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Electrocardiogram and heart rate in response to temperature acclimation in three representative vertebrates

Chong-bin Liu [a,b], Ren-de Li [a,*]

[a] School of Life Sciences, Lanzhou University, Gansu, Lanzhou, 730000, PR China
[b] Department of Life Science, Jinggangshan College, Jiangxi, Ji'an, 343009, PR China

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Abstract

Comparisons of electrocardiogram (ECG) and heart rate characteristics of three representative species in response to temperature acclimation were studied. In toad (*Bufo raddei*), T wave had positive, negative and flat patterns, which was different from positive in lizard (*Eremias multiocellata*), blunt and broad in bird (*Alectories magna*). The duration of P–R interval, Q–T interval and QRS complex interval reduced with increasing temperature in toad, but the P–R and T–P intervals were affected mostly, the QRS and R–T intervals were relatively less affected in lizard. In the bird, the voltage of P, S and T wave scarcely changed, R wave increased slightly with temperature going up in the thermal neutral zone (20–35 °C), T and S waves tended to increase and P–S and S–T intervals shortened when temperature went below the neutral zone. Heart rate was high and relatively steady in bird, but changed linearly in relation to temperature in toad and lizard. The increasing of heart rate with temperature was mainly caused by the T–P interval shortened in lizard, but P–S and S–T intervals shortened in bird. Comparisons of ECG and heart rate characteristics of three representative species in response to temperature acclimation reflected phylogenetically based constraints on pacemaker rates, oxygen supply and modulatory mechanisms.

Keywords: Acclimation; Bird; Body temperature; Cardiac control; ECG; Evolution; Heart rate; Lizard; Phylogeny; Toad; Wave pattern

1. Introduction

We previously reported that the ECG and heart rate of lizard, *Phrynocephalus przewalskii* (Li and Liu, 1992) and bird, *Alectories magna* (Li et al., 1998) were profoundly influenced in response to temperature acclimation, which were basically in accordance with those of the lizards reported by Dawson and Bartholomew (1958), Dawson (1960), Dawson and Templeton (1963), Bartholomew and Tucker (1963), Bartholomew (1964), Licht (1965), Boyer (1967), Wilson and Lee (1970), McDonald and Heath (1971), Yackzan et al. (1972), Mullen (1967, 1974a,b), Porcell and Gonzalez (1986), Gonzalez-Gonzalez and Molina-Borja (1991), and Seebacher (2000) and the Aves reported by Kisch (1951), Szabuniewicz (1967), Hunsaker (1971), Hill and Goldberg (1980), Lumeij and Stokhof (1985), Sturkie (1957,1986), Cinar et al. (1996), Xia et al. (1997), and Ai et al. (2004). However, there was relatively little information about the effects of temperature on the various ECG segments and comparisons of ECG and heart rate characteristics of phylogenetic species in response to temperature acclimation were greatly lacking.

Compared with other vertebrates, amphibians have only spongy or trabecular type myocardium, the ventricular spongiosa of reptiles is encased by myocardium which comprises 20–40% of the ventricular mass, the heart of birds consists of two atria and two ventricles. Because of the differing phylogeny, we wondered about the different characteristics of ECG among amphibians, reptiles and birds, and evolutionary patterns from ectotherms to endotherms. For this purpose, we made a comparative study of ECG and heart rates (HRs) among three phylogenetic species in response to temperature acclimation and reported our work conducted on the toad, *Bufo raddei* Strauch, small ovoviviparous lizard, *Eremias multiocellata* and wild bird, *A.*

* Corresponding author. Tel.: +86 931 8913066; fax: +86 931 8912562.
E-mail address: lird@lzu.edu.cn (R. Li).

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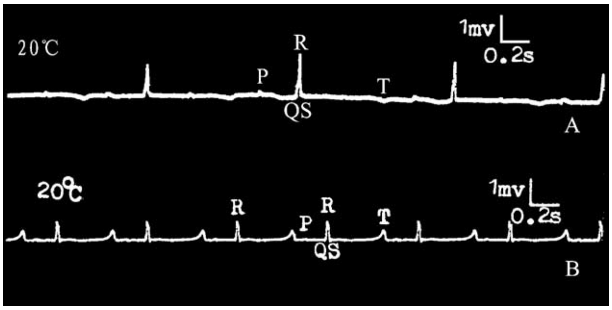

Fig. 1. ECG of two ectotherms at the same body temperature (20 °C) showed that T wave was frequently directed downward in toad, but T wave was upright or positive in lizard.

magna distributed in the desert and semi-desert area in the northwest of China. We suggest that incorporation of representative species in addition to phylogenetic analysis in comparative studies will help to increase our insight on the underlying mechanisms of differences in ECG recordings and the characteristics related to the evolutions of ectotherms and endotherms, particularly in the ectothermic vertebrates.

2. Materials and methods

2.1. Animals

Healthy adult toads (*B. raddei* Strauch) of either sex, weighing 10.41±1.60 g, and lizards (*E. multiocellata*) of either sex, weighing 7.03±1.40 g, snout vent length (SVL) was 60.6±4.9 mm, and wild birds (*A. magna*) of both sexes, weighing 513.1±69.5 g, were used after being captured in the desert and semi-desert area in Gansu province (China). They were housed in the laboratory (25–28 °C) and acclimated for at least 2 weeks and given free access to feed and water before the experiment. Artificial illumination was 12 h light/12 h dark.

2.2. Experimental methods

The ECG was recorded from unrestrained animals using a cardiac coupler electrocardiograph recorder (NARCO, Bio-Systems). Recording methods for limb leads in toads, lizards and wild birds were the same as that in humans. The needle electrodes were subcutaneously inserted in the limbs about 5 mm deep or the bases of the wings after animals being restrained. Acclimation was accomplished by keeping animals in a thermostat controlled ambient (over room temperature) or a thermostat controlled refrigerator (below room temperature) and equilibrated for at least 2 h before recording. After introducing a thermometer probe (Yellow Spring Instrument) into the cloaca, the animals with the attached electrodes were placed in 7 acclimated temperature situations—5, 10, 15, 20, 25, 30 and 35 °C. The recording was started 15 min after the set temperature reached and lasted 4–5 h. The speed of recording paper of ECG was 25 mm/s (in toads and lizards) and 50 mm/s (in birds) respectively. Body temperature (± 0.1 °C) was continually monitored and the records of animals were chosen for analysis. Each experiment was conducted at least 7 days apart and spanned multiple days.

2.3. Analysis methods for ECG

Data were read from the record, quantified and plotted against heart rate or body temperature. Data were presented as mean±S.E. and statistical analysis were performed using One-way ANOVA ($P<0.05$) followed by Bartlett's test for homogeneity of variances and Tukey–Kramer multiple comparisons test. Regression lines were calculated using a computer based Origin 6.1 program.

3. Results

3.1. Comparison of wave pattern characteristics of two ectotherms at the same body temperature

Fig. 1 showed original recordings of ECG of two ectotherms at 20 °C (lead II). In toad, Fig. 1A showed that T wave was frequently directed downward, opposite to the polarity of the QRS wave; the P wave was of very low relative amplitude and upright. In lizard, Fig. 1B showed that T wave was upright or positive and its amplitude was higher than P wave; the Q wave was very small and usually could not be seen.

3.2. Comparison of ECG and heart rates of toads at different body temperatures

Fig. 2 showed original recordings of ECG at 7 different body temperatures. The ECG pattern was profoundly influenced: T wave has positive, negative and flat patterns, some individuals displayed bipolar pattern; the duration of P–R interval, Q–T interval, and QRS complex interval reduced with increasing body temperature. Heart rate in toads changed linearly in relation to body temperature (Table 1). The differences were significant when being compared among

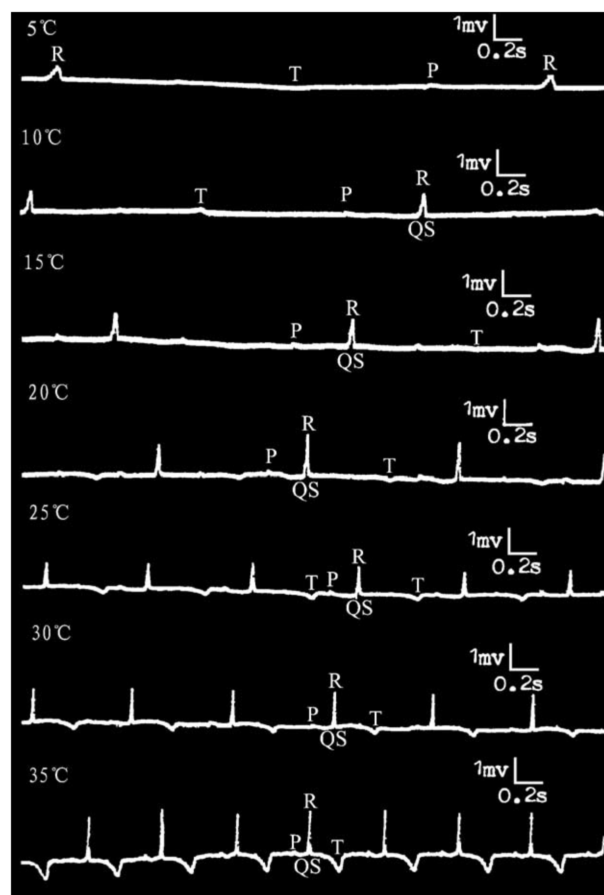

Fig. 2. ECG of toad *Bufo raddei* Strauch at different body temperatures showed the duration of P–R interval, Q–T interval, and QRS complex interval reduced with increasing body temperature.