Chapter II. The circulatory system in Invertebrates (insects)

I. Introduction

In biology, a circulatory system is a system of circulating organs that allows the movement of fluids in an organism. The role of the circulatory system is to ensure the transport and internal exchange of resources (notably nutrients and oxygen) to the body's cells, as well as collecting waste products, such as carbon dioxide. The term 'circulatory system' is very often used to define the blood circulation system, but there is also a circulatory system in plants, or a haemolymph circulatory system in insects.

The circulatory system of insects, very similar to that of other arthropods, is wide open. A single well-defined vessel, the dorsal vessel (to which segmental vessels are added in Dictyoptera) is present; the circulation of haemolymph can also be determined by the body cavity or haemocoele. Tissues and organs are only separated from the haemolymph by their connective membranes. Without respiratory pigments, the blood is only used for respiration; oxygen is delivered to the cells by the tracheal system. The essential role of the haemocoele is to distribute metabolites and transport hormones.

The haemolymph, via its haemocytes, has the function of cleaning the organism of micro-organisms, parasites and solid particles. The water it contains can be used by the tissues in the event of prolonged desiccation.

II – ANATOMY

The haemolymph circulates in the dorsal vessel via the contractions of the myocardium, before spreading out into the general cavity. Anatomical adaptations, diaphragms and accessory hearts facilitate and regulate the circulation of haemolymph which, after bathing the organs, must return to the heart.

1- Dorsal vessel

The dorsal vessel is the most important organ and the only one responsible for blood circulation. It is generally maintained in place by suspensory filaments attached to the tergites and by the dorsal diaphragm. The dorsal vessel may be a simple tube, as in mosquito larvae, or a more differentiated organ, as in the bee, divided into two regions: at the back, the heart, characterised by the presence of ostioles, and at the front, the aorta, which is always open at the end.

2-Diaphragms and accessory hearts

Blood circulation inside the hemocoele is controlled by the presence of well-developed diaphragms in the abdomen.These consist of a lamina of very flattened cells between two thick extracellular layers of fibrous material.

The dorsal diaphragm, located just below the heart and usually fused to it, extends horizontally and attaches laterally to the tergites. It defines a pericardial sinus. It supports aliform muscles.
These muscles, of tergital origin, are attached to the heart or join medially. The muscle fibres are very long, thin and branched, with long sarcomeres. Some of the fibre are connected to the myocardium by intercalary discs, which indicates a functional solidarity.
Pulsatile structures independent of the heart have been described in many insects. These are vesicles, sometimes with lateral orifices, whose role is the same as that of the cardiac ostioles. The rhythm of their contractions is independent of the cardiac rhythm. These accessory hearts facilitate the circulation of blood inside the appendages and wings. Many insects have antennal accessory hearts from which a vessel extends to the antenna. Pulsatile organs are involved in the circulation of haemolymph inside the legs in Hemiptera, Diptera and Odonata.

II-HEMOLYMPH

This is the 'blood' of insects (and arthropods). The role of the haemolymph is to supply nutrients to the organs, carry away metabolic waste (which is evacuated via the Malpighian tubes in particular), eliminate pathogens and intruders (immunity), maintain the turgidity of the soft organs, repair the tissues of the body and protect it from damage turgidity of the soft organs, repairing the watertightness of the integument (healing) and transporting the various hormones used in development and reproduction. It ensures homeostasis, maintaining constant pH conditions and the concentration of organic ions, amino acids, proteins, nucleic acids, sugars and lipids. It also acts as a thermal fluid and, in some cases, plays very specific roles.
In insects, it does not play a respiratory role (except in the case of Diptera larvae, red worms) and does not contain cells similar to the red blood cells of vertebrates. It is a clear, water-based liquid which generally has no particular colour but may be coloured; in this case, it gives its colour to larvae with a transparent integument. The larvae often have more haemolymph than the imagos, which makes up half the weight of a cricket.

1- Chemical composition of plasma

Plasma has a whole range of biochemical characteristics that are not yet very marked in Apterygotes and Palaeoptera (Odonata and Ephemeroptera), but which have become apparent over the course of evolution and are particularly evident in the larvae of certain Coleoptera, Lepidoptera and Hymenoptera.
Osmotic pressure in insects is generally fairly high, corresponding to a cryoscopic drop of -0.5°C to -1.1°C. Insects are generally able to regulate the osmotic pressure of the haemolymph so that it remains constant even during dehydration or rehydration of the animal.
The often-significant variations in osmotic pressure during postembryonic development is certainly related to changes in metabolism.
During hibernation in certain insects, an accumulation of glycerol causes a sharp rise in osmotic pressure.

2- Haemocytes

Insect haemocytes are nucleated cells. They can circulate with plasma, entering body cavities and, depending on the case, moving inside the heart. However, a greater or lesser proportion of haemocytes stay immobile, adhering loosely to the surface of tissues and organs.
Haemocytes are of mesodermal origin and in many insects, the various haemocytic categories are already differentiated before eclosion.

III-Blood circulation

1- Cardiac cycle and regulation of heart rate

Blood circulation is essentially ensured by the rhythmic contractions of the heart. Waves of contraction propagate along the cardiac tube, generally from back to front, although a reversal of the direction of these waves is rarely observed. The frequency at which the heart beats varies considerably depending on the insect's physiological state and activity. In the case of Sphinx ligustri, for example, it is 40-50/nm in the resting imago but 110-140/mn in the active stage; the rate increases with temperature; it is slow in the less active stages, falling from 40-50/mn in the larva to 20 or even l0/mn in the nymph.
The contraction phase of the cardiac cycle, or systole, is caused by the contraction of the myocardium; diastole, or the heart's expansion phase, results from the relaxation of the cardiac muscles, the elasticity of the heart's suspensory filaments and the contraction of the aliform muscles. Diastole may be followed by a resting phase during which the heart stays dilated.
The activity of the heart muscle and these neurons are influenced by the central nervous system, which receives information via the segmental nerves: electrical stimulation of the brain inhibits the heartbeat, while stimulation of the ventral nerve chain accelerates it.

2- Circulation of the haemolymph

The pressure of the haemolymph is generally relatively low in the haemocoele. In insects with a rigid cuticle, it corresponds approximately to atmospheric pressure. However, when the cuticle is only slightly sclerotinised, contraction of the muscles in the body wall can significantly increase the internal pressure; in Odonata, this can reach 75 mm of water at emergence, allowing the wings to expand. Ventilation during breathing can also cause significant variations in pressure.
Blood is pumped by the heart through the lateral ostioles during diastole, when the pressure of the heart is lower than that of the hemocoele. The blood is then propelled forward by the contraction waves and exits at the end of the diastole.
Some of the blood is then pumped by the pulsatile organs. Towards the antennae, the rest flows towards the rear of the animal, according to the pressure gradient: the exit of haemolymph via the aorta leads to an increase in pressure in the head.
The circulation of blood in the wings is well defined: blood enters through the anterior veins and leaves through the posterior veins, with pulsatile organs at the base of the wings aspirating the haemolymph. Similarly, circulation in the legs can be facilitated by pulsatile organs, and is also helped by movements of the legs.

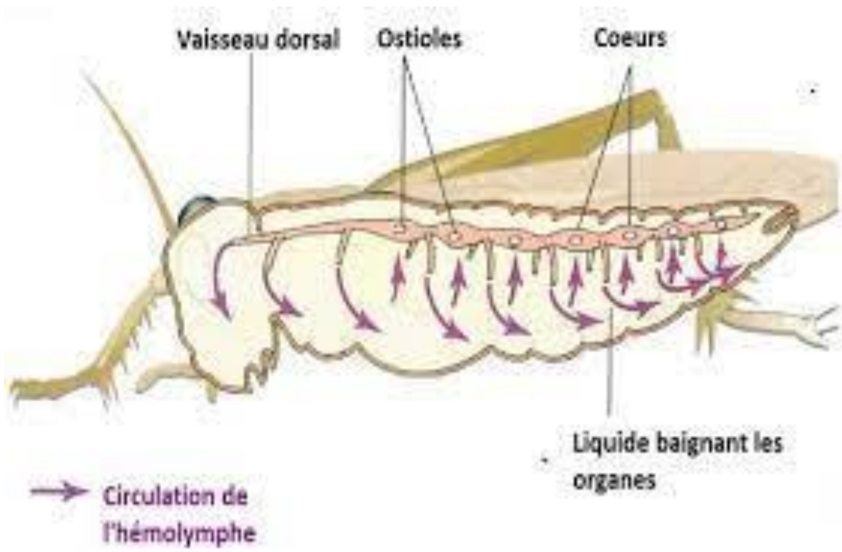

Figure1: Insect circulatory system