THE ELECTROCARDIOGRAM OF THE FRESHWATER BIVALVE *LAMPSILIS RADIATA* (BIVALVIA: UNIONIDAE)

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ABSTRACT

The electrocardiographic configuration of the freshwater mussel Lampsilis radiata *was investigated and described using three standard leads, three augmented leads, and one unipolar lead. Electrocardiograms demonstrated depolarization complexes for both the atria and the ventricle. Longitudinal mean electric axis of the ventricle revealed anterior-to-posterior depolarization and repolarization from posterior-to-anterior. Heart rates were irregular and bradycardic due to the electrocardiographic measurement while the valves of the mussels were closed.*

Electrocardiographic studies in Bivalvia have been employed mainly as a measure of the animals response to various environmental stimuli (Crozier and Stier, 1924; Pickens, 1965; Helm and Trueman, 1967; Trueman, 1967; Coleman and Trueman, 1972; Trueman, et al., 1973). The majority of these studies used marine bivalves, freshwater species being almost completely ignored. Further, most molluscan electrocardiographic studies have only one lead which results in presentation of "rhythm strips" which provide information only on heart rates and their regularity. The present paper describes the electrocardiographic configuration of the North American freshwater mussel, *Lampsilis radiata* (Lamarck, 1819), as revealed by a seven lead system.

METHODS

Electrocardiograms (ECGs) were made for 10 specimens (6 males and 4 females) of *L. radiata* taken from Beech Fork of Twelve Pole Creek, Wayne County, West Virginia. The mussels were maintained in an aquarium for two weeks prior to recording the ECGs. Weight, water displacement, and shell dimensions were measured before each ECG was made.

Two 25 gauge hypodermic needles were placed such that one needle entered between the margins of the valves 2 cm from the anterior and the other 2 cm from the posterior margins of the umbonal ligament. In this manner, electrodes were thus located at the anterior and posterior margins of the pericardium. A third 25 gauge needle was placed in the foot, directly beneath the umbo (Fig. 1). All recording equipment was manufactured by Harvard Apparatus. The needles were connected to a model 369 EKG lead selector with a model 354 bioamplifier input module such that the anterior needle was connected to the left arm input, the posterior needle was connected to the right arm input, and the foot needle was connected to the left leg input. ECGs were preamplified with a model 371A preamplifier with a gain control variable to over 100 and a bandwidth of 0.2 Hz to 12.0 kHz at a gain of 100 and a bandwidth of 0.2 Hz to 4.5 kHz at a gain of 1000. A 10-speed chart mover (0.005 cm/sec to 5 cm/sec) equipped with a model 283 event/time marker module (1 min/ 10 sec/ 1 sec intervals) and a model 350 recorder were used.

Leads measured were I, II, III, aVR, aVL, aVF, and a single unipolar lead recorded by connecting the foot electrode to the chest input jack. ECGs were measured at a variable speed and amplication. Once amplitude was established for a mussel, the entire ECG was run at that amplitude. ECGs were run continuously, using lead II, for one hour intervals to determine rhythmicity. All ECGs were obtained while the mussels were lying on their left valve in a wooden pan of water at 22°C and a pH of 7.5.

blood by a "milking" action of the ventricle. Ventricular QRS complexes were seen to be positive deflections only in a *Vr* and were negative in all other leads.

No T waves could be demonstrated for the QRS_a as they occurred during the repolarization of the ventricle. This is explained by the fact that the repolarization signal of the ventricle, being stronger than the repolarization wave of the atria, will take precedence over weaker signals. Thus, the repolarization of signal of the atria was buried in the T wave of the ventricle. Ventricular T waves had a mean duration of 2.2 sec (range 1.3-4.6 sec). T waves were negative only in aVr and were positive in all other leads.

The placement of the electrodes (Fig. 1) allowed measurement of the mean electrical axis in the longitudinal plane which was desirable, as the heart of *L. radiata* lies in this plane. The mean electrical axis of ventricular depolarization (Fig. 3) was −165° (range −111° − +54°) while the mean axis of ventricular repolarization was −21° (range ±0° −60°). Thus the ventricle of *L. radiata* depolarizes, or contracts, in an anterior to posterior direction and repolarizes posterior to anterior. This may be visualized by superimposing Figure 1 over Figure 3.

The heart rate of *L. radiata* had a mean of 9.5 beats/minute (range 3-18). Rates were irrregularly irregular and long periods of asystole were noted in some ECGs. Ventricular QT intervals had a mean duration of 3.5 sec (range 1.6-60 sec). Other studies (Coleman and Trueman, 1971; Trueman and Lowe, 1971) demonstrated bradycardia in the ECGs of marine Bivalvia recorded while the valves were closed. All of the ECGs of *L. radiata* were recorded under these conditions. The low heart rates may be due to reduced metabolic requirements when the valves are closed (Hill and Welsh, 1966; Coleman and Trueman, 1971), and our data suggests the same mechanism may be present in freshwater mussels. However, further studies are necessary to determine if the position in which the ECGs were recorded, which was different from the position normally assumed by the mussels in their natural habitat, plays a significant role in heart rate. Another aspect of interpretation of ECGs from mussels by the technique used in this study is the degree of change in "normal" ECG findings caused by the invasive method of electrode placement. No correlation between weight, size, or sex could be found for the electrocardiographic intervals measured.

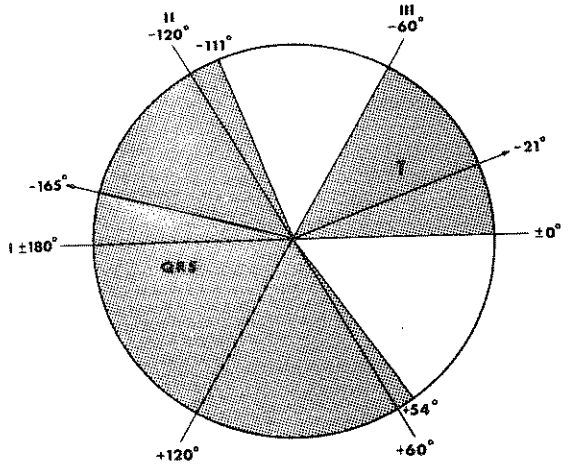

FIG. 3. *Mean electrical axis and distribution for ventricular depolarization (QRS) and repolarization (T) in* L. radiata. *Arrows indicate the arithmetic mean of these axes.*

LITERATURE CITED

Coleman, N., and E. R. Trueman. 1971. The effect of aerial exposure on the activity of the mussels *Mytilus edulis* L. and *Modiolus modiolus* (L.). *Jour. Exp. Mar. Biol. Ecol.*, **7:** 295-304.

Crozier, W. J., and T. B. Stier. 1924. Temperature characteristics for heart beat frequency in *Limax*. *Jour. Gen. Physiol.*, **7:** 705-708.

Helm, M. M., and E. R. Trueman. 1967. The effect of exposure on the heart rate of the mussel *Mytilus edulis* L. *Comp. Biochem. Physiol.* **21:** 171-177.

Hill, R. B., and J. H. Welsh. 1966. Heart, circulation, and blood cells. In, *Physiology of Mollusca*, Vol. 2, K. M. Wilbur and C. M. Yonge, Eds. Academic Press, New York. pp. 125-174.

Lowe, G. A., and E. R. Trueman. 1972. The heart and water flow rates of *Mya arenaria* (Bivalvia: Mollusca) at different metabolic levels. *Comp. Biochem. Physiol.* **41A:** 487-494.

Pickens, P. E. 1965. Heart rates of mussels as a function of latitude, intertidal height, and acclimation temperature. *Physiol. Zool*, **38:** 390-405.

Trueman, E. R. 1967. Activity and heart rate of bivalve molluscs in their natural habitat. *Nature* **214:** 832-833.

Trueman, E. R., and G. A. Lowe. 1971. The effect of temperature and littoral exposure on the heart rate of a bivalve mollusc, *Isognomon alatus*, in tropical conditions. *Comp. Biochem. Physiol.* **38A:** 555-564.

Trueman, E. R., J. G. Blatchford, H. D. Jones, and G. A. Lowe. 1973. Recordings of the heart rate and activity of molluscs in their natural habitat. *Malacologia* **14:** 377-383.

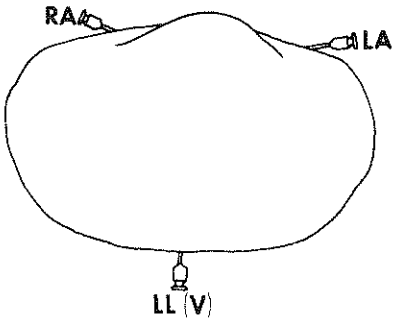

FIG. 1. *Placement of the needle electrodes in* L. radiata. *The left arm electrode (LA) was placed in the anterior end of the mussel and the right arm electrode (RA) was placed in the posterior end. The left leg electrode (LL) was placed in the foot and was used to record the single unipolar lead (V). Electrodes were connected to appropriate input jacks on an EKG lead selector.*

Electrocardiographic intervals analyzed were the QRS complex (which measures the time elapsed during contraction (depolarization), and the strength on contraction), the T wave (which measures the elapsed time during which the heart prepares for the next contraction (repolarization)), and the QT interval which measures the total elapsed time between depolarization and repolarization. The mean electrical axis, which is a measure of the general direction of depolarization and repolarization, was determined by taking the algebraic sum of R waves (+) and S waves (−) of leads I and III and plotting the result on a triaxial reference system. The axis was measured in the longitudinal plane due to the placement of the needle electrodes and was measured for both depolarization and repolarization of the ventricle.

The bivalves were identified by Dr. David H. Stansbery of the Ohio State University Museum of Zoology, The Ohio State University, Columbus, Ohio, where voucher specimens were placed in the collections. Other voucher specimens are in the Marshall University Malacological Collection (MUMC 17), Marshall University, Huntington, West Virginia, and the Delaware Museum of Natural History, Greenville, Delaware (DNMH 107101).

RESULTS AND DISCUSSION

Interpretation of the ECG wave components of *L. radiata* was complicated by the presence of two distinct QRS complex forms (Fig. 2). These complexes could not be related to each other in terms of duration or sequence timing. As the heart of *L. radiata* is composed of a single ventricle and two smaller atria, connected to the ventricle by small vessels, and the ventricle is the largest chamber of the heart, the strongest QRS deflections were interpreted as being ventricular in origin and the smaller complexes as originating from the atria. This phenomenon was best seen in leads I, aVL, and the unipolar foot, or V lead, in the majority of tracings. The QRS of the ventricle (QRS_v) had a mean duration of 1.4 sec (range 0.8-2.0 sec) and the mean duration of the atrial QRS complex (QRS_a) was 0.6 sec (range 0.6-0.8 sec). The smaller size of the QRS_a is to be expected as the atria are smaller and the amount of work necessary to pump blood to the ventricle is less than that required to pump blood to the entire body. The shorter duration of contraction periods of the atria support this supposition. Also, the longer contraction periods of the ventricle may be necessary to pump the molluscan

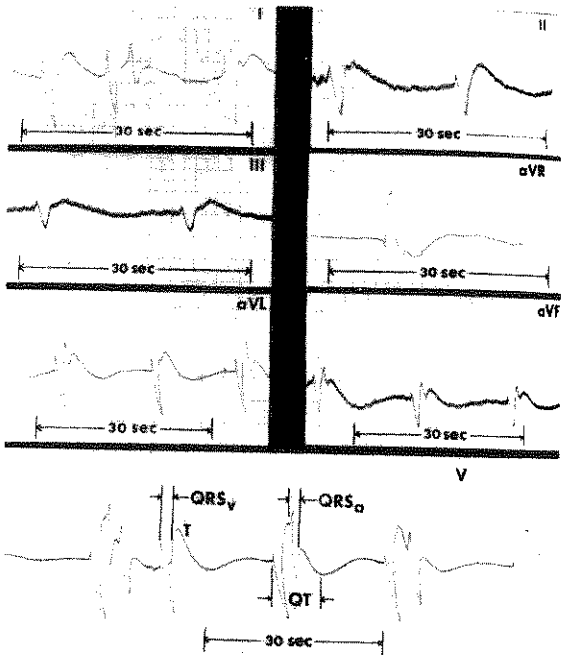

FIG. 2. *Representative electrocardiogram of* L. radiata *demonstrating the independently occurring ventricular (QRS_v) and atrial (QRS_a) depolarization complexes.*