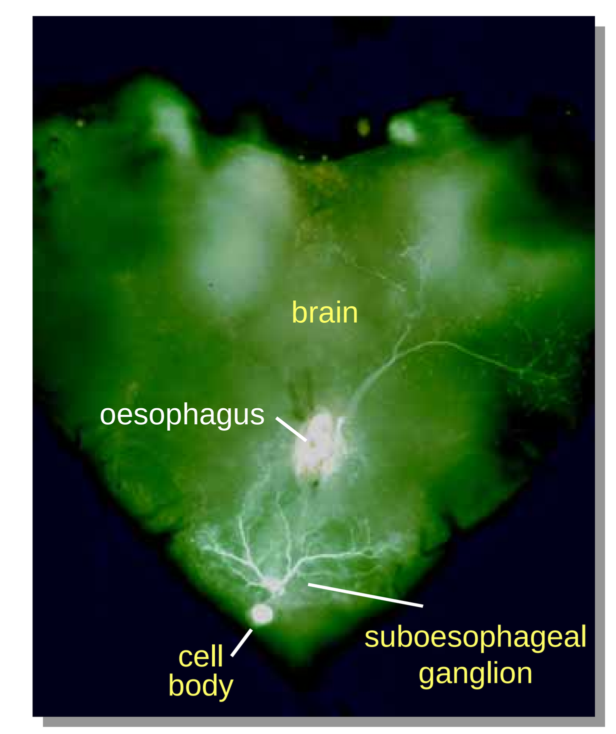
9



The sub-oesophageal ganglion (SOG) of all insects serves the major mouthparts and it's therefore much involved with feeding. This picture is of a frontal section through the SOG of a fly.

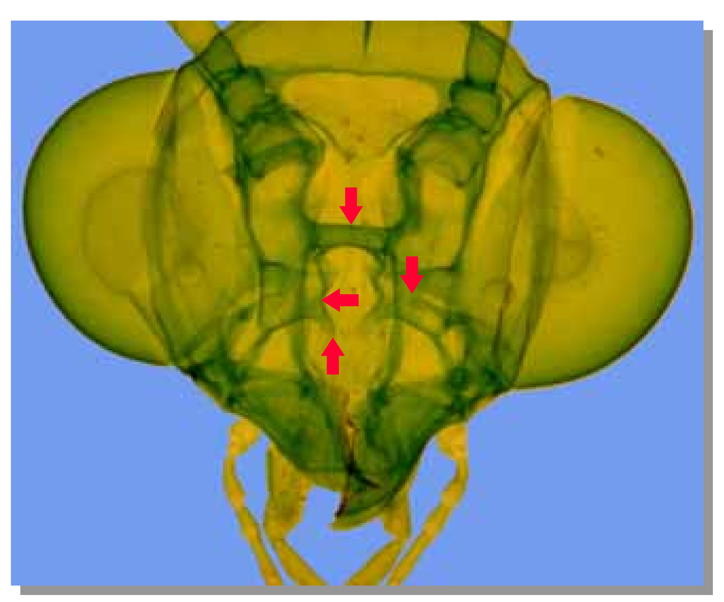
A typical ganglion (functional concentration of nerve cells) is composed of a peripheral region of cell bodies (nerve and glial cells - red) and a region of nerve to nerve connections called the neuropil.

10



This unusual view of the suboesophageal ganglion (SOG) of a flesh fly shows the brain and SOG in the same orientation as the previous picture. Use the oesophagus as a reference point. Here a single neuron has been filled with a fluorescent dye to reveal its extensive branching pattern in the SOG and in the brain. The cell body of this neuron is the bright dot just above the cell body label. This neuron is one of many that process taste input from the labellar sensilla.

11



The inside of the head contains more than the brain, of course. There are many muscles that operate the various appendages - the mouthpart muscles being particularly complex.

This cleared whole mount reveals another aspect of the head that is often overlooked - the tentorium (red arrows).

The tentorium is the “internal skeleton” which gives strength to the head capsule and provides a place for muscle attachment. It is formed by tube-shaped invaginations of the exoskeleton. The mandibles, maxillary and labial palpi are all visible in this frontal view.

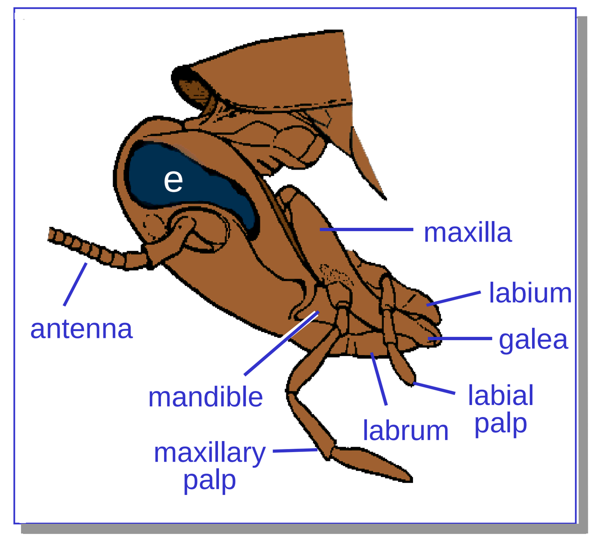
12

Mouthparts of Insects

Insects owe their great success to their abilities to adapt to a wide variety of habitats. Adaptations have occurred, indeed continue to occur, at every level of organization from the molecular to the ecological. The comparative study of insect mouthparts is first and foremost a study of adaptation. We single out mouthparts and the gross morphological level of organization in introductory courses because the variety of adaptations is so great that we can address vast landscapes of insect evolution by looking at mouthparts alone. Also, they are relatively easy to see and appreciate and, perhaps most important, the mouthparts are entral to insect trophic behaviour cfood gathering behaviour).

Supported in part by
Academic Technologies for Learning
and Faculty of Science, University of Alberta

B.K.Mitchell and J.S.Scott
Department of Biological Sciences
University of Alberta

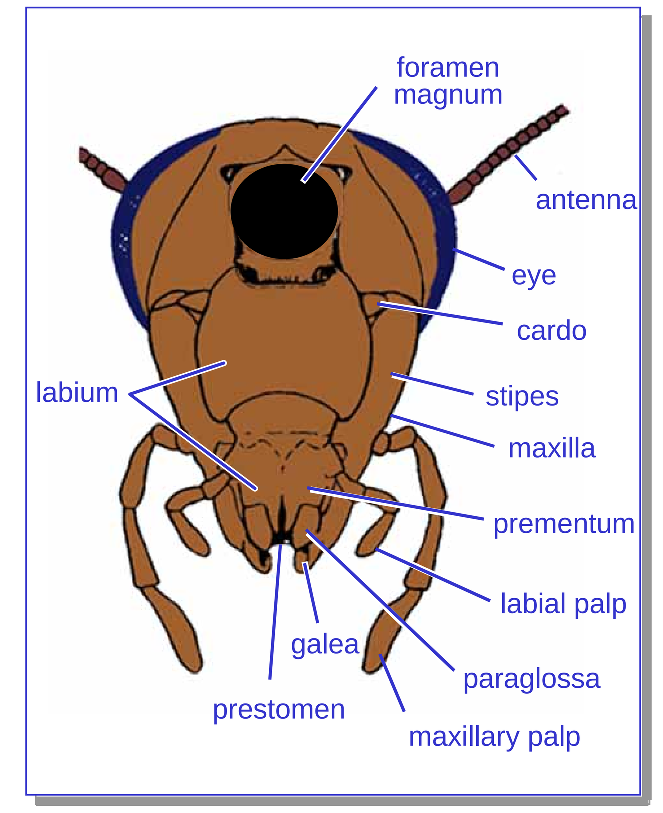


The American cockroach (*Periplaneta americana*) has "generalized" mouthparts. This insect is omnivorous and its mouthparts are well suited to chewing on a wide variety of food items.

The mouthparts are well developed in cockroaches. Each mouthpart pair comprise the two bi-lateral appendages of their segment.

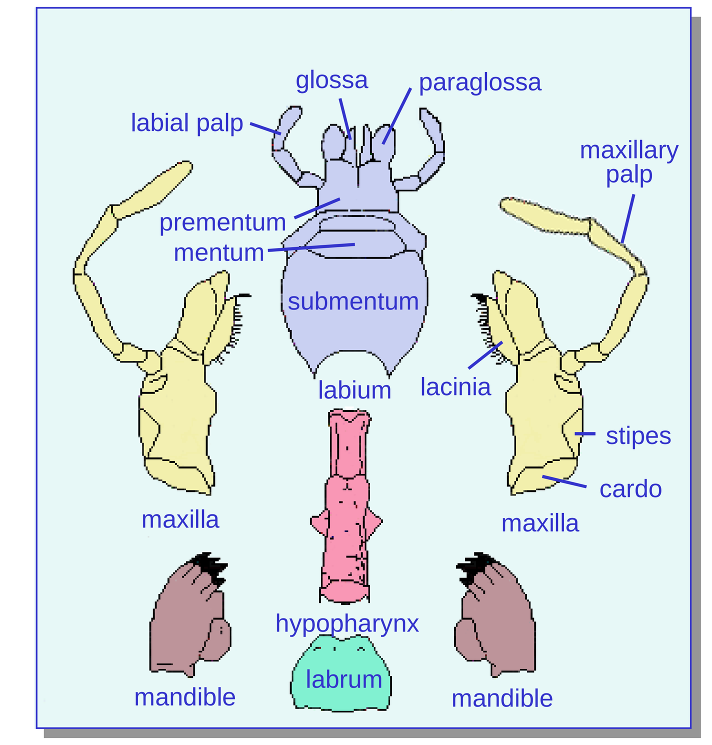
The mouthpart-bearing segments are the labral, mandibular, maxillary and labial. Two of the segments (mx and lab) have sensory palpi as well as other functional parts.

1



This posterior view of the cockroach head shows additional features as well as the various mouthpart appendages.
Note the complexity of the maxilla and labium.
See next slide for additional details.

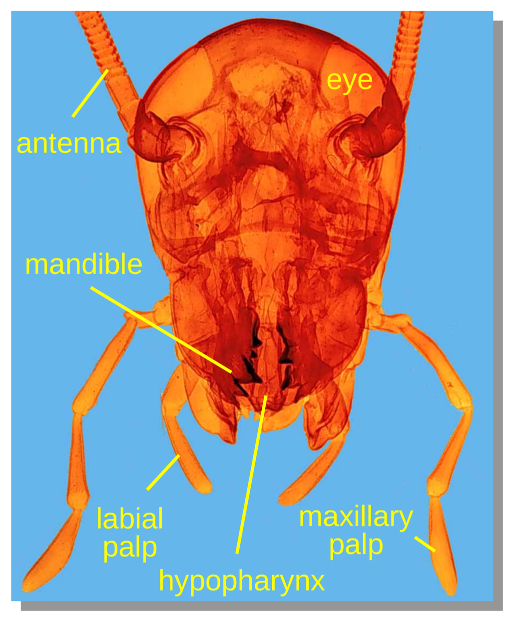
2



Hidden among the maxillae and labium is the "tongue" or hypopharynx. It has very thin (membranous) cuticle and contains the opening of the salivary gland duct.

The labium is the most complex of the cockroach mouthparts and exists as a single piece rather than as two distinct, mirror image parts as in the maxillae. This single labium is clearly formed from a fusion of bi-lateral appendages as the paired palpi, glossae and paraglossae reveal.

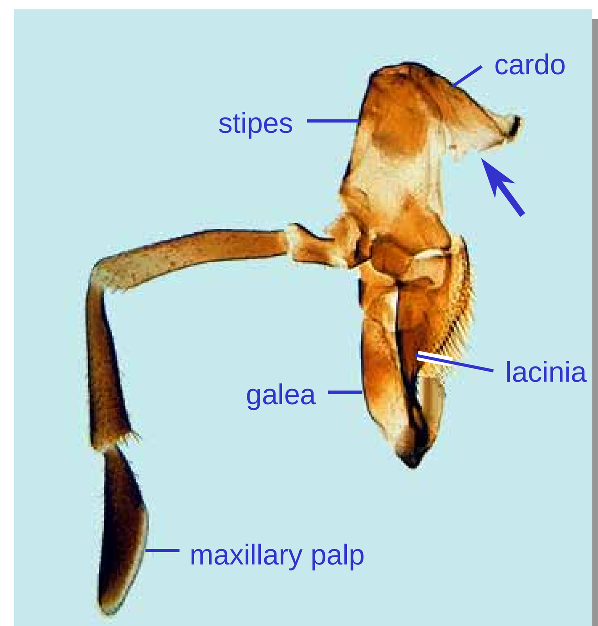
3



This frontal view of a cockroach head gives a better idea of what the mouthparts look like *in situ*. The tentorium is also visible (see module on the head in this series).

Note the well sclerotized mandibular "teeth" (black ridges in lower center) and the protruding galeae/laciniae and paraglossa. The mandibles appear to be at the front since the labrum which largely covers them is transparent in this cleared specimen.

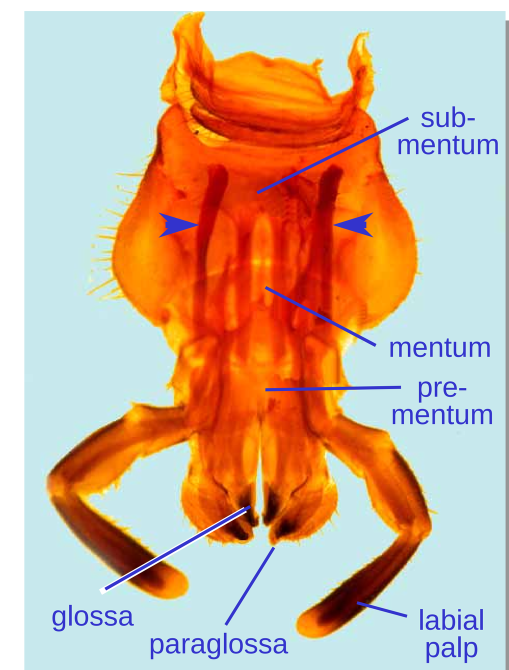
4



This detailed view of a cockroach maxilla clearly shows the sclerites that make up this complex appendage. The darker the cuticle the heavier the tanning and usually the heavier the sclerotization. Thus, the lightest cuticle is membranous-like and semi-transparent while the darkest cuticle is hard.

The blue arrow shows where the maxilla attaches to the head.

5

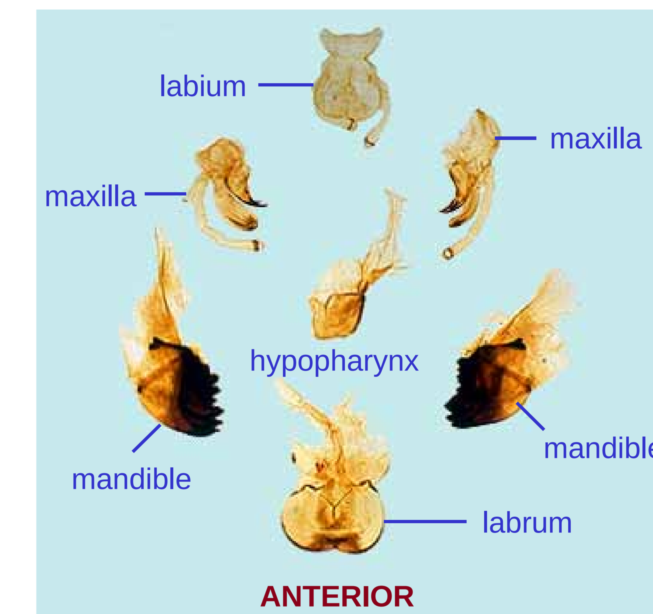


This labium was taken from the same specimen as the maxilla in the previous slide. Note that much of the cuticle is thin, so much so that the muscles operating the labial palpi are visible (blue arrowheads).

Compare the tips of the galea and lacinia in the previous slide with the glossae and paraglossae in this photo. All are dark indicating hardened cuticle. These structures are used to manipulate food.

By contrast, the tips of the palpi in both appendages are covered with membranous cuticle and, as we will see later, with many sensory pegs.

6



You may be asked to dissect the mouthparts of a cockroach in the laboratory and this is what your final dissection should look like. The parts are arranged in the order of segmentation from anterior (bottom) to posterior (top). The hypopharynx is the only part that is not a true segmental appendage but rather a modified part of the prostomium (foregut).

7

REVIEW

Can you recognize the following?

- antennae
- clypeus
- eye
- frons
- labial palpi
- labrum
- mandible
- maxillary palpi

8

REVIEW

Here's a better challenge. This is a lateral view of a cockroach head with the mouthparts extruded. Which of the following can you recognize?

- antennal base
- clypeus
- eye
- galea
- hypopharynx
- labial palp
- labium
- labrum
- mandible
- maxillary palp

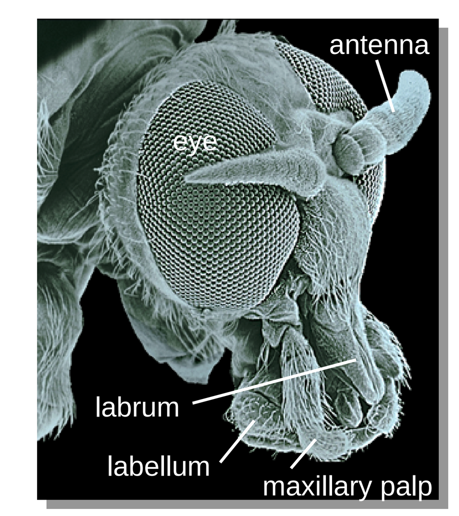
9

This completes our review of basic insect mouthparts as found in the American cockroach (*Periplaneta americana*). Make sure that you understand this basic plan before proceeding.

The rest of this module on mouthparts shows how various insect groups have used the basic mandibulate ground plan to produce highly modified mouthparts exquisitely adapted to their own way of obtaining food.

10

Dipteran mouthpart modifications

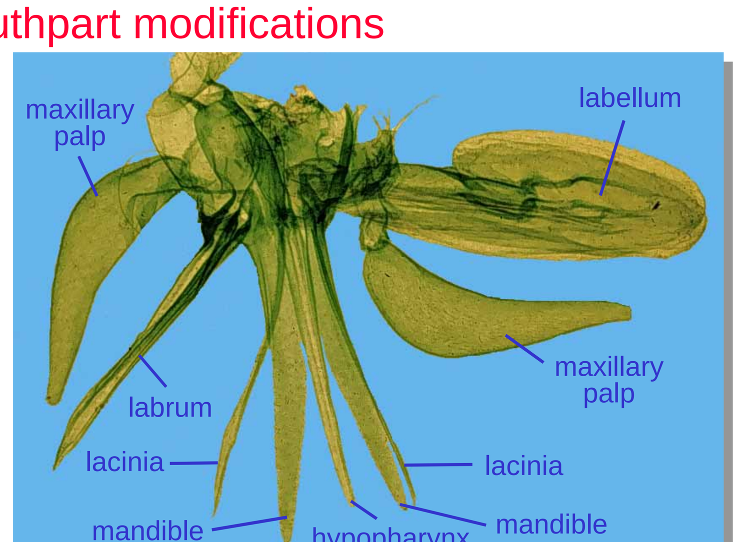


Black flies (Simuliidae) are small insects but their mouthparts are relatively large. All of the parts are present in adults but they are greatly modified from the basic plan. The labellum is used for nectar feeding but the labrum, lacinia, and mandibles are modified as piercing structures for blood feeding. The relatively large wound and the antigenic properties of the salivary proteins lead to ugly skin reactions.

11

Dipteran mouthpart modifications

horse fly adult - dissected mouthparts (*ex.* micro-slide)

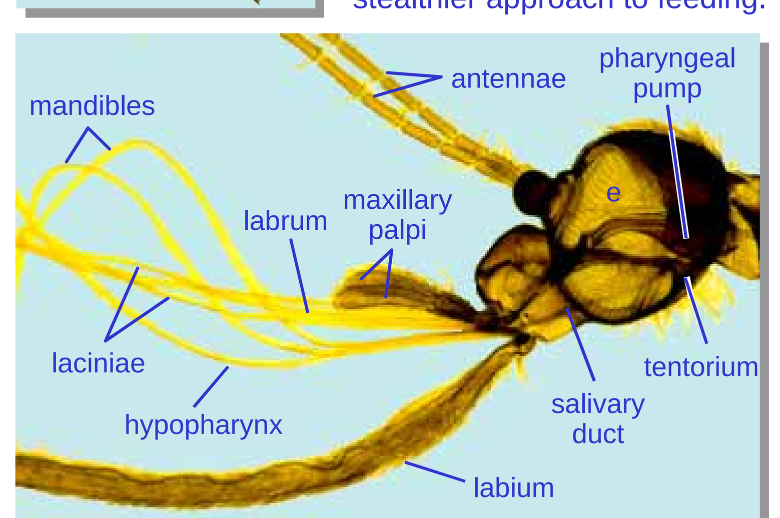


Horse flies (Tabanidae) have the same kinds of mouthpart modifications as black flies, but since they are larger, are easier for us to study (their bite also causes more physical damage). All of the basic parts can be seen here and don't resemble the mouthparts of the cockroach. Nevertheless these are the appendages of the same segments - the result of the same basic developmental plan.

12

Dipteran mouthpart modifications

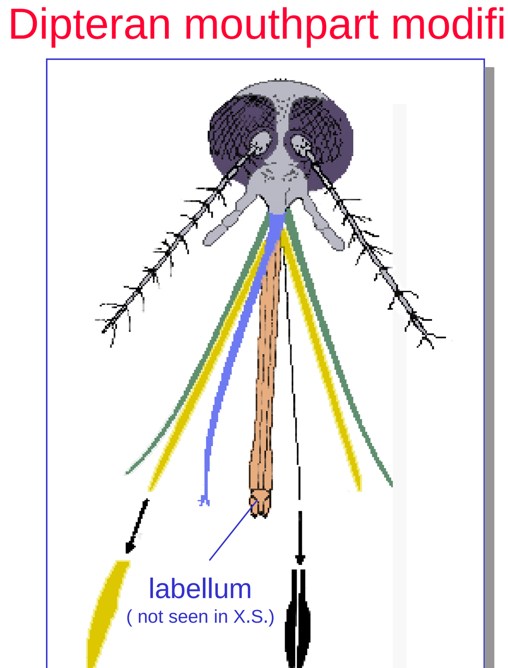
Mosquitoes have carried the business of piercing and sucking to a fine art. The stylets are modified labrum, maxillae, hypopharynx and mandibles, just as in horse flies and black flies, but the cross section size is markedly reduced making for a much stealthier approach to feeding.



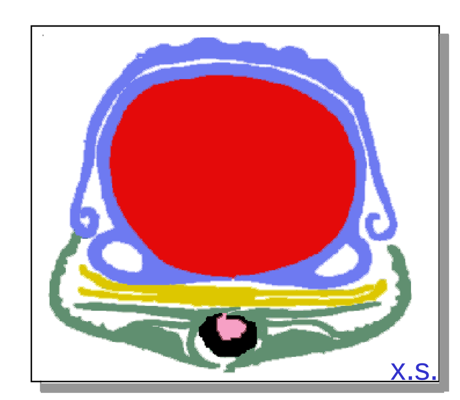
Only female mosquitoes take blood. Males do not possess the necessary m.pts. The mosquito shown has all m.pts hence is a female. Both sexes suck nectar, and possess the large labellum.

13

Dipteran mouthpart modifications



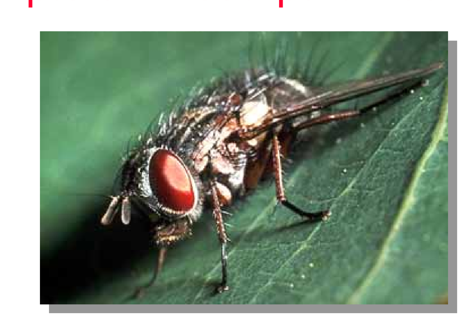
Mosquito head and mouthparts - frontal view



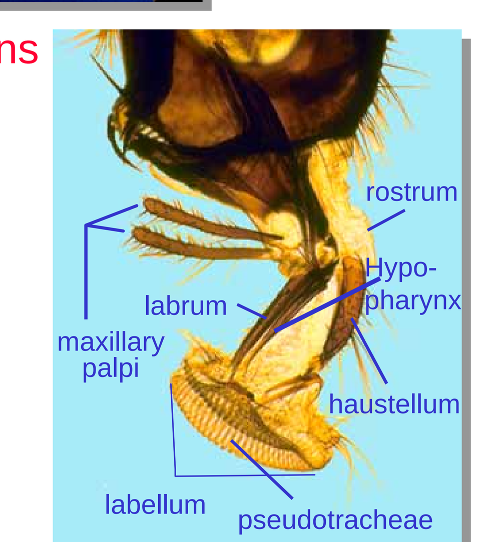
Maxillary stylets- green
Labral stylet - blue
Mandibular stylets - yellow
Food canal - red
Salivary canal - pink
Hypopharynx - black
Labium - tan

14

Dipteran mouthpart modifications



The higher flies (house flies and relatives) have lost the mandibles and maxillae, except for the maxillary palpi. They specialize in modifications of the labial appendages only to produce sophisticated lapping, probing, scraping and piercing mouthparts. Most of them cannot pierce host skin but some, like the tsetse fly (later slide) can.



The fly labellum is a complex sensory organ and feeding structure looking something like a sock. It's dexterous being controlled by numerous small muscles.

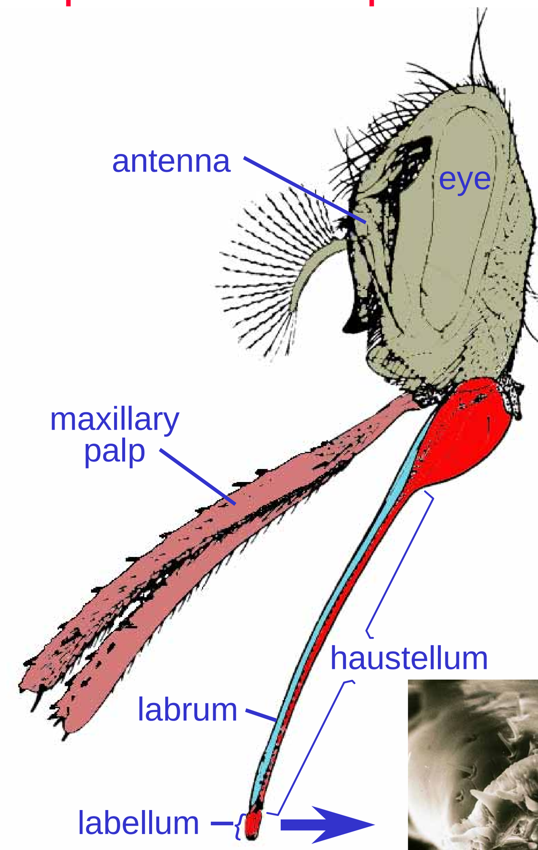
15

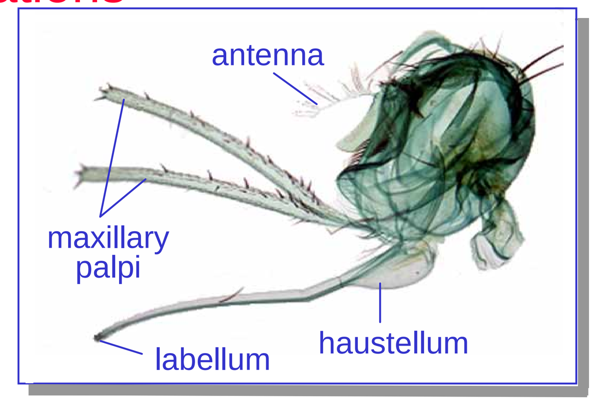
Dipteran mouthpart modifications

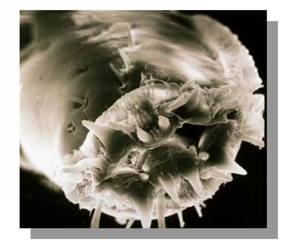
This SEM (Scanning Electron Microscope) micrograph of a flesh fly labellum shows the sensory hairs that cover the surface of the oral surface of the lobes. These sensory hairs taste sugars, salts, amino acids, water and other chemicals as well as conferring a delicate sense of touch on the whole organ.

16

Dipteran mouthpart modifications



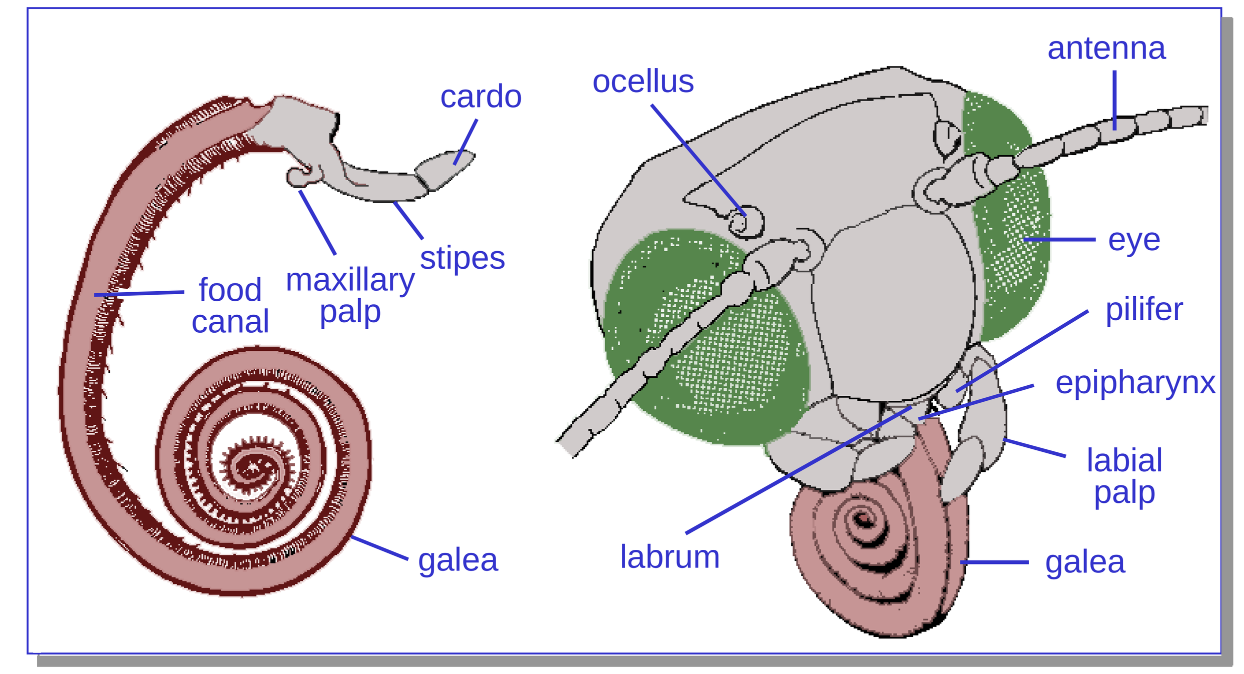




Tsetse flies have carried labellar modification to an extreme unmatched by any other insect. The fine labellum with its tooth bearing tip makes a needle-like penetration of the host skin.

17

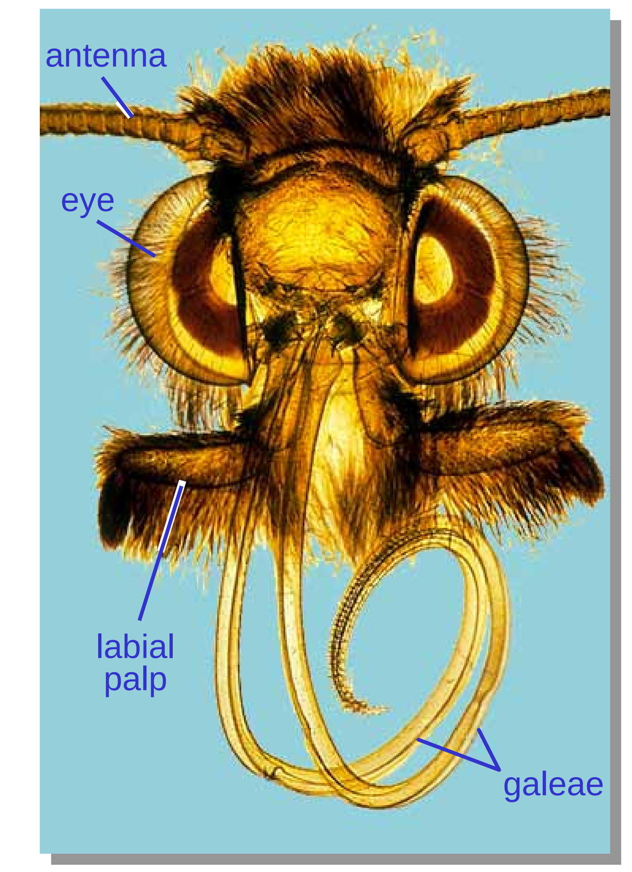
Lepidopteran mouthpart modifications



In moths and butterflies the sucking mouthpart is largely the modified maxillary galeae. The area along the food canal is lined with taste pegs. The maxillary palpi are much reduced and mandibles are absent.

18

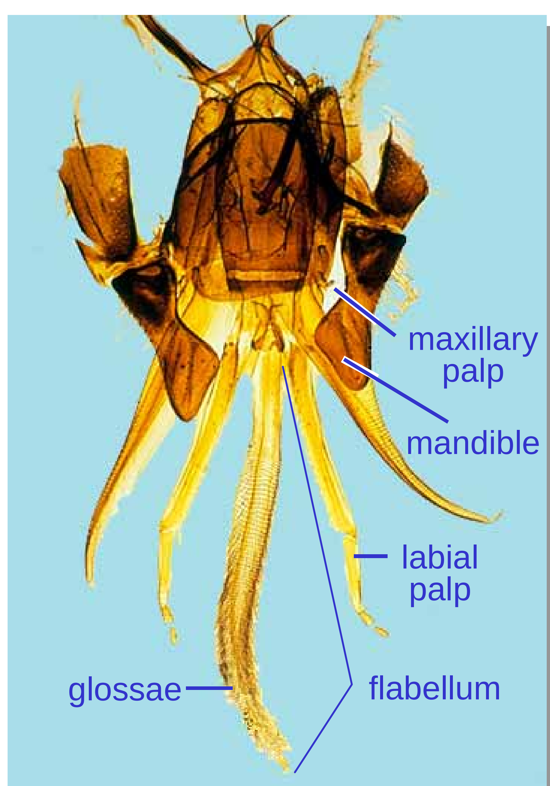
Lepidopteran mouthpart modifications



The real thing looks different from the previous drawing of course. For one thing, moths and butterflies are covered with scales (modified cuticular hairs), as seen in this cleared lepidopteran head. The large labial palpi are sensory, in fact, in some specialized nocturnal moths the organs of hearing are also on the palpi. The galeae are separated in this preparation. During feeding, they are held close together to form a sucking tube.

19

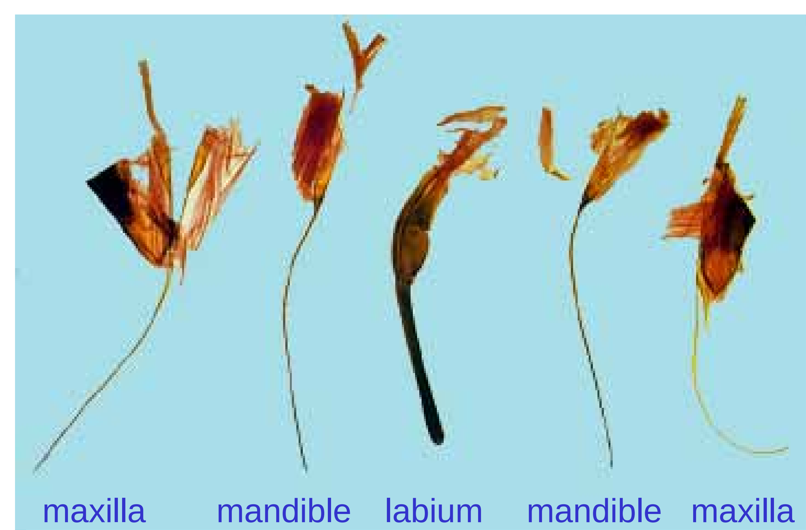
Hymenopteran mouthpart modifications

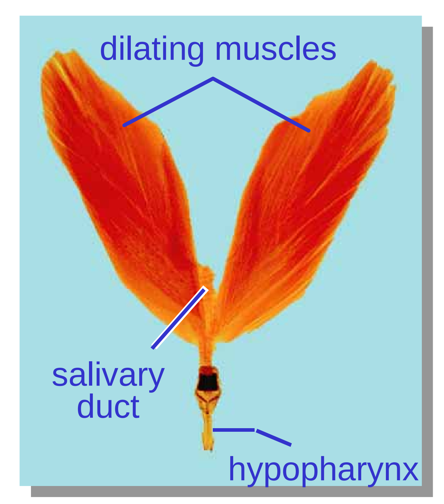


The sawflies, bees and wasps have various arrangements of mouthparts, the most complex being those of bees (photo at right). Like lepidopterans, bees use a tube to suck nectar but they are modified glossae (part of the labium). Mandibles are retained primarily for handling wax - in fact, the structure of the mandibles gives rise to the precise hexagonal arrangement of the cells in the honeycomb.

20

Hemipteran mouthpart modifications





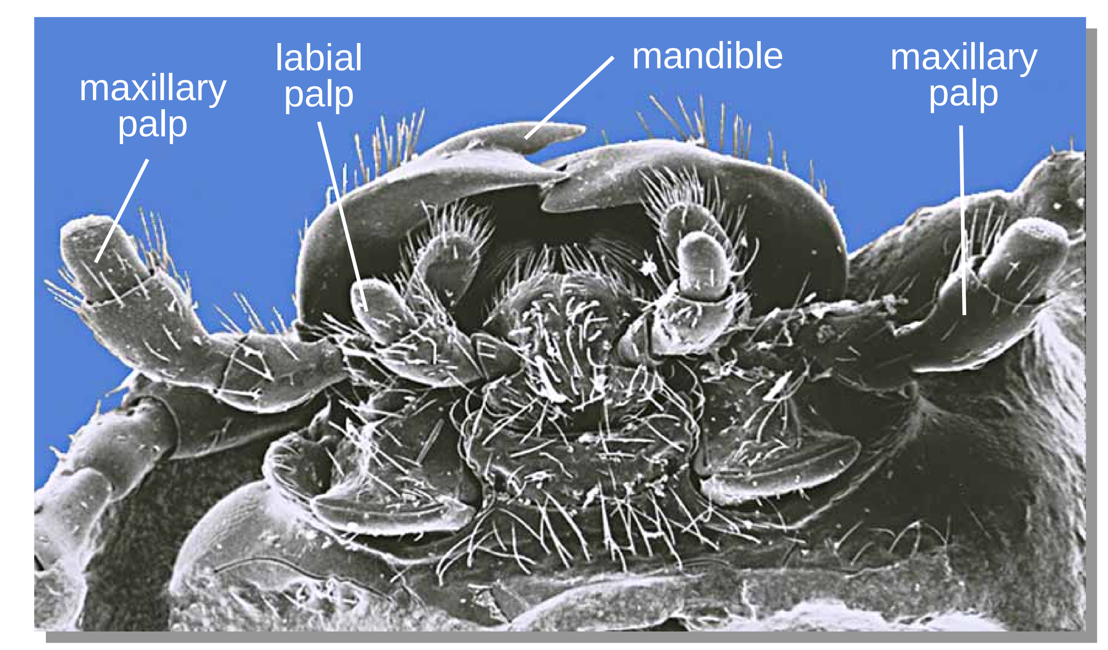
Insects with incomplete metamorphosis also use highly modified mouthparts as shown in the true bugs and their relatives. These are used for piercing and sucking and are similar in some ways to the modifications seen in mosquitoes. The large dilating muscles of the sucking pump are the largest muscles in the bug head.

21

This concludes our survey of mouthpart modifications. In several places we mentioned that sensory structures were present on certain mouthparts, such as palp tips. In fact, one of the greatest concentrations of chemosensilla is found on the mouthparts - the other major site being the antennae.

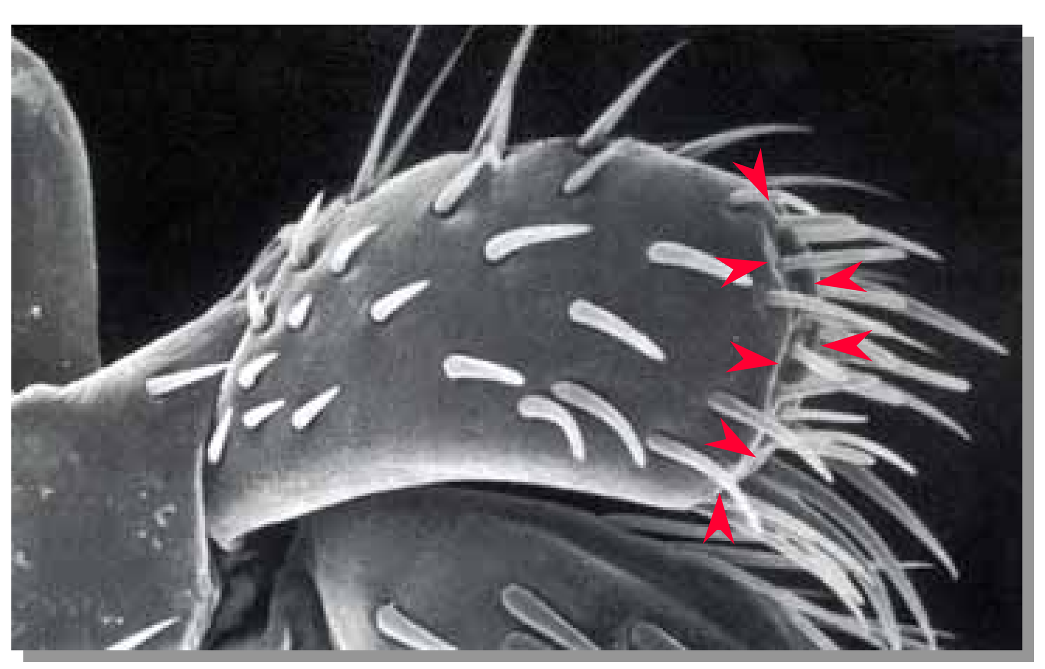
In the next section, we look in detail at some sensory structures and comment briefly on their function. The study of sense organs has major implications for pheromone biology, insect-plant interactions and the chemical modification of feeding by the use of antifeedants.

22



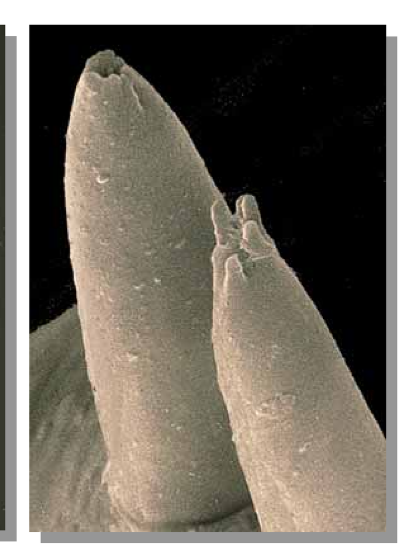
If you have been studying this module carefully, you will likely be able to quickly make sense of this ventral view of the head and mouthparts of a leaf beetle (Chrysomelidae). Leaf beetles chew leaves hence have strong mandibles. The palpi are well developed for sensory purposes as are parts of the labrum and the galea.

23

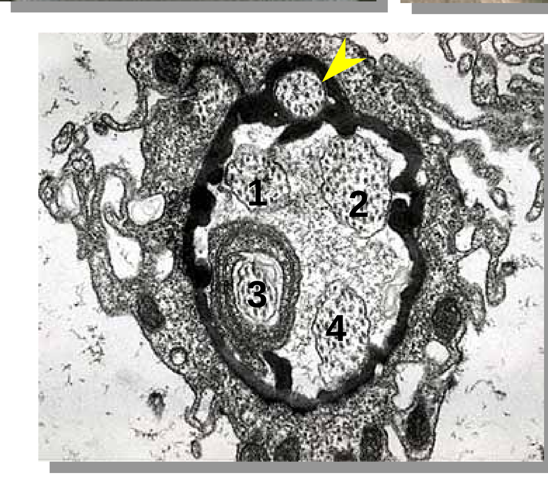


Galeae of leaf beetles have specialized taste hairs with rounded tips (red arrowheads). These are used to taste leaves before a decision is made to take a meal. Leaves of poor host plants don't taste right to the beetle so small meals are taken. Leaves of host plants are assessed quickly and extended feeding occurs.

24

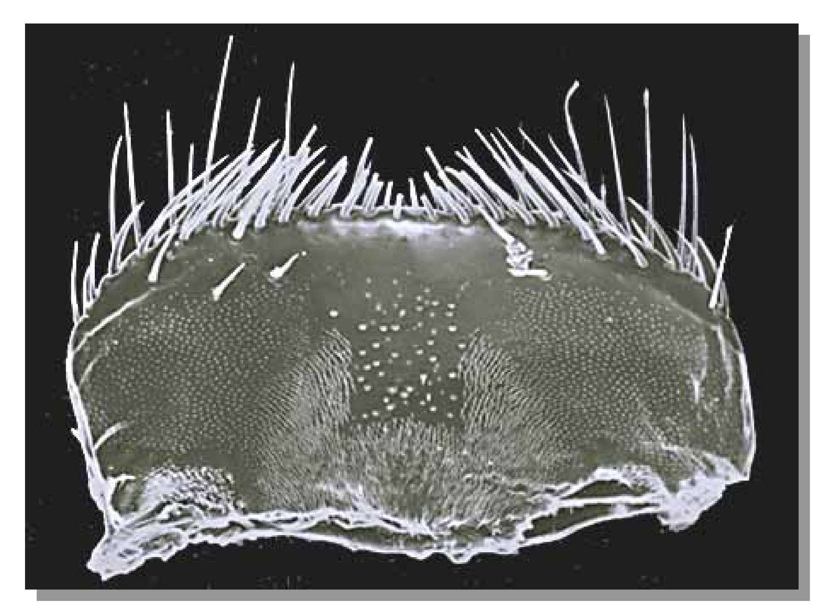


These two examples of taste hairs were taken from leaf beetle galea. The pore in the tip is where the leaf juice enters in order to be tasted. The sensillum with the little fingers in the right hand picture does not have much of a pore and is probably used to sense temperature and humidity.

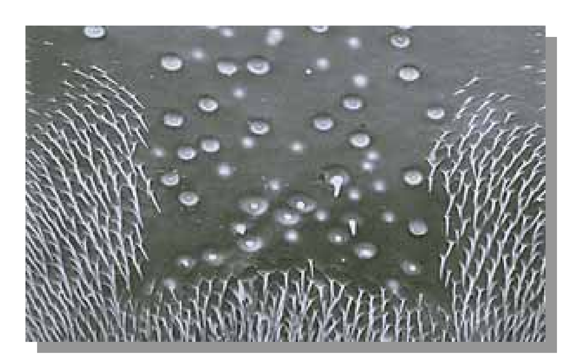


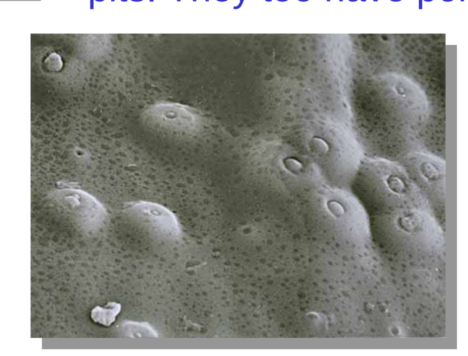
Inside the large taste hairs we find the sensory cells, as this electron microscope cross section through the base of the larger sensillum at top right shows. The four numbered cells are chemosensory while the one marked with a yellow arrowhead is mechanosensory. Most taste hairs in insects can also sense movement.

25

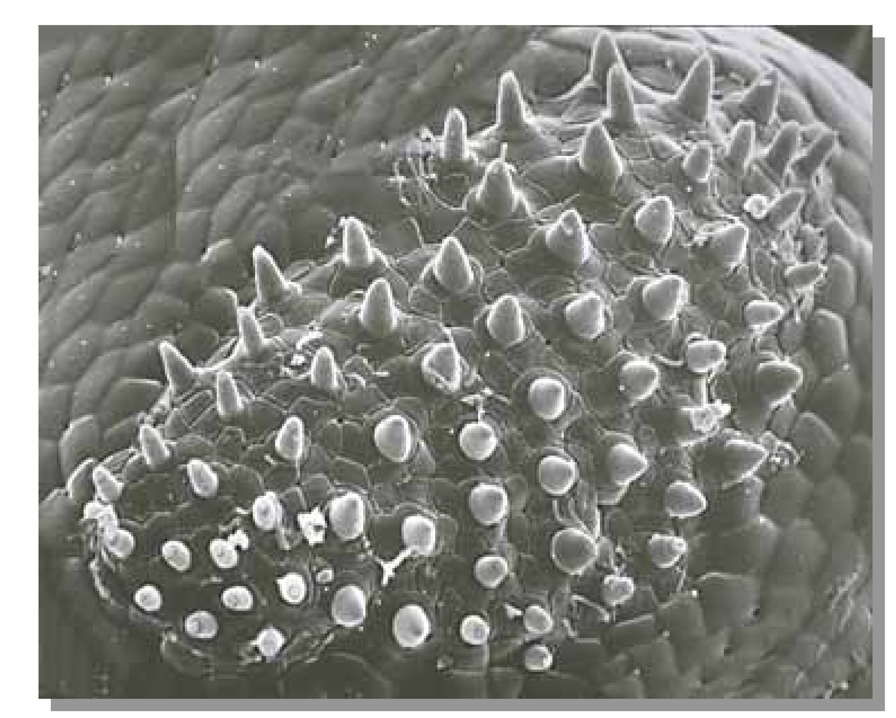


This series of increasing magnifications are taken from the inside of the labrum (epipharynx) of a leaf beetle. The epipharynx forms the anterior surface of the buccal cavity (roof of the mouth so to speak) and it also bears taste-sensitive structures. These sensilla are not hair-like but take the shape of short pegs-in-pits. They too have pores.





26



The most obvious of the mouthpart sensory structures are the palpi (maxillary and labial). In leaf beetles, the palp tips provide four surfaces that are covered with small sensory pegs - some for taste and some for smell.

27

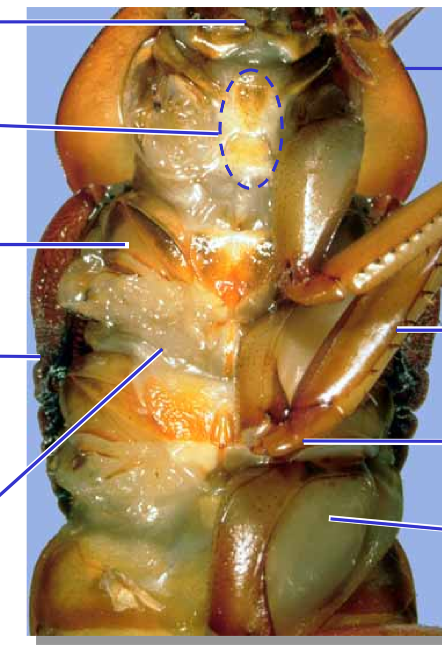
The Insect Thorax and Abdomen

In the simplest terms, the thorax is the locomotory centre of the insect since all six legs and the wings are found there. The largest muscles are also found in the thorax. The thorax is a box-like structure with extensive internal cuticular cross bracing. It also sports numerous cuticular plates (sclerites) that are intimately involved in locomotion. To conserve mass, some of the thoracic muscles are involved in both walking and flying. This works because these are mutually exclusive behaviours and the motor nervous system plays the appropriate motor program at the appropriate time. The abdomen is simple in its anterior region getting quite complex in the last three segments where the sclerites of the external reproductive system are found. Both male and female insects have extensive cuticular modifications for reproduction, females particularly for oviposition (egg laying) and males for sperm insertion. Many insects can be identified at the species level only by looking carefully at the male genitalia.

Supported in part by
Academic Technologies for Learning
and Faculty of Science, University of Alberta

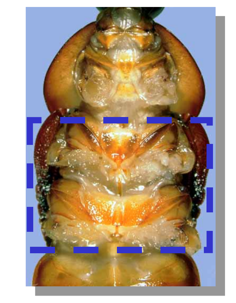
B.K.Mitchell and J.S.Scott
Department of Biological Sciences
University of Alberta

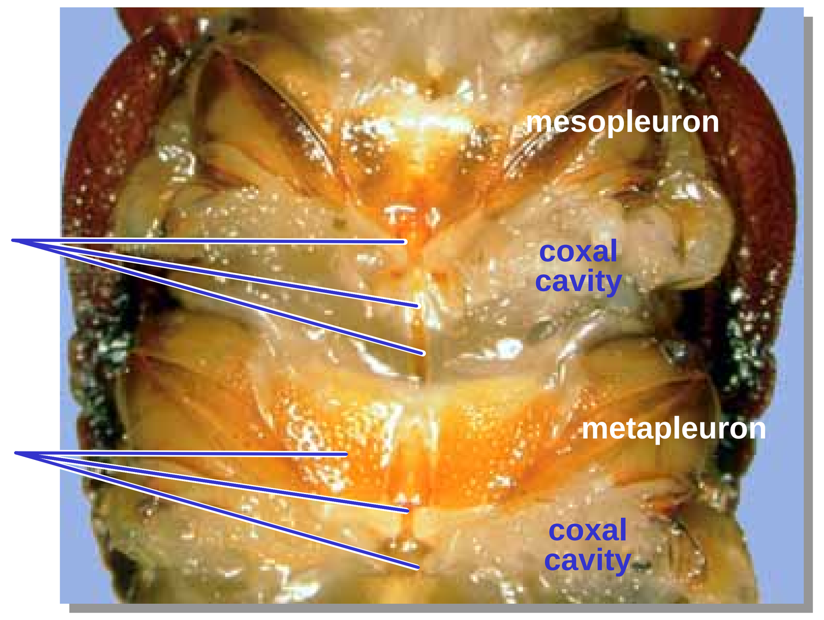
Ventral View of *Periplaneta* Thorax



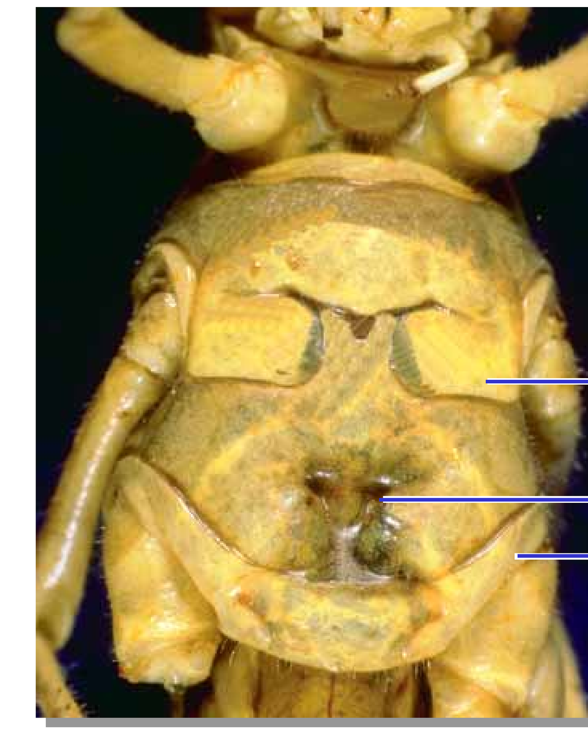
1

Meso- and Metathoracic Segments of *Periplaneta* - ventral view





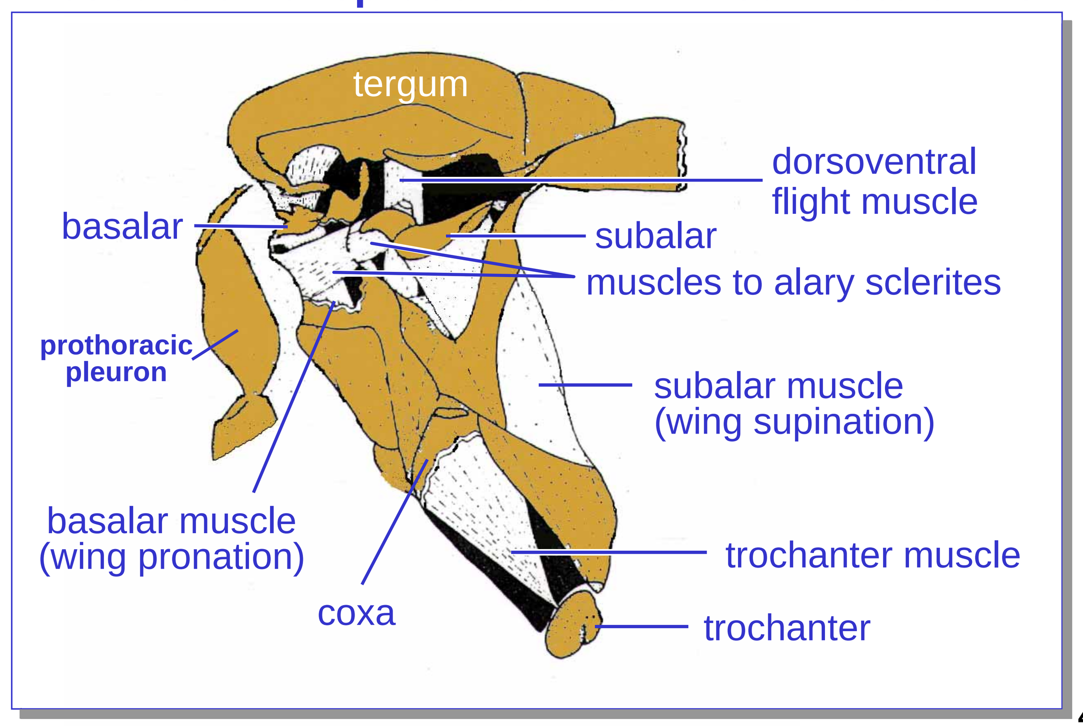
2



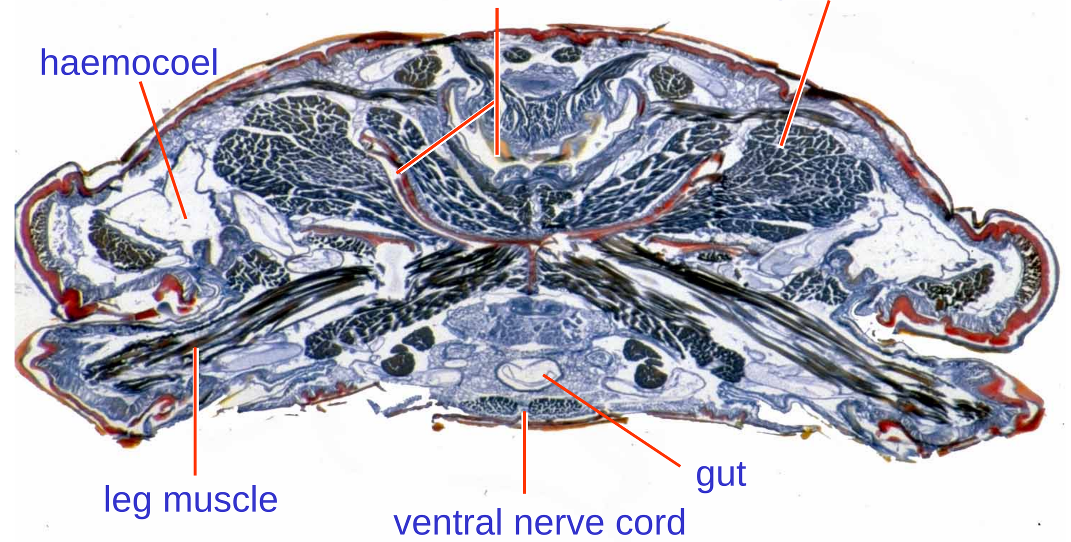
Grasshoppers are much stronger flyers than cockroaches and this is clearly reflected in the structure of the thorax. Note the greater fusion of the ventral thoracic sclerites to form a strong pterothoracic "box" to support flight.

3

Mesothorax of spruce budworm moth - lateral view

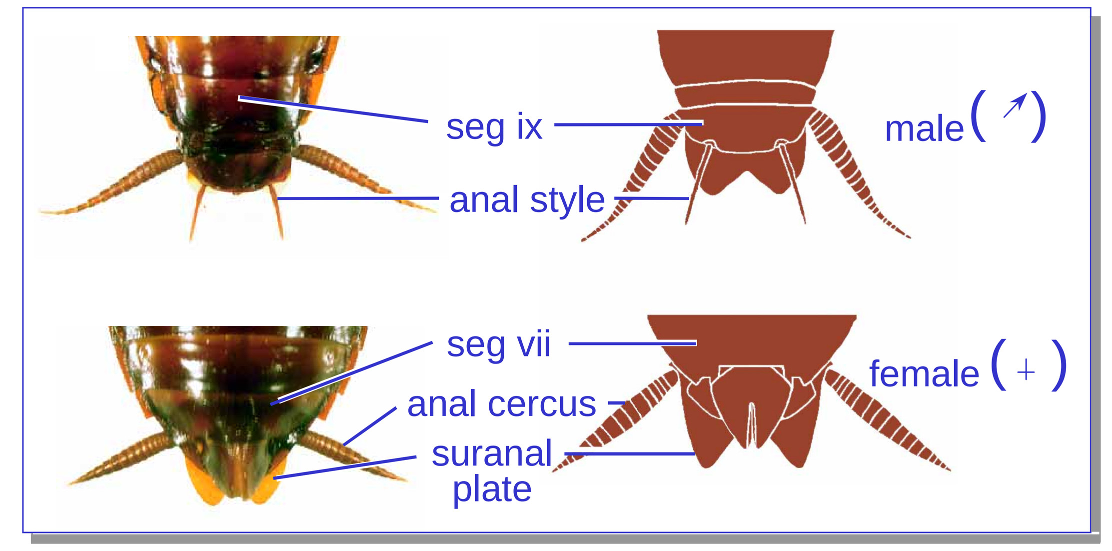


4



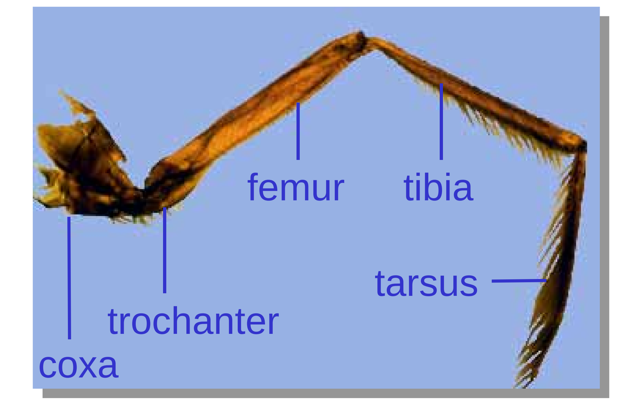
Cross section through the thorax of a cockroach showing some major internal structures. Note the size of the muscles and that some are cut in longitudinal section while others are cut in cross section.

5



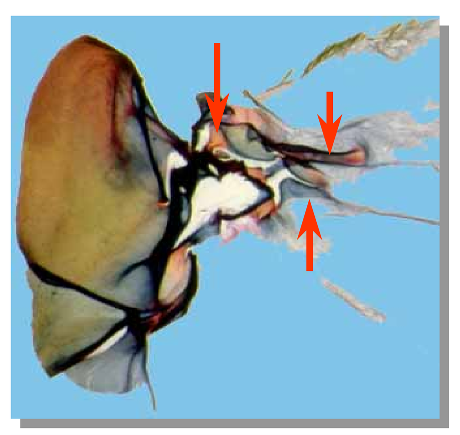
As with most insects, the cockroach abdomen is composed of a series of similar segments until the terminal end where sex complicates things. Mating behaviour, pheromone production, egg production and release are all handled largely by the abdomen and particularly by modifications of these last abdominal segments. The male and female cockroach abdominal tips shown here clearly reveal some obvious differences.

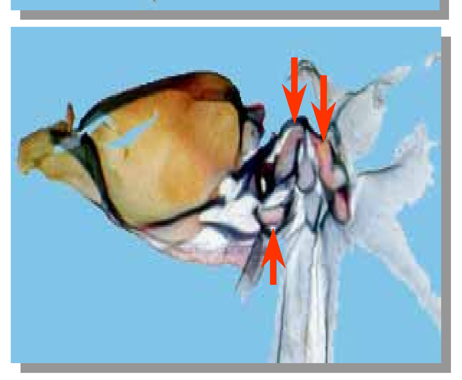
6



Insect legs have numerous adaptations that depend on the insect's lifestyle. Here are two examples. At top, a leg from an aquatic bug (note the numerous fine hairs that spread for swimming). It is also used to name the basic leg parts. At bottom, raptorial forelegs from a mantispid used for seizing prey then clamping it during feeding.

7

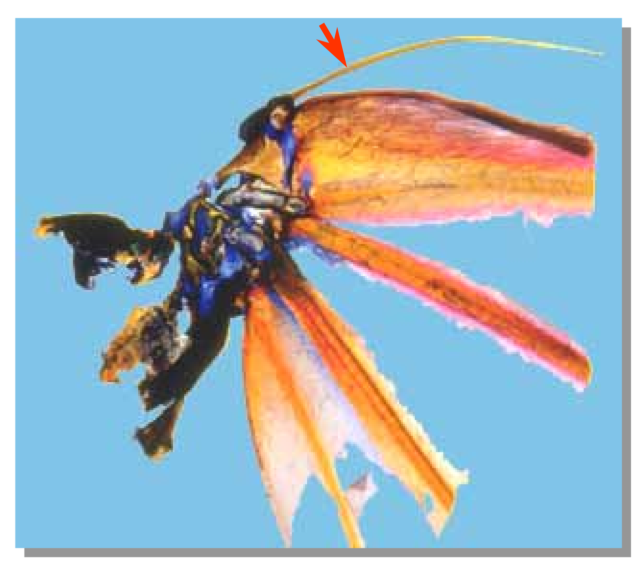




The Wing Base

The wing must move with great dexterity if the insect is to fly properly. The axillary sclerites (red arrows) provide a major part of this complex attachment and the muscles that insert on them are responsible for small but crucial movements of the wing in flight. This sclerite/muscle system is also involved in wing folding.

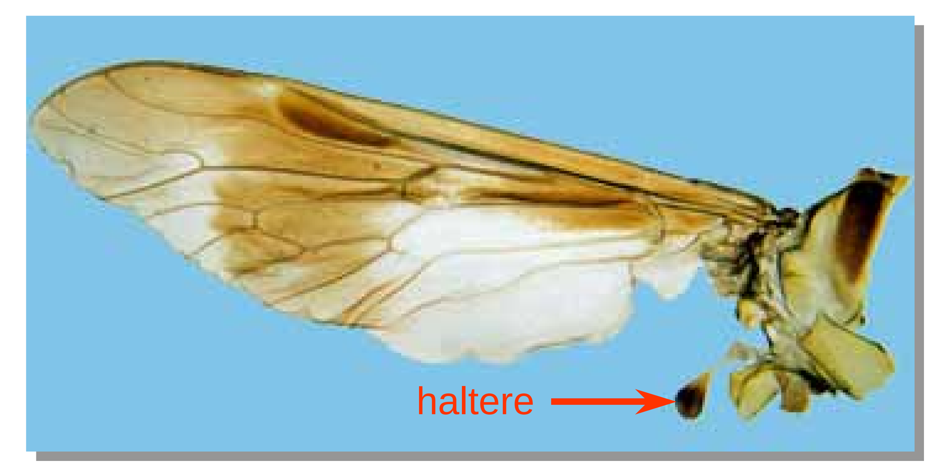
8



Most insects have four wings which either beat quite independently as in dragonflies or with varying degrees of unity. The front and hind wings of moths are strongly linked together and the hind wing has a strong structure called the frenulum (red arrow) that is part of the linking apparatus. It hooks into a process on the front wing called a jugum (in jugate moths in any case).

In the honeybee (not shown), the hind wing has little hooks that look very much like the hooks in a Velcro strip and the fore wing has a corresponding surface for attachment.

9



Diptera (true flies), as you can see from the name, have two wings instead of four. In flies, the hind wings take the form of dumbell shaped structures that act as balancing organs during flight. These highly modified and specialized hind wings are called halteres

10

Wing veins provide support for the thin, delicate membranous cuticle that make up the rest of the wing, as shown here by these two wings from a horse fly. Many veins also house tracheae and provide a passage for haemolymph (blood). Numerous sense organs are found on the wings, especially wind sensitive hairs, and the cells in these organs must respire and receive nutrients. Accessory hearts at the base of the wing provide a sometimes complex flow of haemolymph in the veins. Wing veins can also be important taxonomic characters at the Family level.

11

Respiration in insects is mediated by a complex, multi-branched tracheal system. The tracheal tubes (tracheae) are epidermal in origin and so are lined with thin cuticle. They communicate with the outside via segmental openings called spiracles found on the thorax and abdomen. When present, there are two spiracles per segment. Not all segments have spiracles, for example, compare the spiracles in an adult cockroach and an adult fly. These photos show examples of spiracles and associated tracheae. The spiracle on the right has a filter system to prevent entry of dust. Many spiracles have complex opening/closing mechanisms.

12

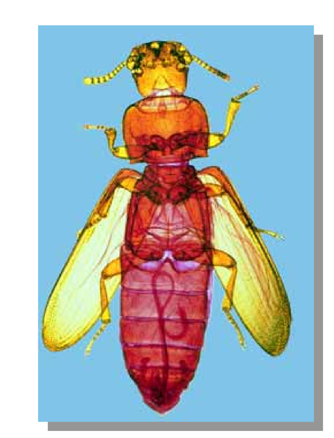
Mating behaviour in insects is often a complex business that is a critical part of the species isolating mechanism. Thus, intricate behaviours correctly performed signal species identity.

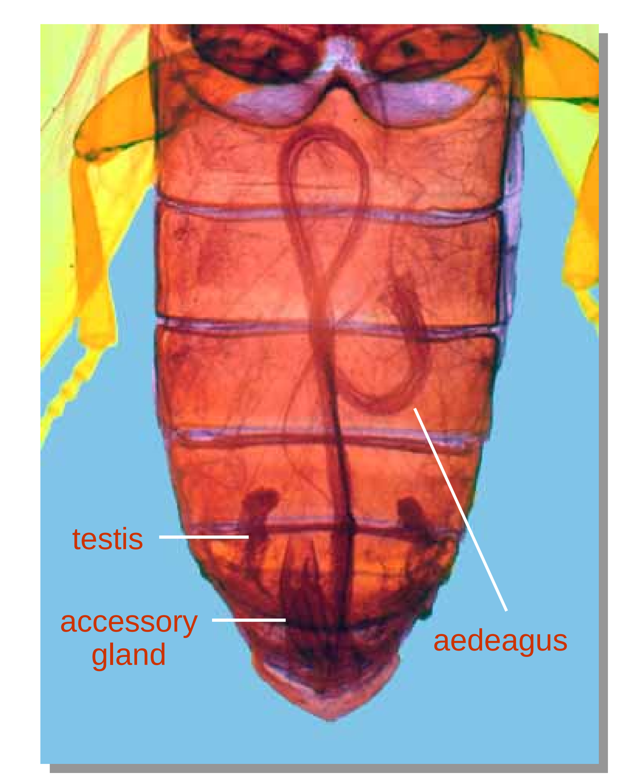
In addition to behaviour, the structure of the last few abdominal segments plays a major role in species recognition. Here two craneflies are locked in copula. Specialized sclerites of the last three abdominal sclerites (terminalia) allow only members of the same species to proceed this far.

13

In the Odonata the male actually grabs the female by the prothorax (damselfly) or top of the head (dragonfly) during mating. As they fly or perch, the female reaches around with her abdomen and takes sperm from a specialized holding pouch near the junction of the male thorax and abdomen. These are damselflies.

14

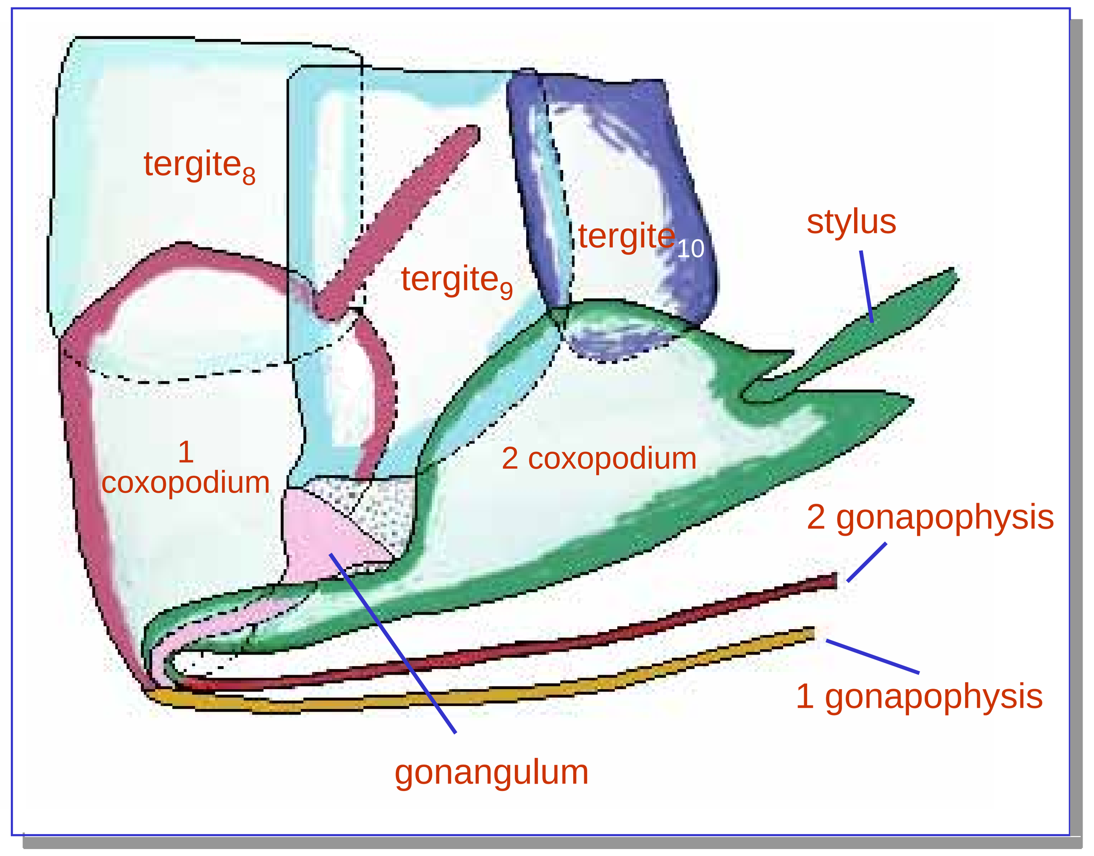




Insects often have rather astonishing reproductive structures, especially the male intromittent organ or aedeagus. In this flour beetle the aedeagus is withdrawn into the abdomen when not in use.

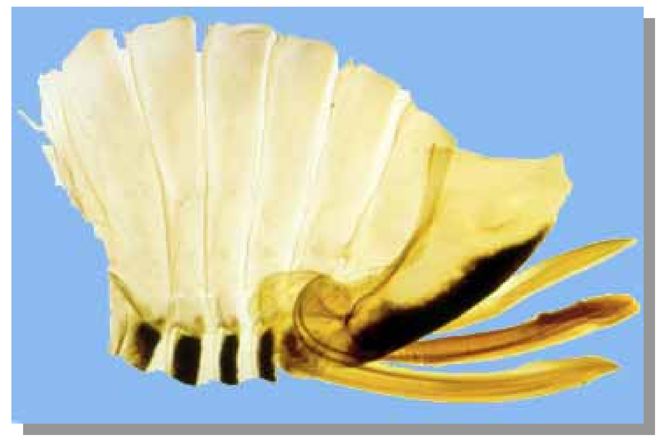
Continued on next poster

15



This drawing shows, in generalized form, the way female abdominal segments 8, 9 and 10 are modified for egg laying. Along with mating, egg laying requires extensive modification of sclerites.

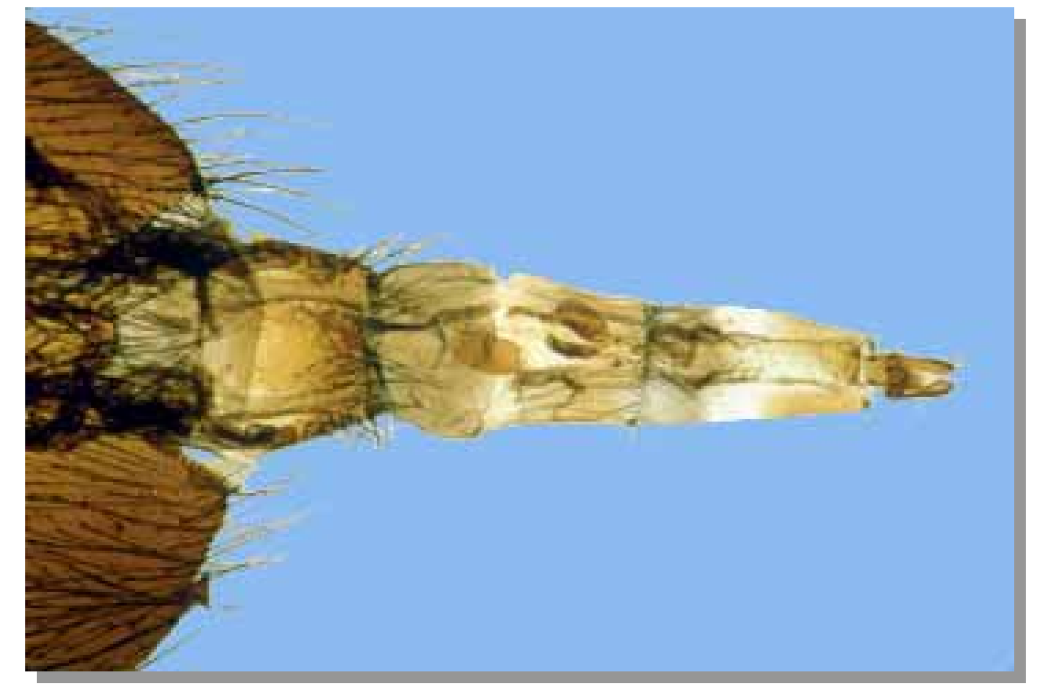
16



In these views of actual specimens you can identify some of the cuticular parts shown in the drawing of the generalized female abdomen. This specimen is a leafhopper.

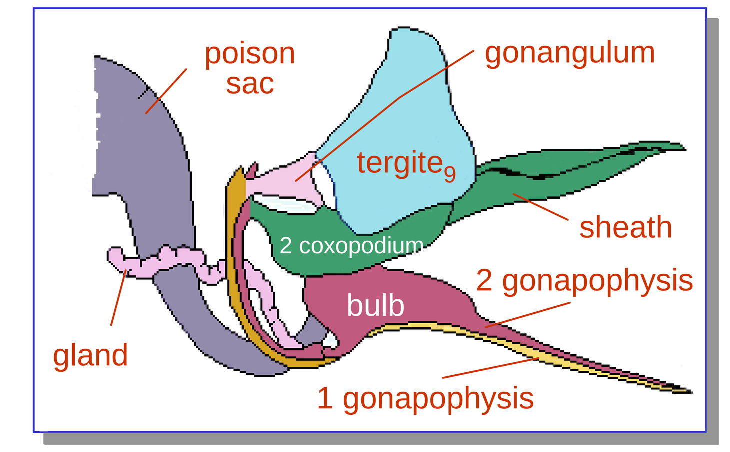
Parasitic wasps take the business of ovipositor modification to an extreme but all of the basic parts are there. 50% of all wasps are parasitic on other insects and need to lay their eggs with great precision since many are quite host specific.

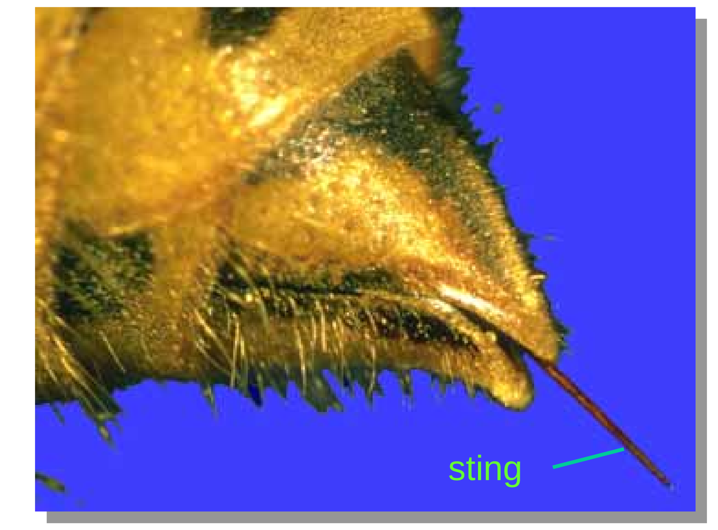
17



Flies, such as this housefly, have a different version of the ovipositor. The last few abdominal segments telescope into the larger anterior abdominal segments except when the fly is laying eggs. Then these segments are extended as shown here.

18



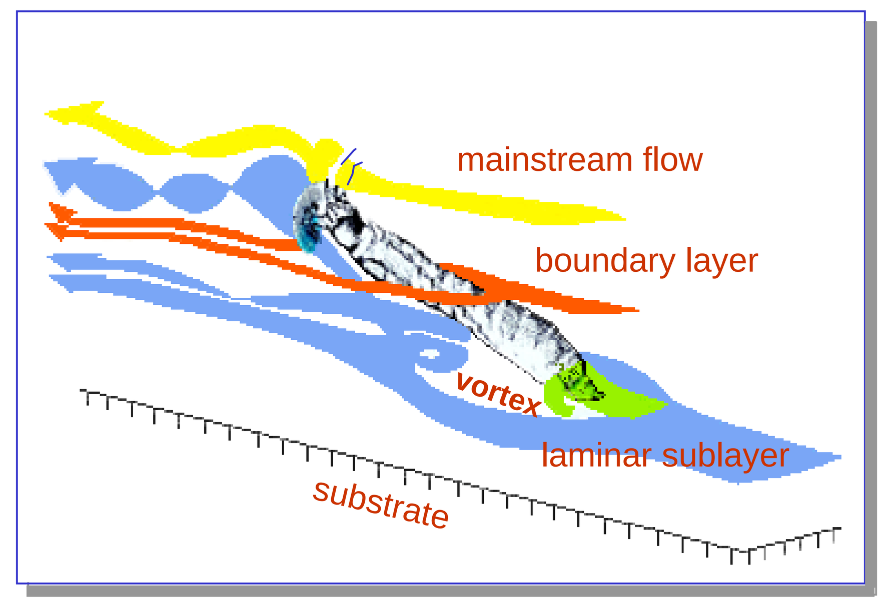


In bees, the ovipositor function is subsumed by the sting which is served by a poison gland. Oviposition is through a simple opening.

19

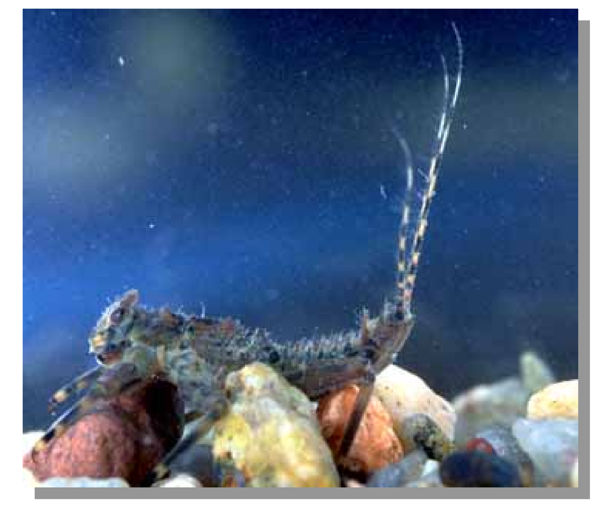
Male and female abdomens are also variously modified, mostly for, in the case of the male, holding the female in position during copulation and in the female accepting the male during copulation and also for oviposition (egg laying).

20



The entire abdomen can also serve important functions in arthropods. The tail flick that is part of the escape response of the crayfish is perhaps the best known (it's part of the reason that lobster tails are such good eating). Here is another use of the whole abdomen displayed by black fly larvae. They twist their abdomen 180 degrees so that their feeding fans can be properly oriented in the mainstream water flow.

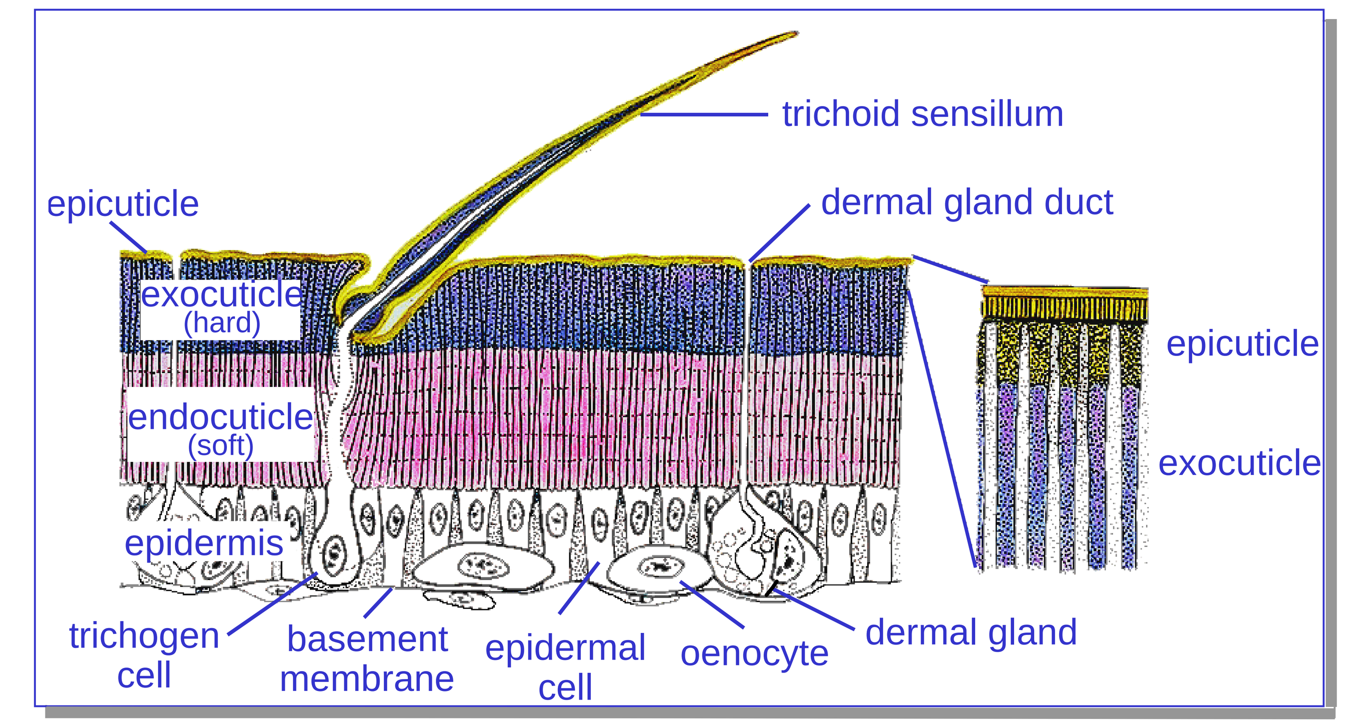
21



Many aquatic insects use special adaptations of the last abdominal segments for orienting in the stream or for breathing. Notice how this mayfly nymph uses its caudal filaments for orientation.

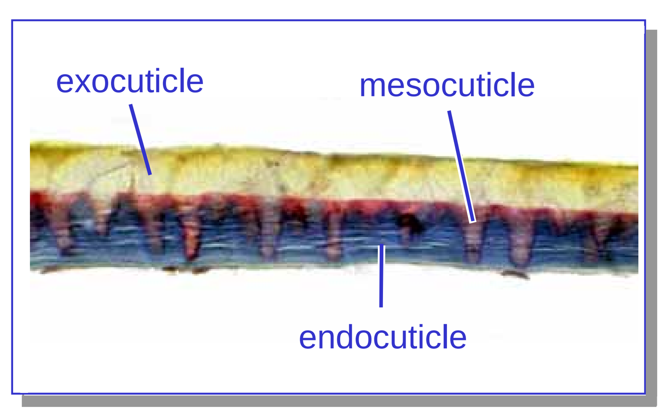
Requirements of internal organs also influence the shape of the abdomen. The midgut of this mosquito is so full of blood that the abdomen is swollen to near maximum size (cuticle does not stretch). A large egg load can also swell the abdomen like this.

22

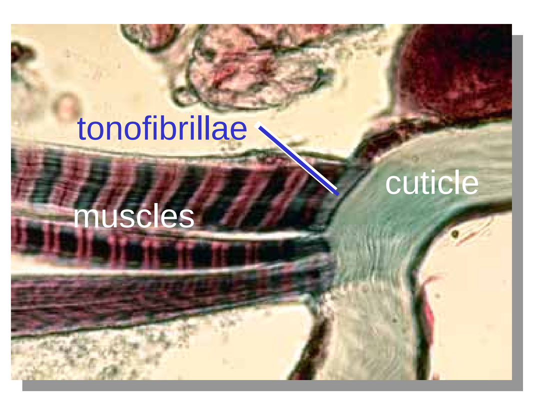


The head, thorax and abdomen are covered with cuticle as are the foregut, hindgut and tracheal system. These are the basic components of insect cuticle that you should be familiar with. The epicuticle provides a continuous wax covering to prevent desiccation. The exocuticle is a mix of chitin (like cellulose) and tanned protein. You can see why it won't stretch. The endocuticle, including mesocuticle is flexible and elastic.

23



This is a section of bending cuticle. As you can see, it is not exactly like the previous drawing. Not all cuticle looks alike. Some is very thick, others thin. Some cuticle has well developed mesocuticle, as shown here. The blue endocuticle is elastic, so this cuticle is highly bendable.



As the functional skeleton of arthropods, the cuticle is the primary place for muscle attachment. This section shows how intimate is the connection between muscle and cuticle. Muscle extensions called tonofibrillae make the actual link. At moulting, these connections must remain functional until the last moment when new connections are established with the new cuticle developing beneath the old.

24

The spectacular picture of a wing base of a moth, shows a top view of bending cuticle. The yellow ovals are the cones of mesocuticle protruding down into the blue endocuticle, so this particular sclerite is very flexible. The large areas of yellow cuticle are exocuticle and are relatively hard.

25

INTRODUCTORY ENTOMOLOGY
Biological Sciences
University of Alberta

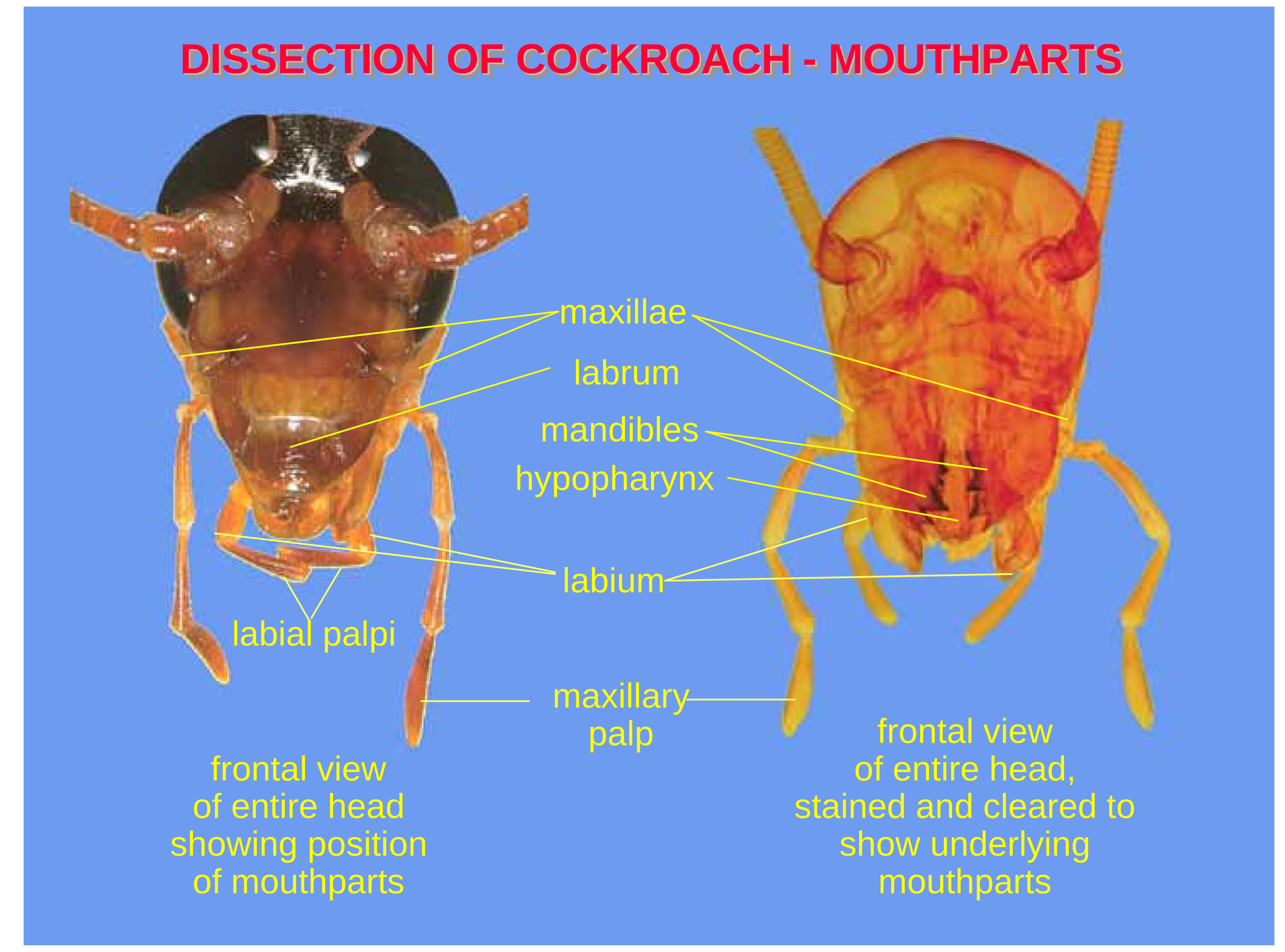
Cockroach Dissection

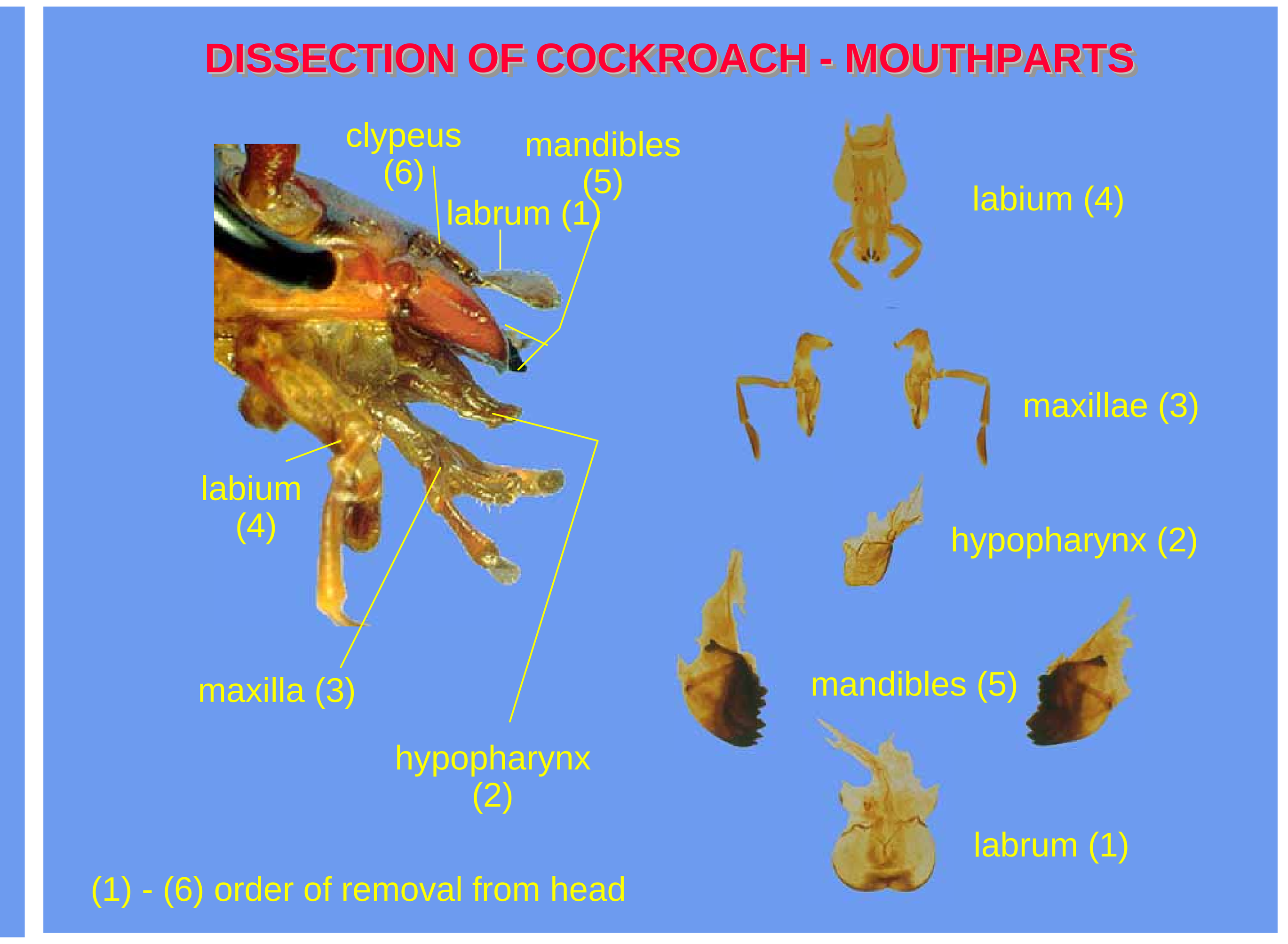
While it is impossible to chose an insect species that truly represents the morphology of all, the cockroach has gained a commanding position as the insect of choice for illustrating the 'basic' insect body plan. Another strong contender for this role is the grasshopper. Even terms like 'the cockroach' and 'the grasshopper' are terribly misleading, since there are many species of each with sometimes marked differences in various structures. Nevertheless, cockroaches and grasshoppers are good representatives of insects with chewing mandibles and lacking extreme morphological specializations of the major body parts.

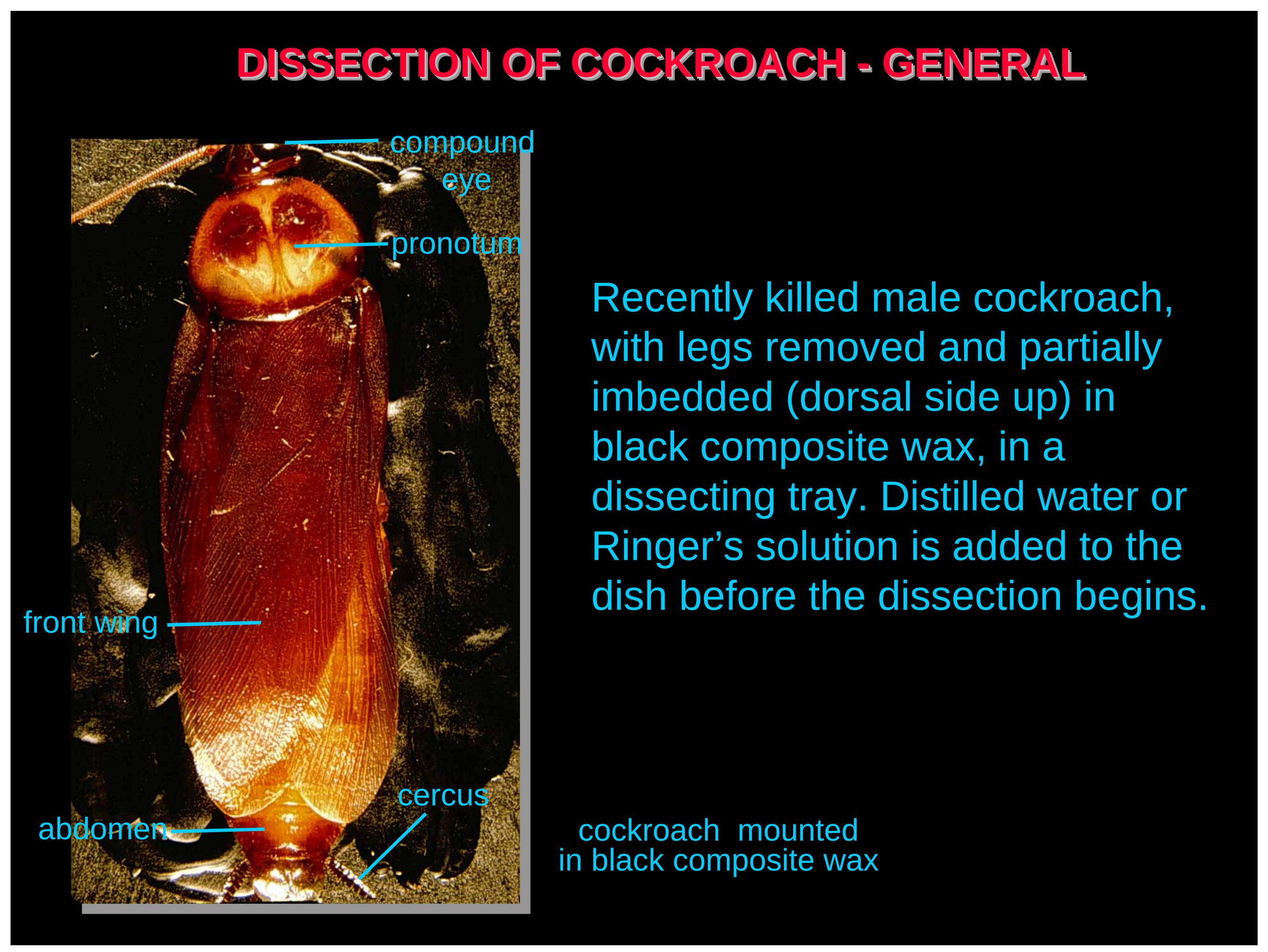
Here we address the major external and internal parts of the American cockroach, *Periplaneta americana*. Some of the terms will be new but many will be strikingly familiar for they are named after their, sometimes very approximate, counterparts in vertebrates.

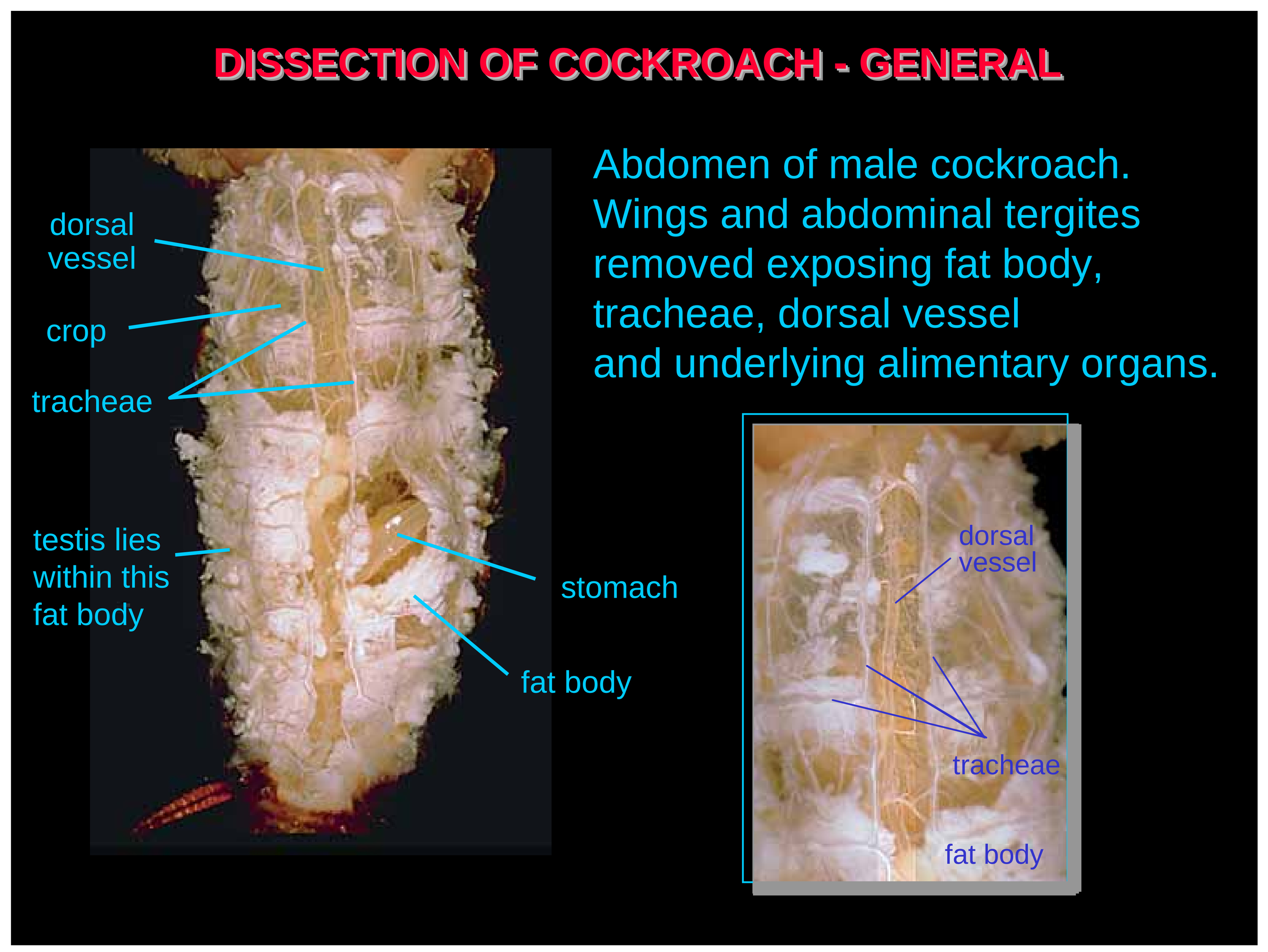
Supported in part by
Academic Technologies for Learning
and Faculty of Science, University of Alberta

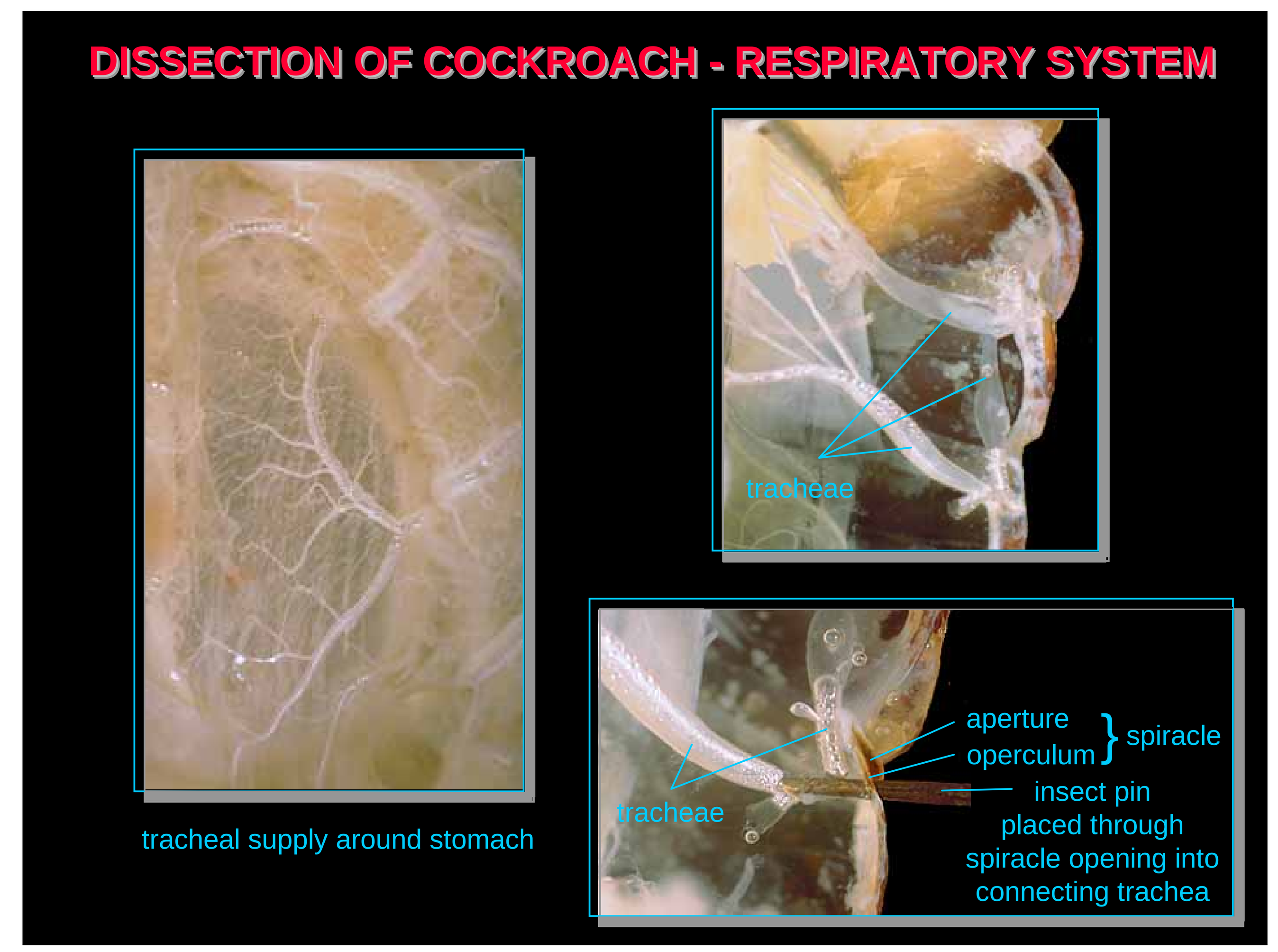
B.K.Mitchell and J.S.Scott
Department of Biological Sciences
University of Alberta

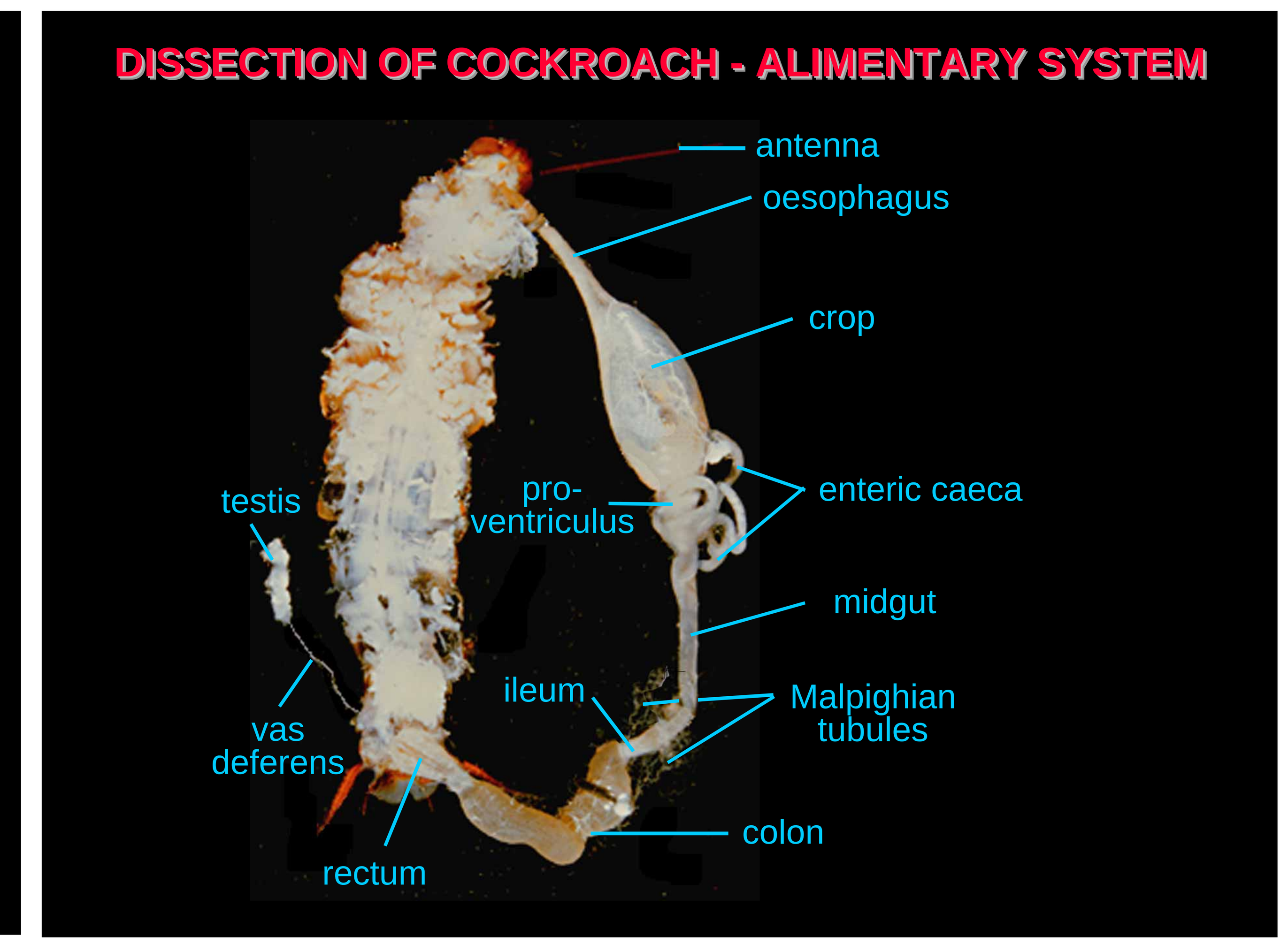


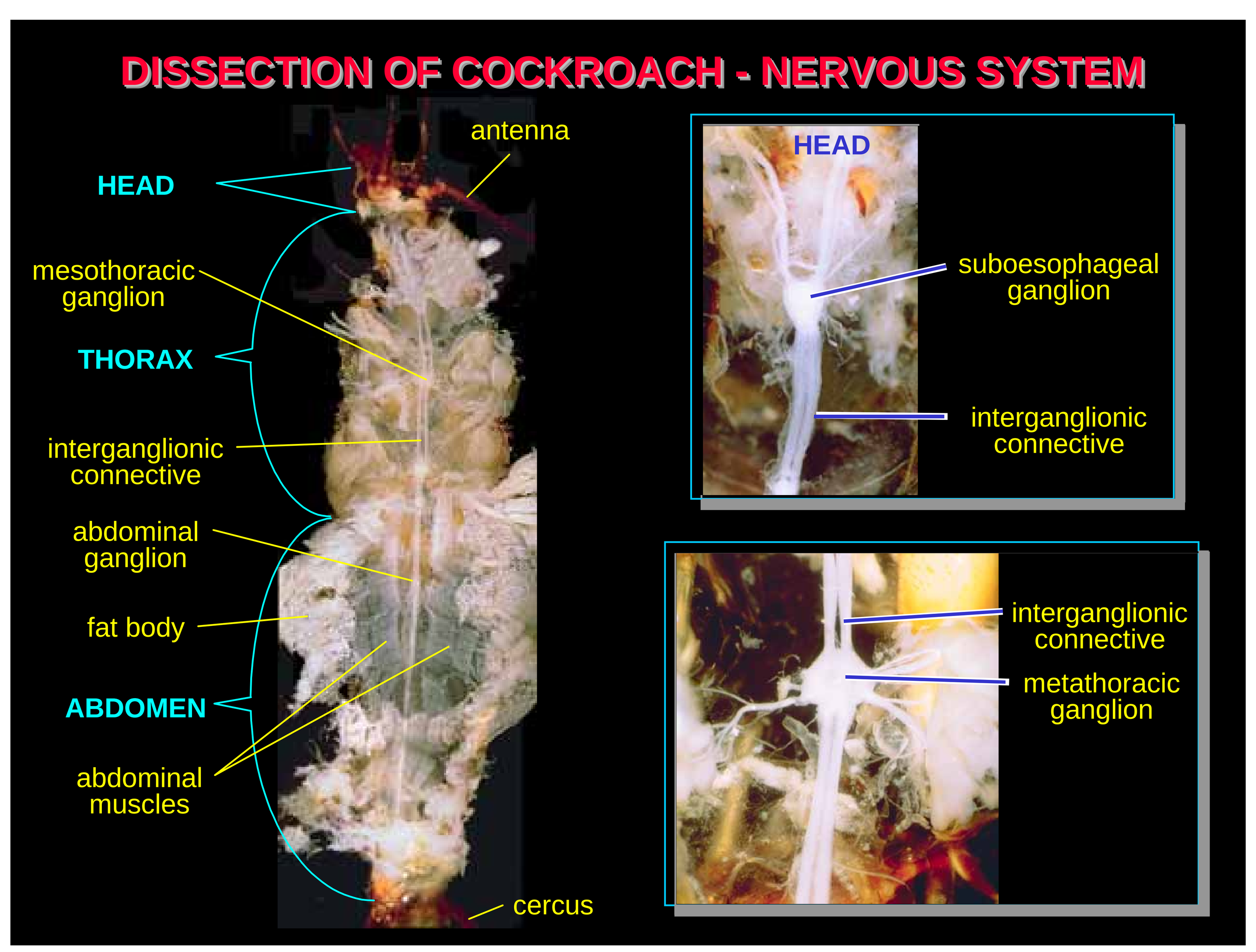


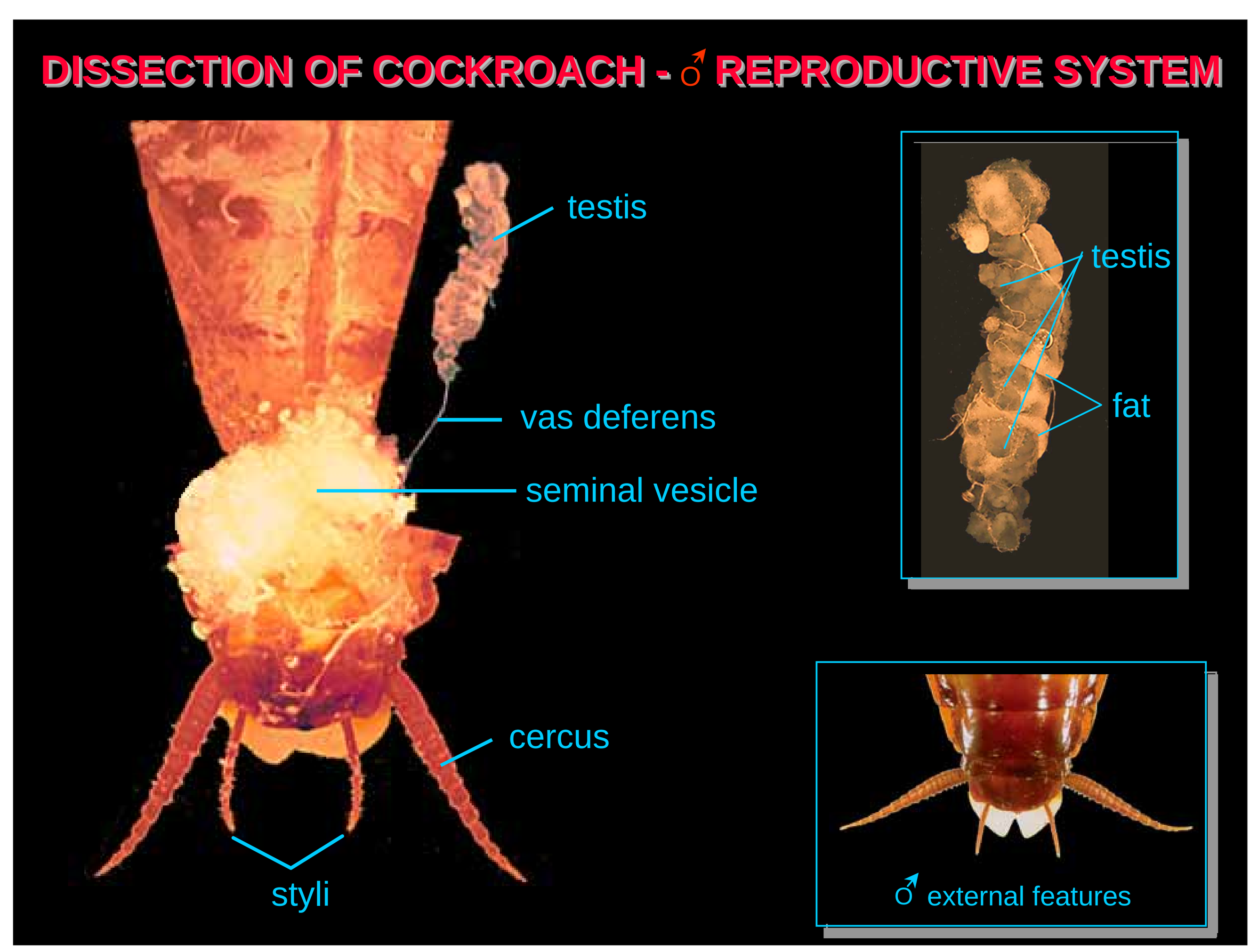


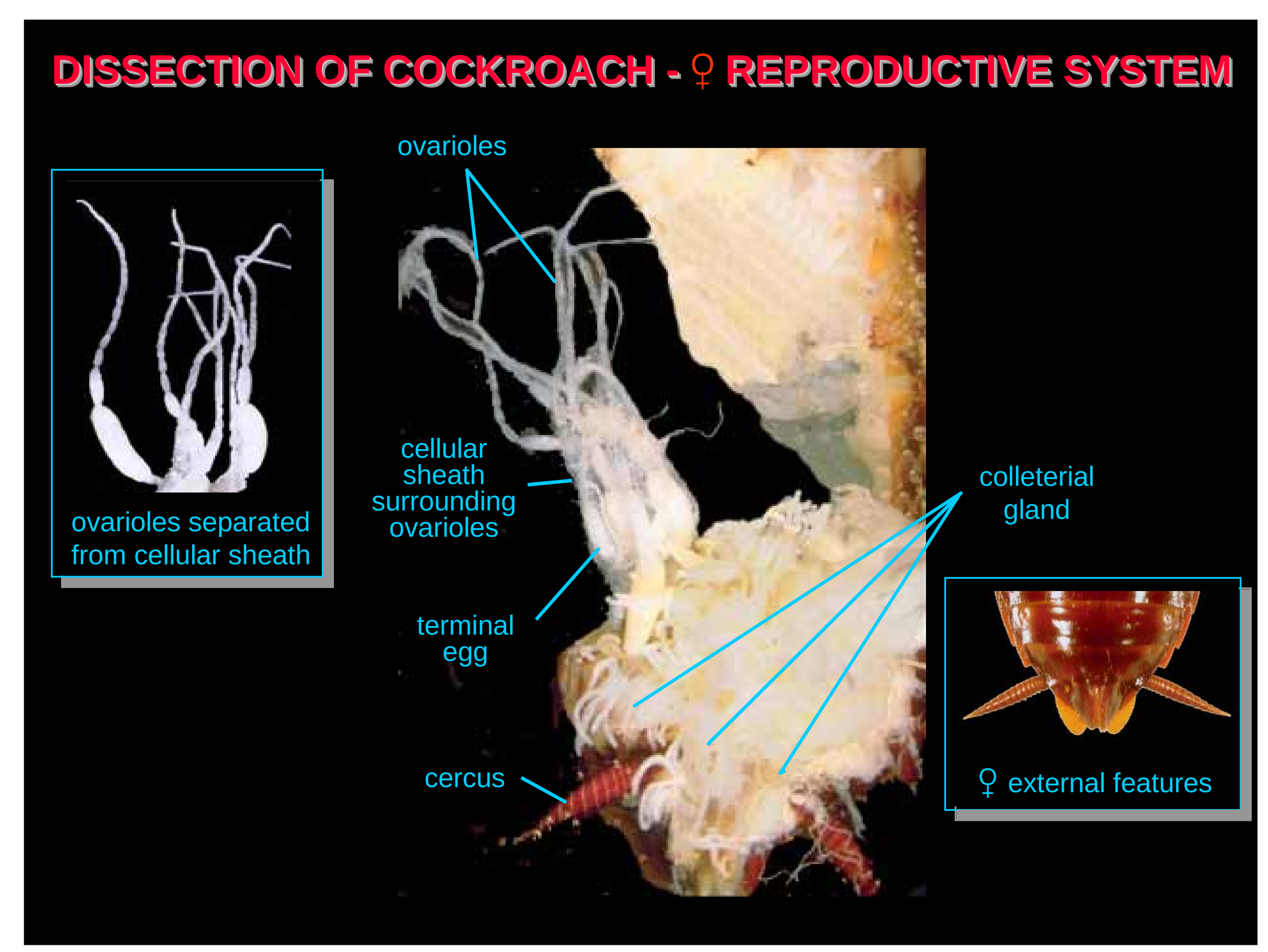












INTRODUCTORY ENTOMOLOGY
Biological Sciences
University of Alberta