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Master Degree in Bionics Engineering

Course of Principles of Bionics and Biorobotics Engineering

Lesson title:

Bionic locomotion principles – Terrestrial legged locomotion

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THE BIOROBOTICS INSTITUTE

Scuola Superiore Sant'Anna

About LOCOMOTION

- Terrestrial locomotion:
  - without limbs
  - with limbs
- Swimmimg
- Jumping
- Flight

About LOCOMOTION

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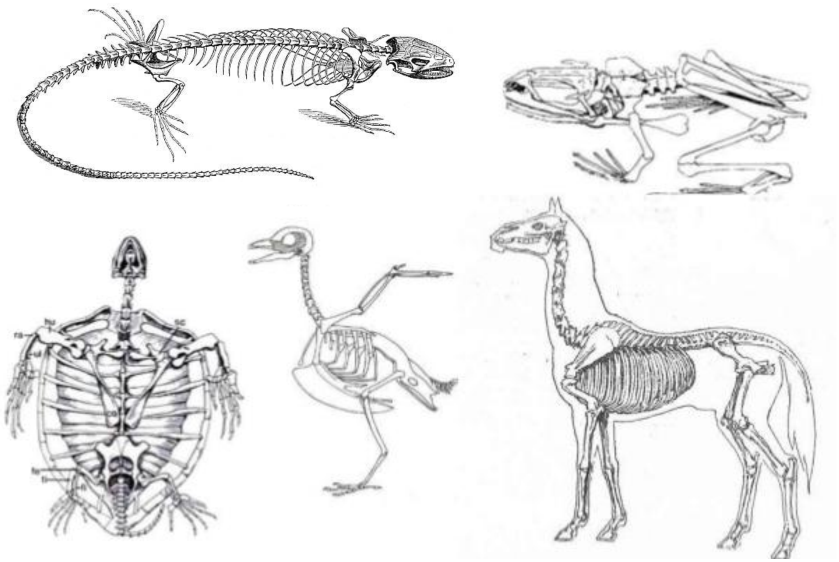
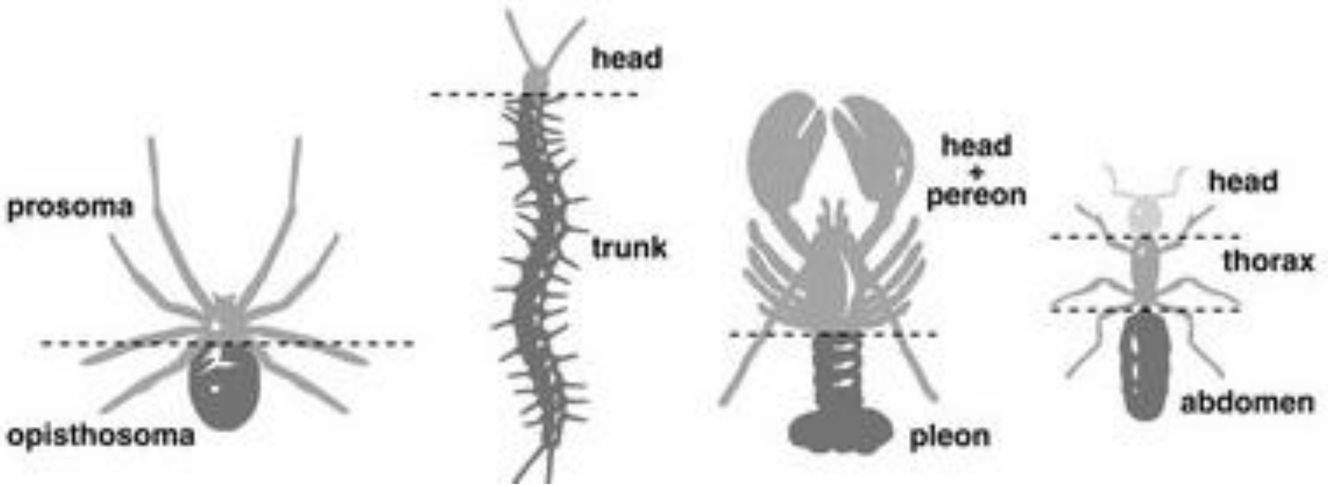
Terrestrial legged locomotion

Basic form of locomotion of vertebrates and arthropods, based on the movement of appendages.



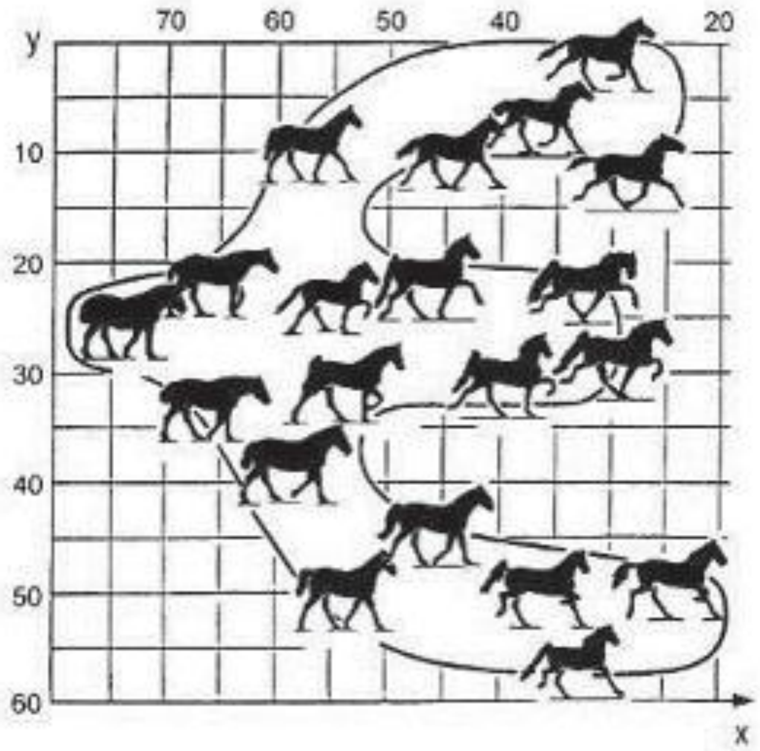
Arthropods (from Greek ἄρθρον arthron, "joint" and πούς pous, "foot") are invertebrates having an **exoskeleton** (external skeleton), a **segmented body**, and paired **jointed appendages**. They include insects, arachnids, myriapods, and crustaceans.

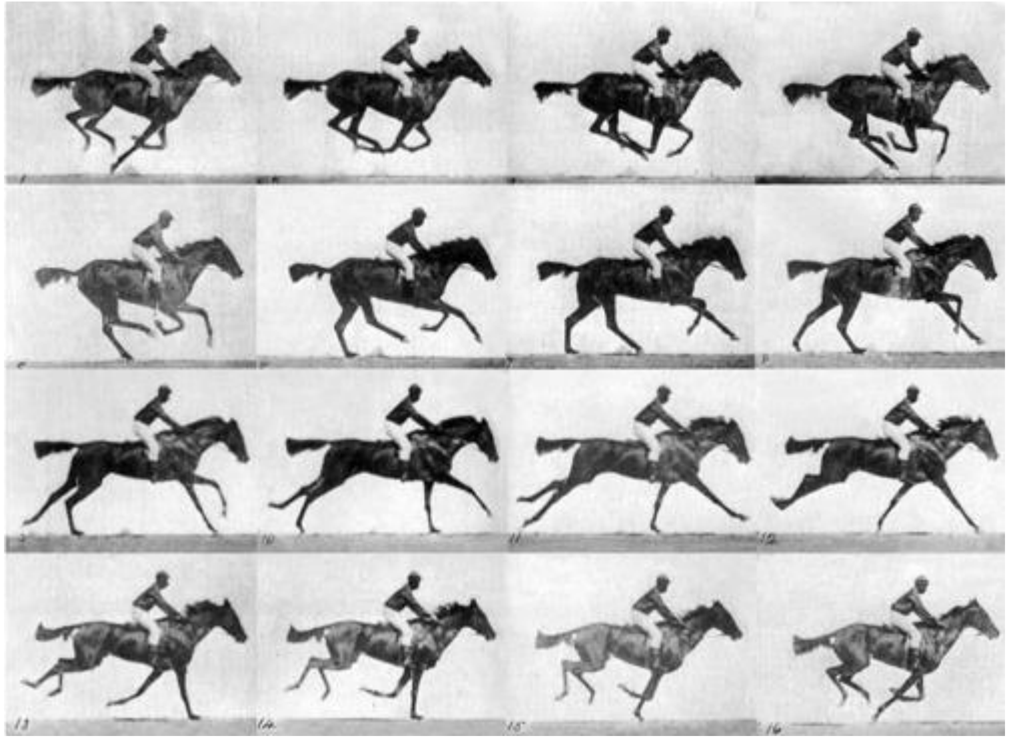


Different problems compared to the locomotion in water:
- reduced friction around the body
- gravity

Terrestrial legged locomotion

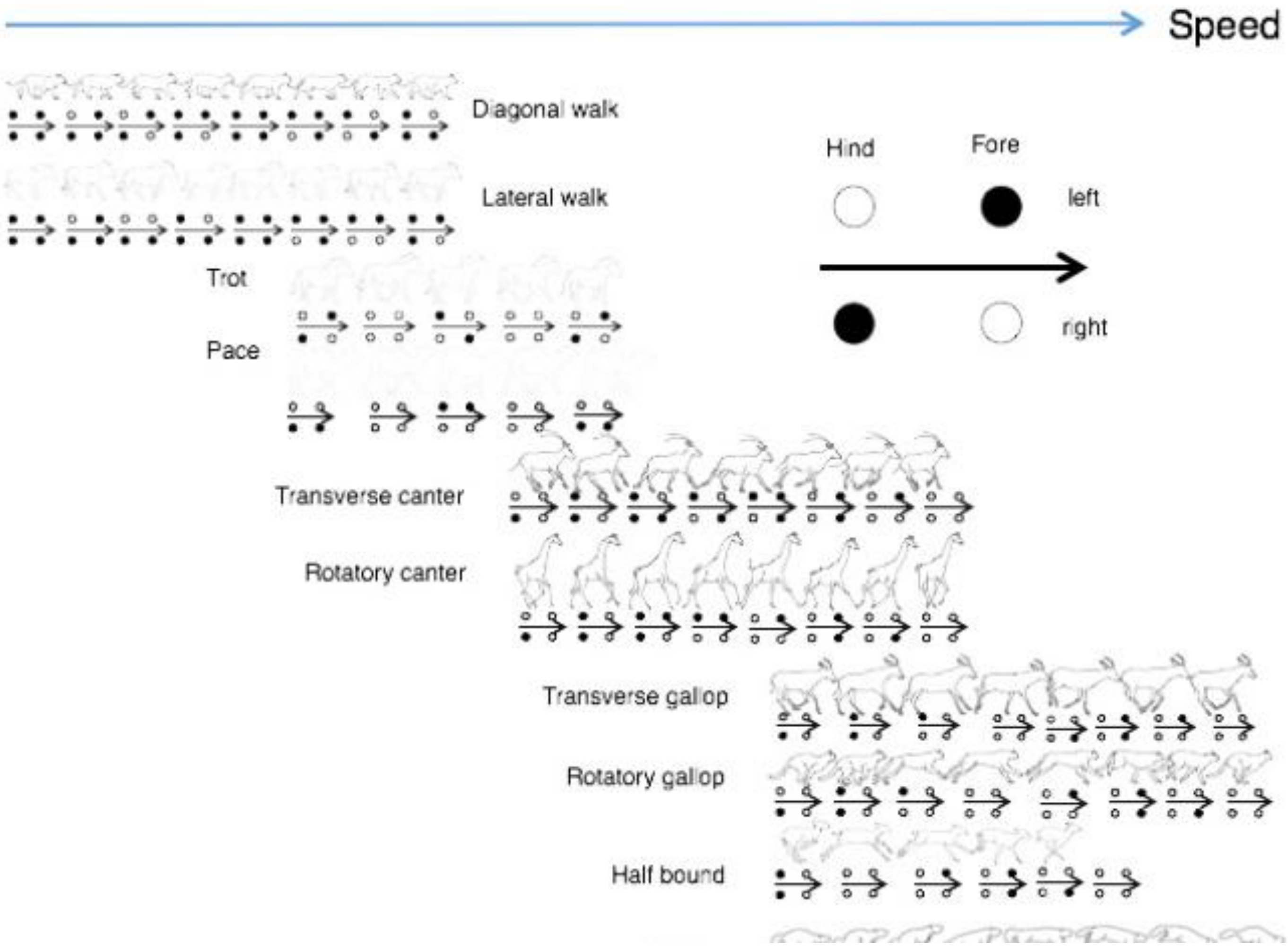
Walking is a terrestrial locomotion in which at least one leg is always in contact with the ground. The speed of walking is limited by the lack of an aerial or leaping phase in which the animal propels itself through the air. To increase their speed, animals must change their gait from walking to running. Running is locomotion with an aerial phase in which the body is lifted from the ground in order to extend the length of a stride.





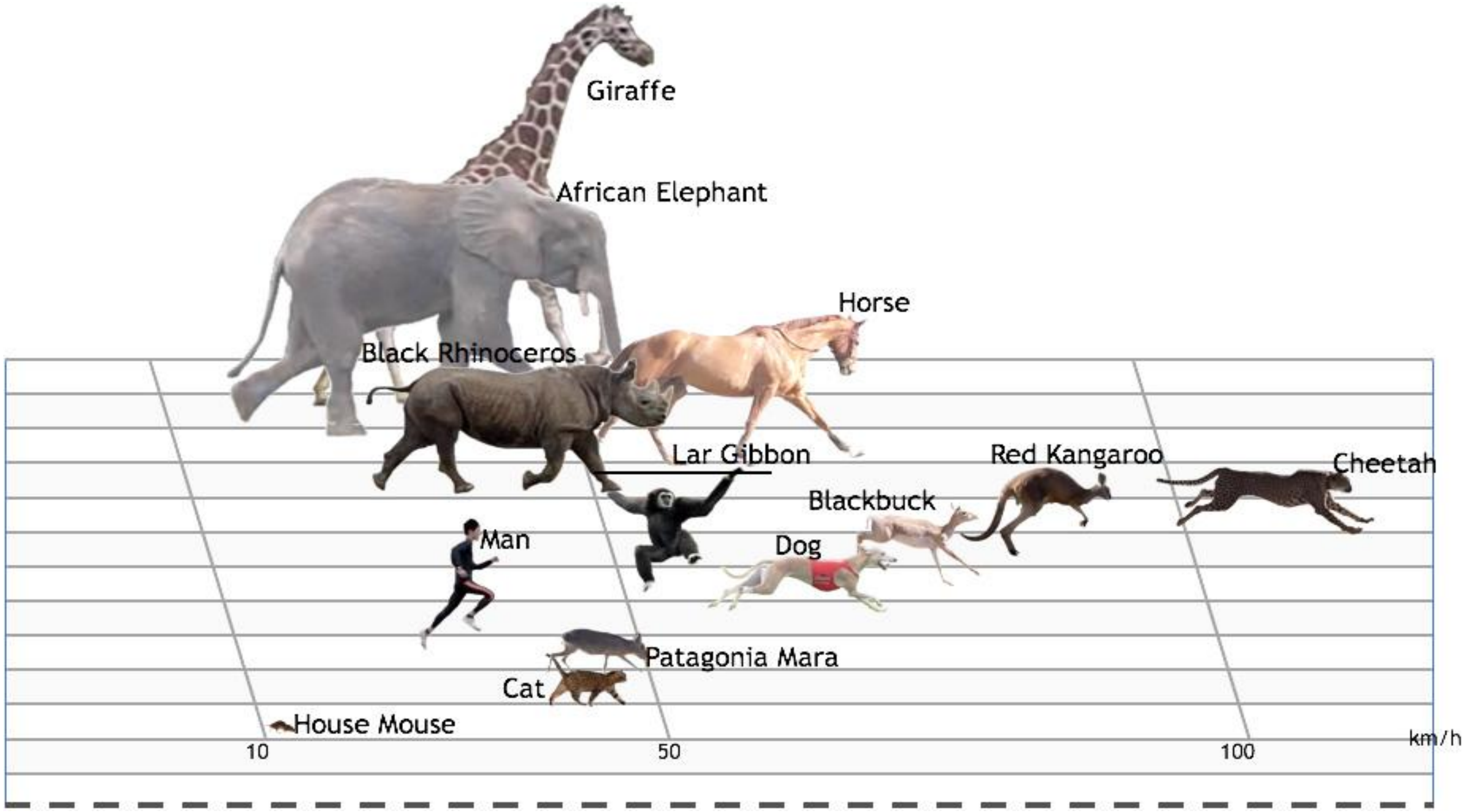
Terrestrial legged locomotion

Gait is a regularly repeating sequence and style of limb movements used in walking and running. The gait of **two-legged** runners and walkers is simple, while **four or more-legged** animals have more complex and varied gaits which are classified into five types: walking (lateral sequence walk, diagonal walk), trotting, pacing; cantering (rotatory canter, diagonal canter), galloping (rotatory canter, traverse canter),half bound, and bound.



Terrestrial legged locomotion

Speed is a crucial aspect of locomotion in most mammals. An ability to move faster may increase success in hunting or escaping. Running speed is controlled by two components of the stride - **length** (the distance travelled in a single step cycle) and **frequency** (the rate at which one step follows another). Both stride length and stride frequency are related to body size, with large animals tending to take fewer, longer strides than small species. These differences compensate for one another to some extent, but because stride length increases with increasing body size more rapidly than stride frequency decreases, larger animals generally run faster than small ones, with some notable exceptions.

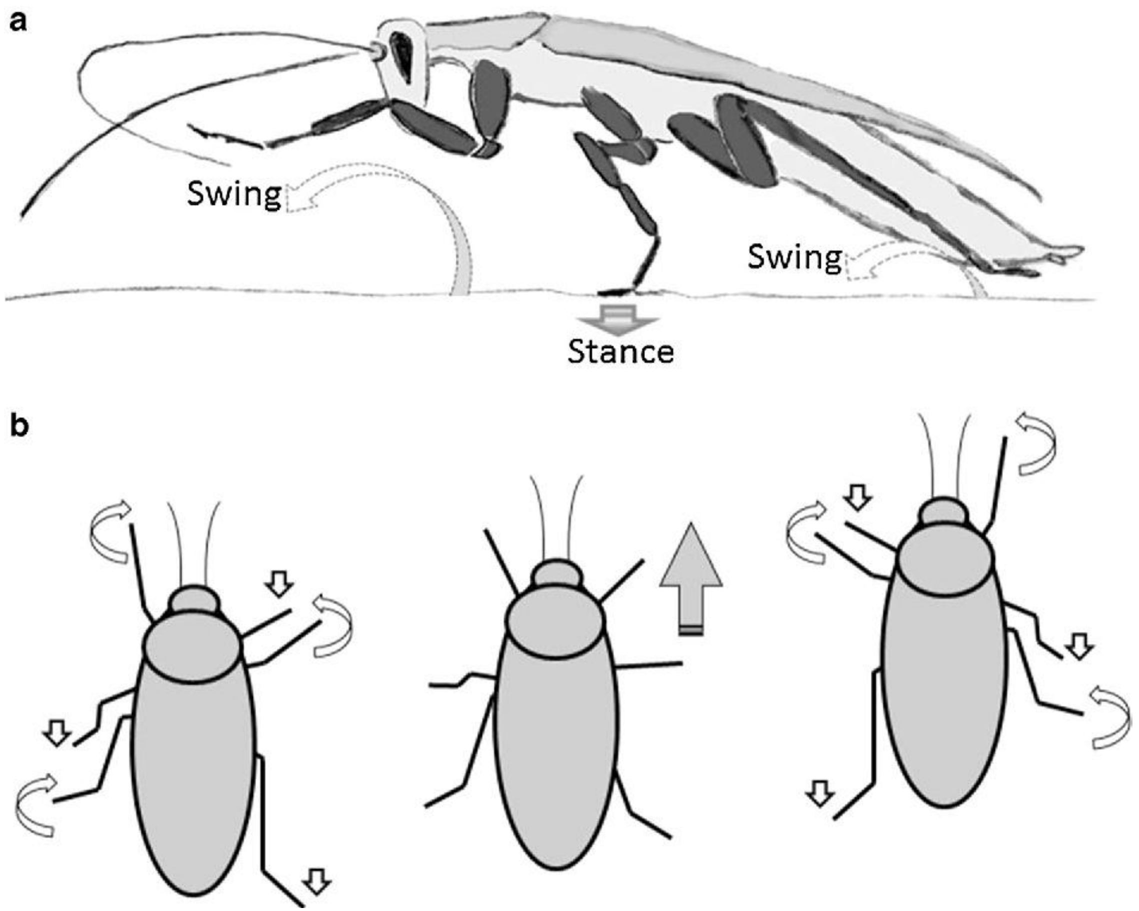


Some of the swiftest-running animals, including the cheetah, pronghorn antelope and several species of hare achieve stride lengths well beyond what might be expected from body size alone, by hurling themselves into the aerial phase of galloping and greatly increasing the distance travelled in each cycle.

The Scuola Superiore Sant'Anna "Zoo"

Biological model	Scientific problem	Engineering application
Polychaeta	New computational models of locomotion kinematics	*Rescue, field robotics*
Oligochaeta	Role of friction in locomotion	Endoscopy of GI tract
Legged insects	Modeling compliant substrates	Endoscopy of GI tract
Cricket	Scale effects on locomotion	Mobile sensor networks
Lamprey	Neuroscientific models of goal-driven locomotion	River exploration, new robots (soft bodied)
Mouse	Animal-robot interaction	Entertainment, …

Terrestrial legged locomotion



Insects are masters of movement

In **insects** (as in all legged animals) the step cycle of a single leg can be divided into a **stance** phase, in which the leg contacts the ground, carrying the body's load and propelling it forward; and a **swing** phase, in which the leg is lifted from the ground and moves forward through the air.

Gait is a regularly repeating sequence and style of limb movements used in walking and running.

Insect locomotion

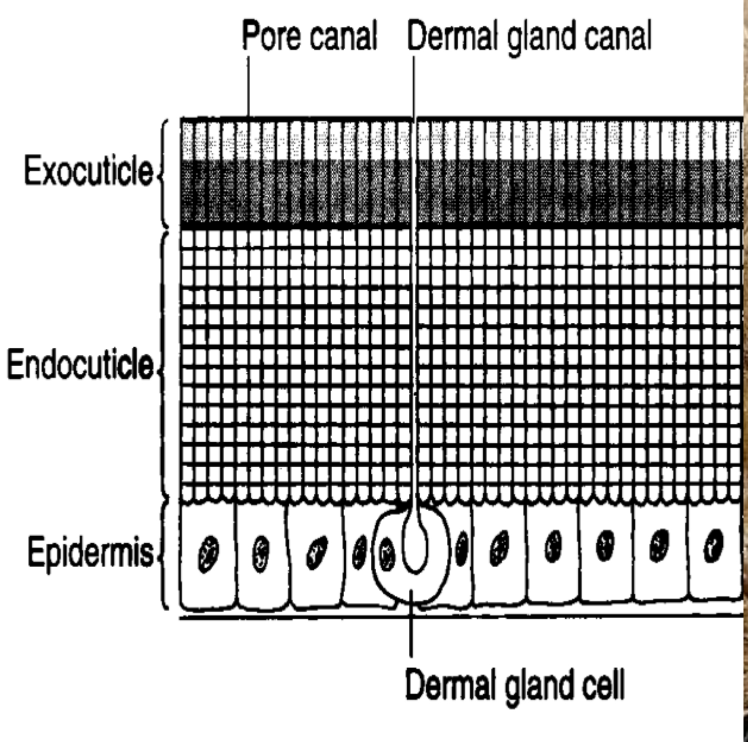
Insects have been described as 'ideal miniature robots’.
Indeed, the way they move is extremely efficient and is being used as a basis by roboticists to develop locomotion in artifacts.

Insect locomotion has two main advancements:
- The **jointed limbs**.
- The **tough exoskeleton** supports the weight of the animal and also has internal projections to which the muscles attach.

The joints permit the rigid exoskeleton to move and consist of softer articulating membranes.

Tough 'tendons’ attach to inside the exoskeleton and can be pulled like levers to move the leg.
The muscles attach to these tendons which are internal extensions of the exoskeleton (and really constitute an internal skeleton).

Exoskeleton



The support and attachment of muscles in insects is ensured by an external skeleton which also acts as an integument.

It has many fundamental functions:

- Being a physical structure
- Protection from physical harm
- A place of attachment for muscles
- Serves as an interface between the insect and the environment
- Serves as the site of sensory input
- Helps to maintain water balance (the wax layer)
- Helps to prevent the entry of harmful microbes and chemicals
- Helps to maintain an ionic balance

The exoskeleton is made up of several layers including a living layer, called the **epidermis**, and a non-living layer, called the **cuticle.**

Muscles attachment

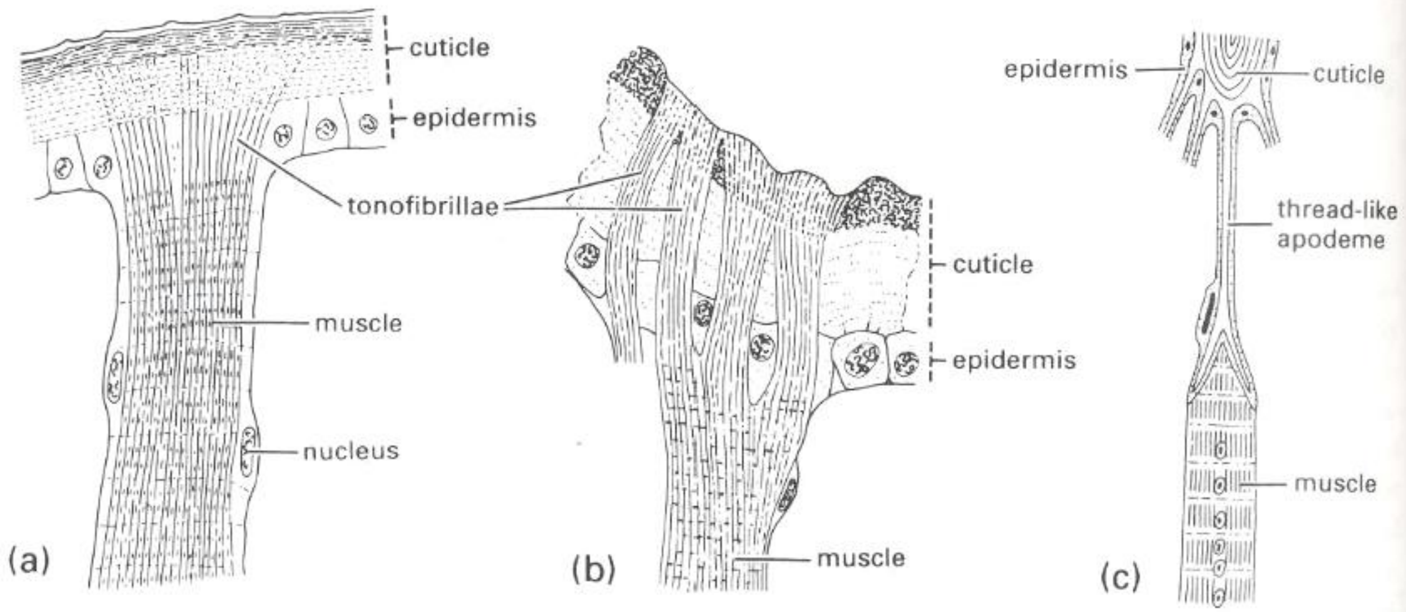
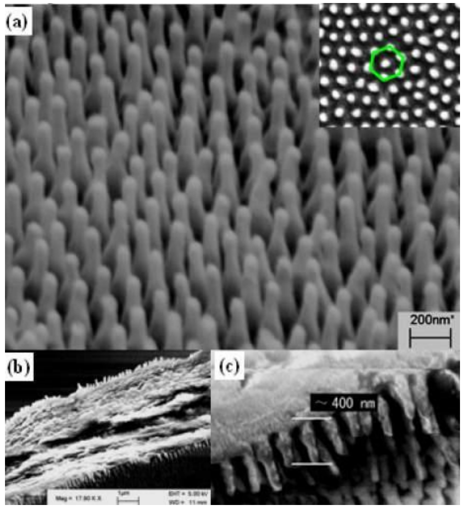


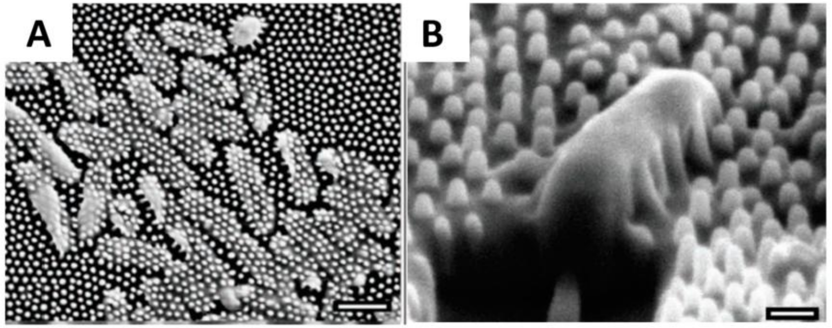
Fig. 3.2 Muscle attachments to body wall: (a) tonofibrillae traversing the epidermis from the muscle to the cuticle; (b) a muscle attachment in an adult beetle of *Chrysobothrus femorata* (Coleoptera: Buprestidae); (c) a multicellular apodeme with a muscle attached to one of its thread-like, cuticular 'tendons' or apophyses. (After Snodgrass, 1935.)

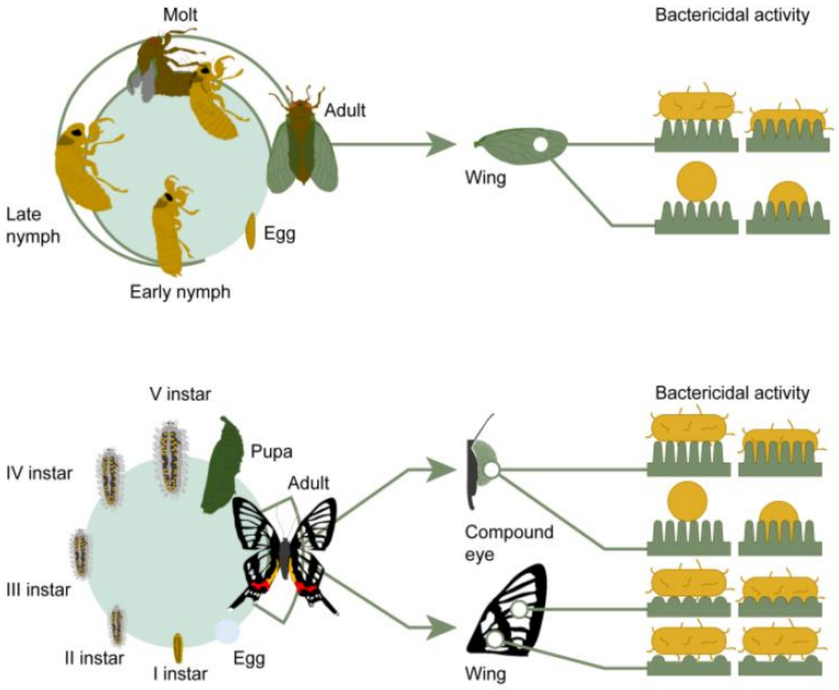
Insect Ultra-Structures as Effective Physical-Based Bactericidal Surfaces

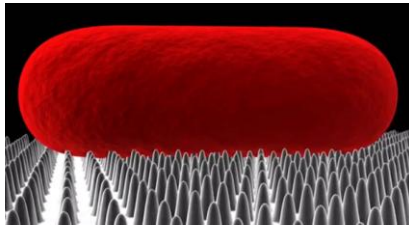
Donato Romano, Jette Bloemberg, Tim McGloughlin, *Member, IEEE*, Paolo Dario, *Member, IEEE*, and Cesare Stefanini, *Member, IEEE*

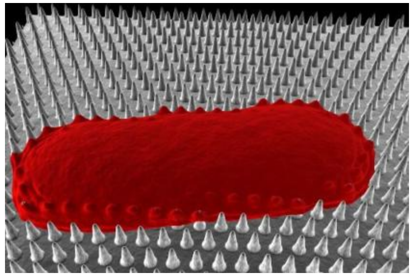
Bacteria colonization of substrates is a key issue threatening the health of humans worldwide. This review summarized recent bactericidal activity evidences of different structures developed by insects. We evaluated different mechanisms in bactericidal activity among several insect species and we also provided a glimpse at attempts at fabricating bactericidal bioinspired structures. In addition, we investigated the link between species with mechano-bactericidal surfaces and their evolution and ecological dynamics. It emerged that mostly hemimetabolous insects evolved bactericidal nanostructures on their wings, probably due to development of their wings externally during postembryonal development. Whereas, holometabolous insects, which develop their wings internally during metamorphosis, have their wings exposed to the environment just in the adult instar, and thus subjected to bacteria for a shorter period compared to hemimetabolous insects. Bio-inspired high-aspect-ratio nanopillared surfaces with bactericidal properties might broaden the application area of bactericidal surfaces, to mechanically decrease the number of bacterial infections.





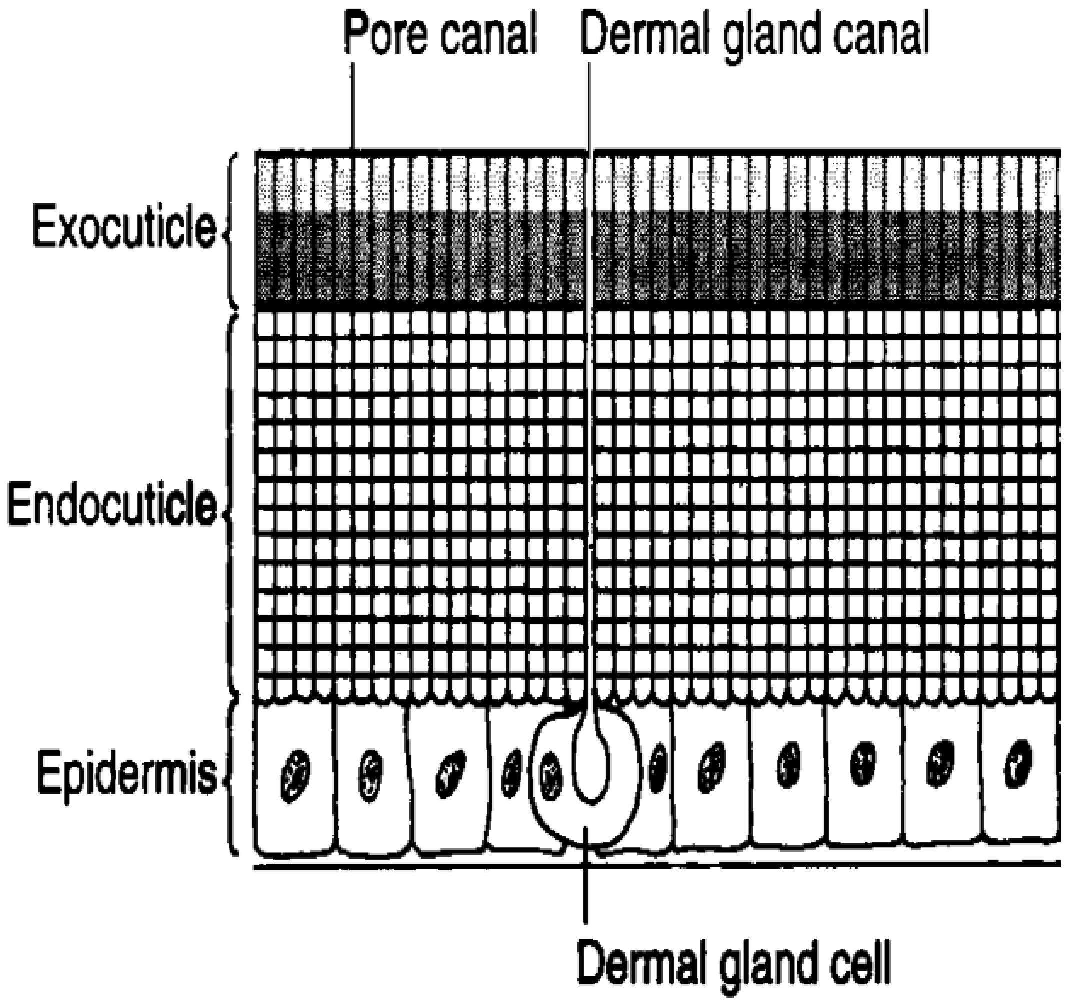






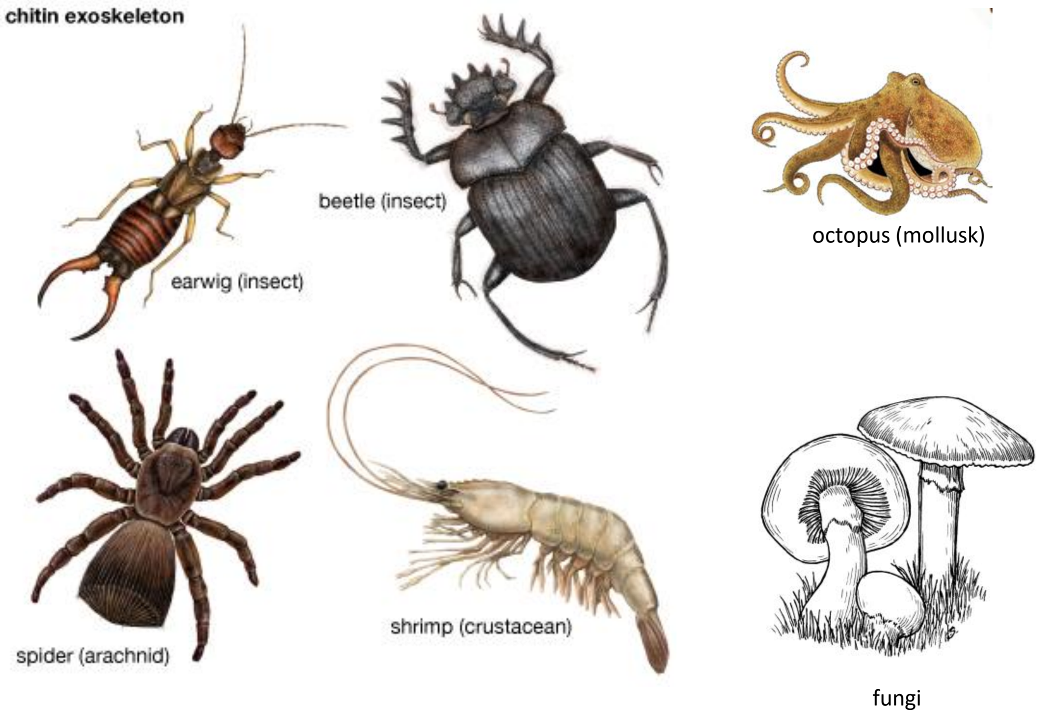
Exoskeleton

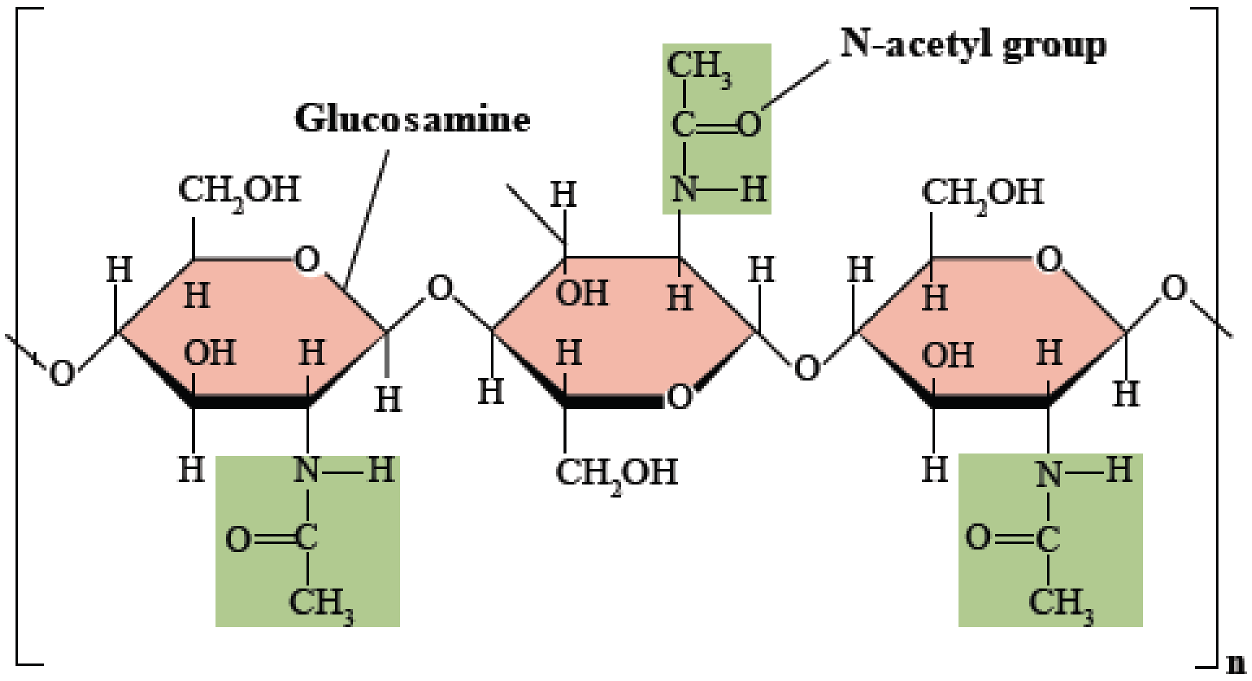
First, you have the **epicuticle**, which is the very top part of the exoskeleton (shown as a thick black line on the top of the diagram). The epicuticle is the outermost layer of the exoskeleton, it is very thin, but consists of many different layers. There are usually **4 layers** within the epicuticle, but the details of the layers vary among the different insect groups, and this it is not always the case. Then there is the **chitinous cuticle**, which is comprised of the exocuticle and endocuticle.



Chitin

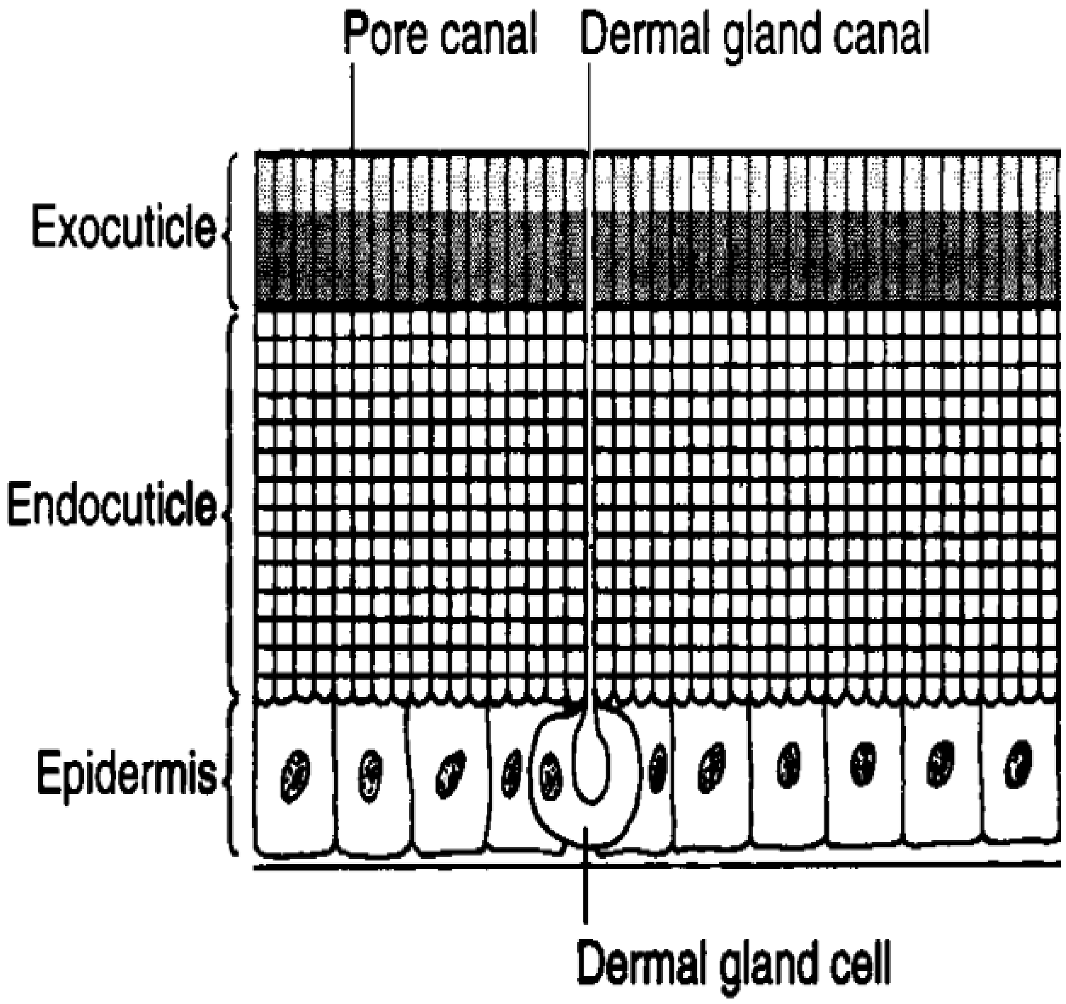
Chitin $(C_8H_{13}O_5N)_n$ is a long-chain polymer composed of units of N-acetyl-D-glucosamine, that derive from glucose. These units form covalent β-(1→4)-linkages.





Exoskeleton

The chitinous cuticle comprises the **exocuticle** and **endocuticle**. These parts are very thick, and chitinous (meaning tough, protective, and semi-transparent). These parts of the exoskeleton serve a **structural function**, they help the exoskeleton keep its form. These two parts taken together are usually referred to as the cuticle. Cuticle is composed of both chitin and protein, 20-50% being chitin, and the rest being protein. Lastly there is the living portion of the exoskeleton, which is the **epidermis** and the basement membrane (basal lamina). This part of the exoskeleton secretes the cuticle, which ages and rises closer and closer to the top (going through the endocuticle and exocuticle) until it is part of the epicuticle, or the outer, hardened "shell" of the insect. The molting of the shell happens when new cuticle pushes the old cuticle out of the way. The epidermis has one cell layer, and includes specialized cells, such as gland cells and sensory cells. The basement membrane (Basal lamina) underlies the epidermis (hence the name), serves as a molecular sieve, which means that the basal lamina has control over what materials are absorbed by the epidermis, and therefore, what materials go into the creation of the cuticle.

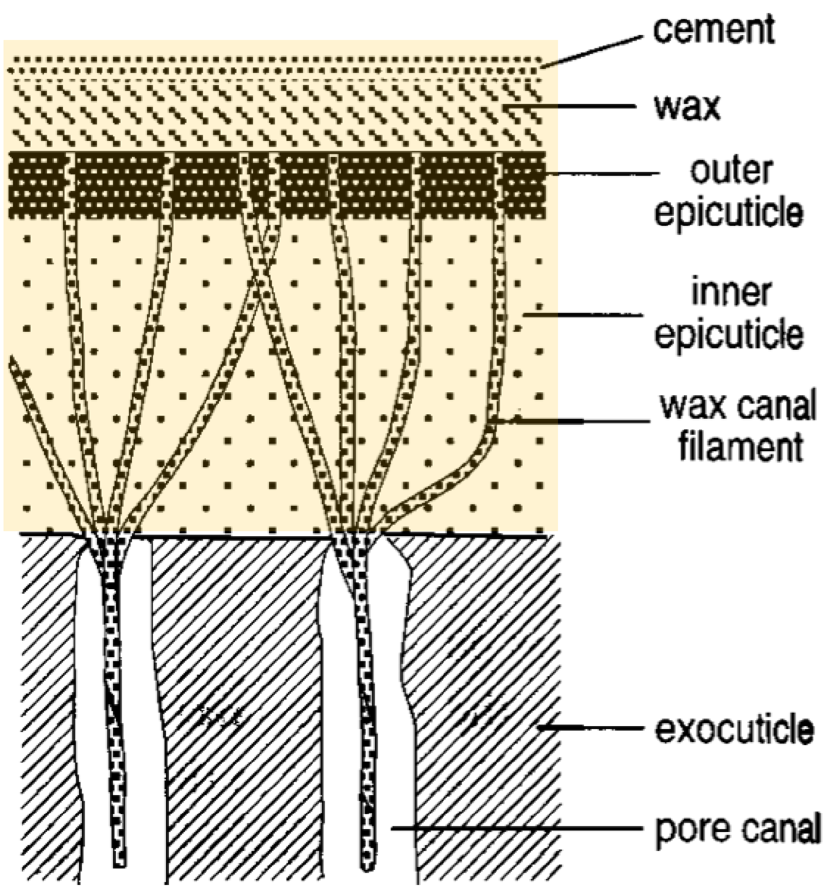


Exoskeleton

The Epicuticle

there are four major layers of the epicuticle.

1. Cement layer serves to protect the wax layer.
2. Wax layer serves as waterproofing for the insect.
3. Outer epicuticle serves as a place for muscle attachmen and as protection for the nee cuticle against enzymes an may also contribute to the surface pattern.
4. Inner epicuticle, that may serve as an enzyme reservoir.

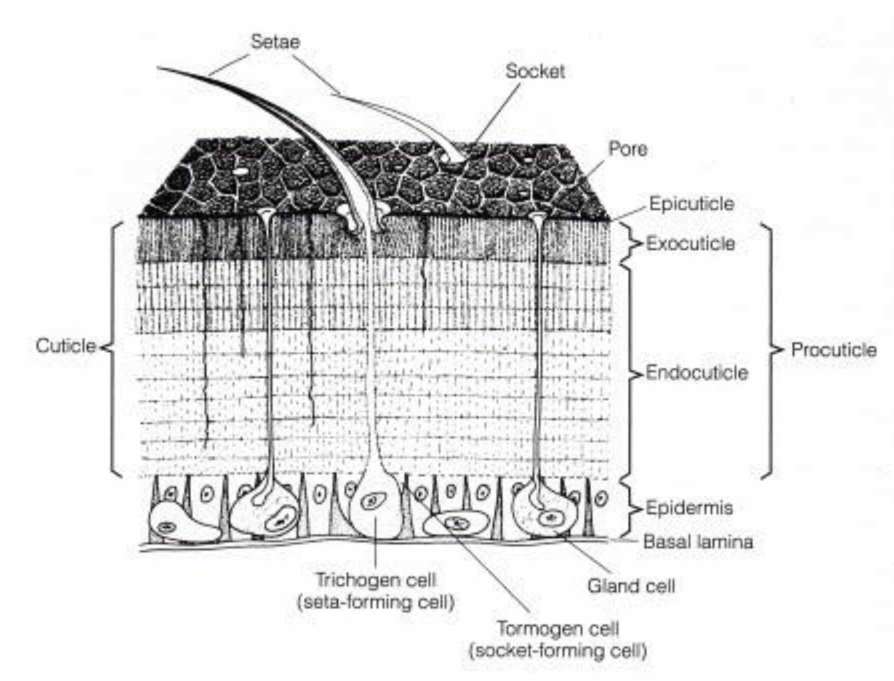


Exoskeleton

The exocuticle

is tanned (sclerotized, darkened), and it functions for all the physical, hard properties.
It is responsible for:

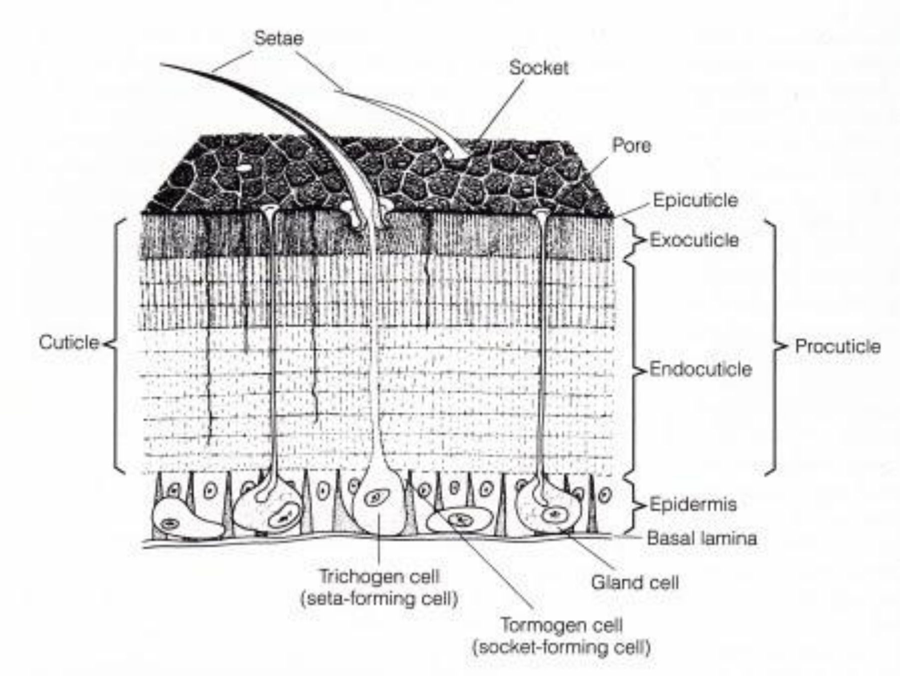
1. Hardness and color
2. Muscle attachment
3. Rigidity
4. Physical protection

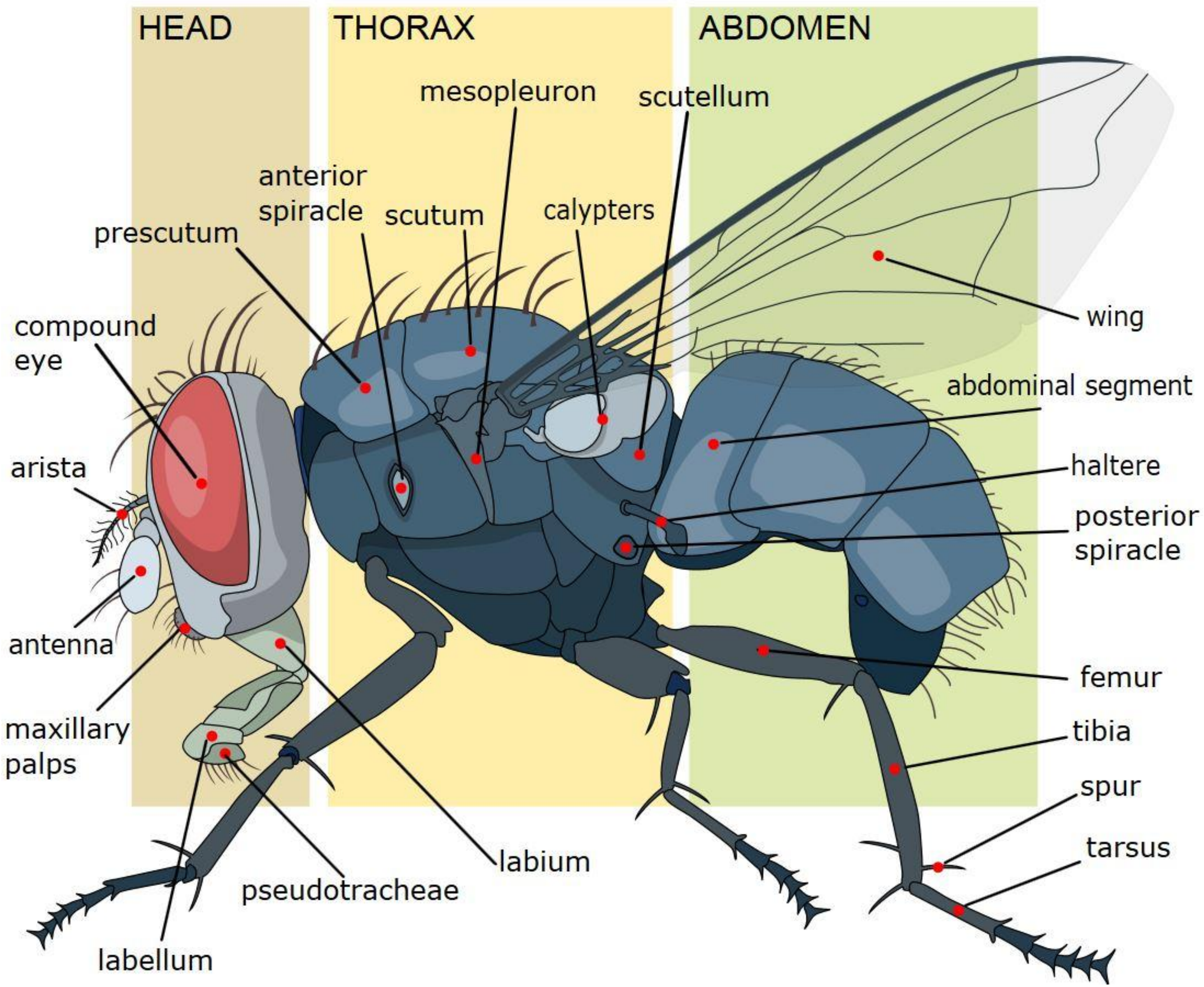


Exoskeleton

The endocuticle

is usually not tanned (sclerotized, darkened), and its main function is to serve as the flexibility to the exocuticle's rigidity. Otherwise, the insect would be completely hardened and would not be able to move. The endocuticle is usually clear, or colorless, and membranous.




HEAD
THORAX
ABDOMEN
mesopleuron
scutellum
anterior spiracle
scutum
calypters
prescutum
compound eye
wing
abdominal segment
arista
haltere
posterior spiracle
antenna
femur
maxillary palps
tibia
spur
tarsus
labium
pseudotracheae
labellum