

BLOOD PRESSURE IN THE LEECH *HIRUDO MEDICINALIS*

By BODO KRAHL AND IRENE ZERBST-BOROFFKA

*Institut für Tierphysiologie und Angewandte Zoologie, Freie Universität
Berlin, Grunewaldstrasse 34, 1000 Berlin 41, Federal Republic of
Germany*

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SUMMARY

1. Intravascular pressure recordings in the lateral vessels of the leech, *Hirudo medicinalis*, show two distinct pressure patterns: high pressure phases (diastolic pressure: 5 ± 3 mmHg, systolic pressure: 48 ± 14 mmHg) alternate with low pressure phases (diastolic pressure: 4 ± 2.5 mmHg, systolic pressure: 26 ± 11 mmHg).

2. The lateral vessel of one side produces high pressure pulses during peristaltic action while the other vessel generates low pressure pulses during non-peristaltic action. After 20–60 pulses a transition occurs, which sometimes appears more gradually.

INTRODUCTION

The morphology of the circulatory system of the leech, *Hirudo medicinalis* L., is well documented (Gaskell, 1914; Boroffka & Hamp, 1969; Hammersen & Staudte, 1969; Hammersen, Staudte & Möhring, 1976). The whole system is of coelomic origin (Mann, 1962; Herter, 1968).

Four longitudinal vessels run through the animal: one pair of lateral vessels (the so-called heart tubes), the dorsal vessel and the ventral vessel (encasing the ventral nerve cord). The lateral vessels produce rhythmic constrictions. Segmental branches ramify to an extensive capillary network which supplies all organs. The lateral vessels contain sphincters which are arranged segmentally: one 'main sphincter' and the 'latero-abdominal sphincter'. These sphincters and the valves at the outlets of the latero-lateral and the latero-dorsal vessels to the lateral vessels prevent a backflow during the constriction phases (Boroffka & Hamp, 1969; Hammersen *et al.* 1976).

A final concept of the coordination of the blood flow in the leech has still to be developed. The circulation model of Boroffka & Hamp (1969), confirmed by Hammersen *et al.* (1976), is based on vital microscopic observations. It assumes that both lateral heart vessels constrict peristaltically but alternately. The blood circulation would be characterized by:

- (1) longitudinal forward flow through the lateral vessels,
- (2) backward flow through the dorsal and the ventral vessel,

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(3) a simultaneous segmental circulation *via* the capillary system including both heart tube sections.

The neuronal control of the heartbeat in the leech was investigated by Thompson & Stent (1976). They described for the first time the bilateral antiphase peristaltic and non-peristaltic constriction mode. One lateral vessel generates a frontward peristaltic constriction wave while the contralateral heart tube sections constrict nearly simultaneously (non-peristaltic or synchronic). After a certain number of heart beats the peristaltic mode changes to the synchronic mode. The opposite change occurs in the contralateral heart tube (Thompson & Stent, 1976). Though the peristaltic mode was confirmed only in the front third of the heart tubes the blood flow should be described as bilaterally-asymmetric and not as bilaterally-symmetric as assumed by Boroffka & Hamp (1969). Nevertheless the conclusions on which Thompson & Stent (1976) base their concept of blood flow, reviewed by Calabrese (1979), include some misinterpretations of the morphological results of Boroffka & Hamp (1969). For example, they neglect the role of the sphincters and valves.

Our aim is to elucidate the haemodynamic properties of the circulatory system in the leech, including the coordination of the blood flow. Moreover, we are interested in the correlation of blood pressure and blood volume with respect to salt/water regulation, because blood volume seems to be a controlling factor for body water homeostasis (Zerbst-Boroffka, 1978). This first paper presents measurements of the hydrostatic blood pressure.

MATERIALS AND METHODS

Specimens of *Hirudo medicinalis* were purchased from a commercial supplier. The leeches were maintained in tap water at a temperature of 20°C ($\pm 1^\circ\text{C}$). The water was changed twice a week.

The unanaesthetized animals were fixed in a stretched position in a wax dish by needles stuck through the anterior and posterior suckers. The body wall was opened by a small incision along the lateral midline exposing the heart tube. The preparation site was pinned out and covered with physiological saline (Nicholls & Baylor, 1968). Only the connective tissue overlying the selected puncture site of the lateral vessel was removed. In some cases both lateral vessels were exposed in an anterior region (segment 4, 5 or 6), in others the lateral vessel of one side was exposed at two different sites in segments 4–6 and in segments 8–14 (segment numbers according to Kristan, Stent & Ort, 1974).

The pressure recording system consisted of a glass capillary (tip diameter 50–70 μm) connected *via* polyethylene-tubing and a three-way stopcock to a CP01 pressure transducer (Century Technology Company). The transducer-amplifier was hooked up to a thermal writing recorder (Gould). A micromanipulator held the capillary in place. The capillary and the whole tubing system were filled with de-aerated physiological saline. The pressure transducers were calibrated with a calibration manometer (Gauer) at the experimental temperature (20°C $\pm 1^\circ\text{C}$). The zero level was set at the level of the cannulated vessel. In addition to this static calibration the dynamic properties of the pressure recording system were determined following the method described by Jones (1970).

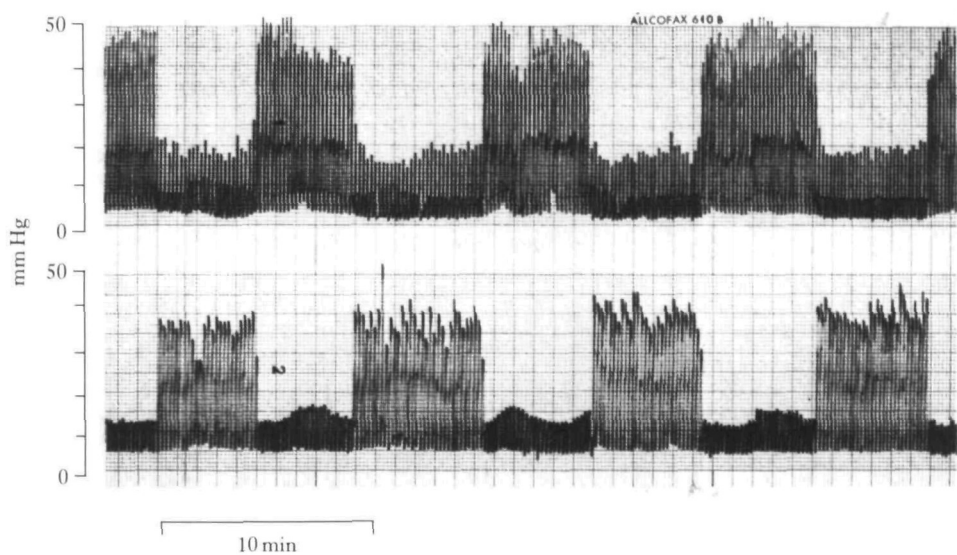


Fig. 1. Simultaneous recording of the blood pressure in both lateral vessels in segment 5. Upper trace, right lateral vessel; lower trace, left lateral vessel.

RESULTS

Pressure recordings of the two lateral vessels in the leech are characterized by the alternate occurrence of high pressure phases (HIP-phase) and low pressure phases (LOP-phase) (Fig. 1).

During the course of the experiment the pressure amplitudes of the two phases remained constant for more than 2 h. However, the pulse rate changed considerably (Fig. 2). At the beginning of an experiment the frequency started with 7–8 pulses min^{-1} . After 20–30 min it slowed down to 5–6 pulses min^{-1} . Usually this pulse rate did not change during the rest of the experimental period (Fig. 2). Probably preparation and handling increased the pulse rate to a higher level, followed by a quick recovery, but no change in pressure was observed.

The pressure recordings of 28 animals are summarized in Fig. 2. During the HIP-phase the average systolic and diastolic pressures were 48 ± 14 mmHg and 5 ± 3 mmHg, respectively. In some animals the systolic pressure would build up to 100 mmHg. During the LOP-phase the diastolic pressure (4.0 ± 2.5 mmHg) resembled that of the HIP-phase. However, the average systolic pressure was only 26 ± 11 mmHg, and differed significantly from that of the HIP-phase.

Simultaneous pressure recordings of the lateral vessel in a midbody segment (segment 14) and a more anterior one (segment 5) demonstrated that during the LOP-phase

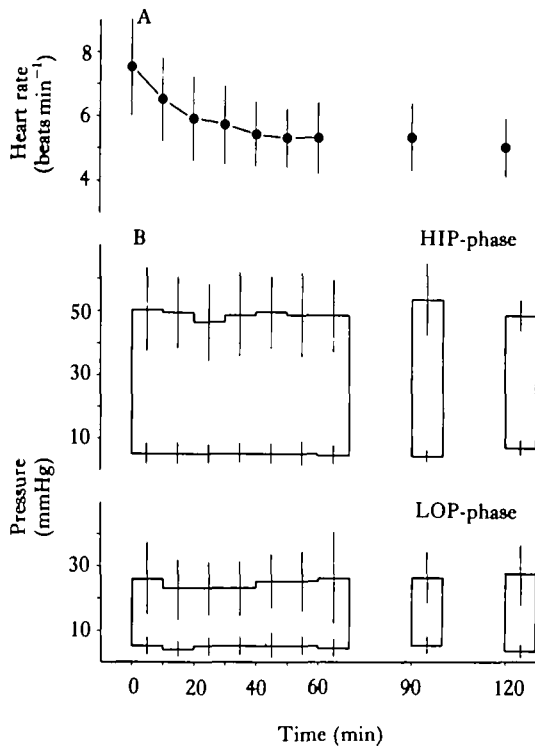


Fig. 2. (A) Mean heart rate during the first 2 h of the experiments. The mean was calculated by summing the values of 10-min periods. $N = 28$ animals, mean \pm s.e. (B) Mean systolic and diastolic pressure obtained over a period of 2 h. HIP-phase, upper diagram; LOP-phase, lower diagram. The mean was calculated by summing the values of 10-min periods. $N = 28$ animals, mean \pm s.e.

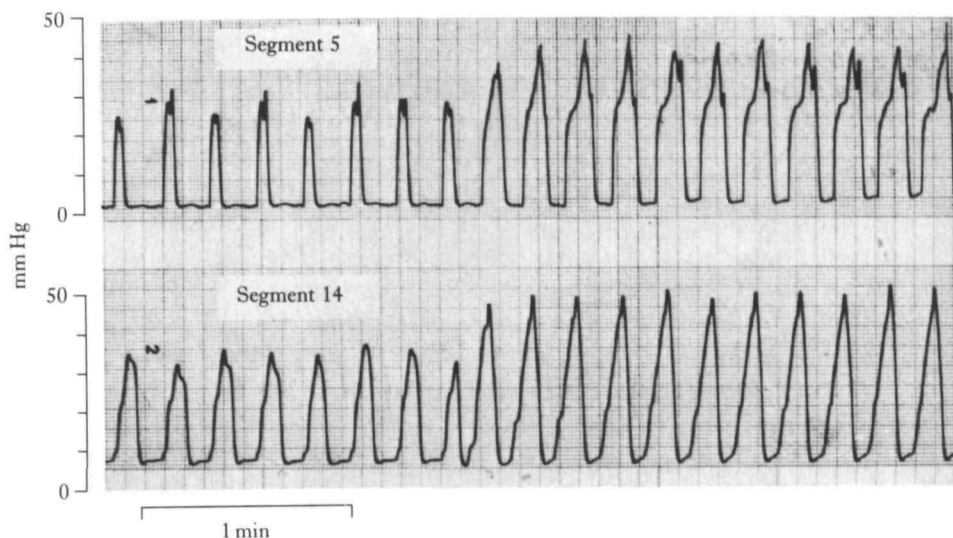


Fig. 3. Simultaneous recording of the blood pressure in the right lateral vessel in segment 5 (upper trace) and segment 14 (lower trace), showing the transition from LOP- to HIP-phase.

the pressure pulses in segments 14 and 5 started almost simultaneously. In the HIP-phase the systole in segment 14 started when the heart tube in segment 5 was still in diastole (Fig. 3). The high pressure pulses were thus achieved during the peristaltic mode of the lateral vessel, and low pressure pulses during the non-peristaltic mode. This coincidence of the HIP-phase and the peristaltic mode, and the LOP-phase and the non-peristaltic mode was found in all segments examined.

Simultaneous pressure recordings of both heart tubes in one segment demonstrated that one lateral vessel generated LOP-pulses while the other one produced HIP-pulses. Identical constriction modes in both lateral vessels were never found. After 20–60 heart beats a transition occurred, the heart tube with LOP-pulses switched to HIP-pulses and *vice versa* (Fig. 1). The reciprocal transition of HIP- and LOP-phases could be accomplished during a single pressure pulse or could extend over two or more pressure pulses. This is in agreement with results obtained by intracellular recording from the heart motoneurons (HE) in an isolated nerve cord (Calabrese, 1977).

DISCUSSION

Hirudo medicinalis represents a further example of an invertebrate with a closed circulatory system capable of producing a remarkably high blood pressure. The heart tubes of this leech are able to generate pressure pulses as high as 100 mmHg. In this they resemble those found in *Glossoscolex giganteus*, the first annelid of which blood pressure recordings have been published (Johansen & Martin, 1965).

In the leech, the two propulsive blood pumping organs extend over the entire length of the animal. They produce a rhythmic, bilateral antiphasic HIP- and LOP-pulse pattern, which is unique. The HIP-phase is connected with the peristaltic mode and the LOP-phase with the non-peristaltic mode, but peristalsis mainly occurs in the

eight anterior segments. In the posterior segments the heart tubes always constrict synchronously, independent of the mode expressed by the particular anterior body half (Thompson & Stent, 1976). HIP- and LOP-phases however, occur in the anterior as well as in the posterior segments (Fig. 3, segments 5 and 14), so the peristaltic or non-peristaltic mode of contraction is not responsible for the development of both the different pressure amplitudes. The pressure level in the lateral heart tubes may depend on various parameters. Johansen & Martin (1965) discuss for the earthworm, *Glossoscolex giganteus*, that the force of contraction of the lateral hearts depends on their end-diastolic volume or distension. In the leech, information about this is lacking. Another possibility could be the neural modulation of the force developed by the heart muscle (R. L. Calabrese, personal communication).

The blood flow is not only influenced by the heart blood pressure and the peripheral resistance but also by the heart frequency. In contrast to the investigation of Fournier & Pax (1972) on the earthworm, *Lumbricus terrestris*, our experiments indicate no correlation between heart rate and systolic pressure in the leech.

The functional consequences of the two pressure phases (HIP- and LOP-phases) and the corresponding constriction modes in the anterior region of the heart tubes are still unknown. Our further investigations will focus primarily on the regulation of the segmental blood flow.

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