Comparison of Propagation of Atrial Excitation with the Cardiopotential Distribution on the Body Surface of Fish

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Abstract. *This research was aimed at studying the sequence of depolarization the atrial epicardium and formation of the cardioelectric field on the body surface (BSPM) of Atlantic cod Gadus morchua (n=9). The initial zone of depolarization appeared on the atrial epicardium of fish before the origin of the P-wave in the ECGII. During the ascending phase of the PII-wave the excitation wave evenly spread from the caudal part of the dorsal side to the cranial part in the right-lateral area of atria. At the peak of the PII-wave and during the first half of the descending phase of the PII-wave the dorsal side and the caudal part of the ventral side in the right-lateral area of atria were depolarized. Atrial depolarization during initial phases of are projected on BSPM by the distribution of zones of positive and negative cardiopotentials before the beginning of the P–wave in the ECG. The location of zones of positive and negative cardiopotentials and the movement of extrema on the BSPM reflect the propagation of the excitation wave along the atrium from the venous sinus to the heart ventricle of fish.*

Keywords: *atrial depolarization, body surface potential map, epicardium, Atlantic cod Gadus morchua*

1. Introduction

The heart of poikilotherms consists of one atrium and ventricle [1]. In the fish heart there is only one specialized system: the pacemaker [2]. The ring-shaped structure around the venous sinus can function as a pacemaker in Zebrafish [3].

In European grayling and pike, the depolarization wave successively spreads along atrial walls from the sino-atrial area to the atrioventricular opening providing a successive contraction of the heart walls from sino-atrial area to the atrioventricular opening [4].

In mammals, the sequence of atrial depolarization is reflected on BSMP by the location of areas of positive and negative cardioelectric potentials [5, 6].

The pattern of the sequence of atrial depolarization and regularities of the reflection of excitation on BSPM in fish is not described.

This research was aimed at studying the sequence of depolarization along the atrial epicardium and formation of the cardioelectric field on the body surface of Atlantic cod *Gadus morchua*.

2. Methods

Subject and Animals
Experiments were carried out on nine Atlantic cod *Gadus morchua* (a habitat of the White Sea, Republic of Karelia). Fish were caught by fixed nets and spinning. They were placed on a specially made table, a tube through which water was given to gills was inserted in a mouth (the water temperature was kept within the limits of natural habitat t = 12-11° C).

The investigation conforms with the Guide for the Care and Use of Laboratory Animals published by the US National Institutes of Health (NIH Publication No. 85–23, revised 1996) and was approved by an institutional ethical committee.

Experimental protocol

Body surface potential mappings (BSPM) were simultaneously recorded from 32 subcutaneous needle electrodes (registering surface-0.06 cm2), uniformly distributed on the torso surface of fish. After opening the thorax and cutting the pericardium, by using multipolar electrode with 40 leads (contacting electrode surface 0.004 cm2) unipolar epicardial electrograms (EG) were recorded from atria in the same fish (32 deferent electrodes were placed on the dorsal side of the atrium, and 8 discharging electrodes were placed on the ventral surface).

Electrocardiography

Simultaneous data acquisition was done by means of a custom-designed mapping system (16 bits; bandwidth 0.05 to 1000 Hz; sampling rate 4000 Hz) [7]. Unipolar epicardial electrograms EG and ECGs were recorded in reference to Wilson's central terminal. By unipolar ECGs from the body surface isopotential mappings were constructed. Sequence of spreading of the excitation wave was constructed through the first temporal derivative of epicardial EG. BSMP and sequence of epicardial depolarization were compared relative to R-peak in the ECGII in the limb leads. The data processing was carried out using the software of our development [7].

Statistical analysis

Data were analyzed using Statistica software version 6.0 for Windows statistical package (StatSoft, Inc., Tulsa, OK, USA). All results were expressed as mean±standard deviation. Statistical analysis was performed using an independent samples t-test. Differences were considered to be statistically significant if the p value was <0.05.

3. Results

Before the beginning of the P-wave in the ECG II from the limb leads, on the atrial epicardium of fish the initial zone of depolarization appears in the caudal part of the dorsal side (Fig. 1, D, - 269.00 ms). On BSMP in this period of time (Fig. 1, A, - 269.00 ms), the area of positive cardiopotentials occupies the largest part of the ventral and dorsal sides, the area of negative potentials occupies the caudal part of the dorsal side, the positive extremum is located left-laterally from the ventral side, the negative one – caudally in the middle part of the dorsal side.

During the ascending phase of the P_{II}-wave, the excitation (Fig. 1, D, - 246.00 ms) evenly spreads along the atrial epicardium from the caudal part of the dorsal side to the cranial part along the right-lateral area. On BSMP (Fig. 1, A, - 246.00 ms) the zone of negative potentials increases and occupies the left-lateral part of ventral and dorsal sides, while the zone of positive ones is situated right-laterally from the ventral and dorsal sides. Such location of the areas of positive and negative cardiopotentials remains up to the peak of the P_{II}-wave. During the ascending phase of the P_{II}-wave, on BSMP the extrema move cranially: the positive extremum – to the ventral side, the negative extremum – to the middle part of the dorsal side. Such location of the extrema remains in the peak and the descending phase of the P_{II}-wave.

In the peak and the first half of the descending phase of the PII-wave, on the atrial epicardium (Fig. 1, D, - 213.50 ms) the whole dorsal side and the caudal part of the ventral side in the right-lateral area are depolarized. During the first half of the descending phase of the PII-wave on BSMP, (Fig. 1, A, - 213.50 ms) the area of positive cardioelectrical potentials increases and occupies the largest part of the ventral and dorsal sides, whereas the area of negative ones shifts and occupies the caudal part of the dorsal side.

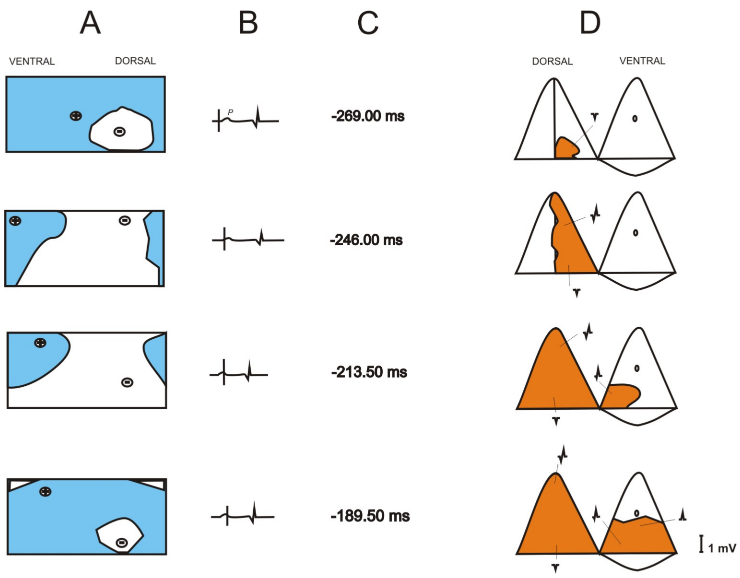

Fig. 1 Sequence of depolarization along the atrial epicardium and formation of the cardioelectric field on the body surface of Atlantic cod *Gadus morchua*.

By the end of the PII-wave (Fig. 1, D, - 189.50 ms) while spreading along the epicardium the excitation wave reaches the junction of the atrium and ventricle.

Isopotential body surface map (BSPM) on the fish's body surface (A). Shaded areas are positive potentials; «+» and «-» - locations of positive and negative extrema. ECG in the II limb lead with the time market (vertical line) (B). Time of time market relative to the peak RII (C) Scheme of sequence of the excitation wave on atrium epicardium of fish. (D) Near the map there are original electrograms registered in the areas marked with pointers.

4. Discussion

Before the beginning of the *P*-wave in the ECG II on the atrial epicardium of fish, the initial zone of depolarization appears which is reflected on BSMP by a characteristic location of areas of positive and negative cardioelectric potentials. On the body surface of mammals the inversion of mutual location of areas of positive and negative potentials is observed before the beginning of the *P*-wave in the ECG II [8]. On BSMP of fish during atrial depolarization, the inversion of mutual location of the areas of positive and negative potentials isn't observed before the beginning in the ECG II of the *P*-wave. It's connected with a simple organization of the conducting system of the fish heart [3]. The early zone of atrial depolarization in fish is located in the place of the junction of the sinous node and atrium. It is known that in African lungfish the pacemaker of the first order is located in the sinous node, under certain conditions the pacemaker can shift [9]. The distribution of the excitation wave through the atrium in zebrafish happens evenly, there is a small delay in excitation passing from the atrium to the ventricle [10].

On BSMP during ascending and descending phases of the PII-wave, there are no significant changes in the location of positive and negative cardiopotentials. During the ascending phase of the PII-wave, the excitation wave evenly spreads along the atrial epicardium from the caudal part of the dorsal side to the cranial part in the right-lateral area. At the peak of the PII-wave and during the first half of the descending phase of the PII-wave, on the epicardium the whole dorsal side and the caudal part of the ventral side in the right-lateral atrial area are depolarized. In mammals, the shift of positive and negative extrema on BSMP during the ascending phase of the P-wave is associated with the passage of the excitation wave from the right atrium to the left one [5, 11, 12]. In fish, on BSMP the movement of extrema reflects the passage of the excitation wave from the caudal part to the cranial one along the dorsal side and from the dorsal side to the ventral side along a single atrium.

Study limitations

Cold-blooded animals depend on the ambient temperature. During the experiment, we kept the temperature of the animal body within 10 - 12° C. Changing the temperature of fish will significantly influence the myocardial electrical activity.

5. Conclusion

Initial phases of atrial depolarization are projected on body surface potential map by the distribution of zones of positive and negative cardiopotentials before the beginning of the P–wave in the ECG. The location of zones of positive and negative cardiopotentials and the movement of extrema on the cardioelectric field on body surface reflect the propagation of the excitation wave along the atrium from the venous sinus to the heart ventricle of fish.

Acknowledgments

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