Comparative Electrocardiographical Studies on the Wave Form of QRS Complex in Vertebrates

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Abstract. Bipolar electrocardiograms along the longitudinal heart axis (A-B lead) were recorded on twenty species of vertebrates. The wave forms of the QRS complex indicating the activation process in the ventricles were compared among these species from a comparative electrocardiographical point of view. They were arranged phylogenically in the order of Rs → RS → rS or Rs (qRs) types. The shifting process in the wave forms of the QRS complex was the same as that observed ontogenically in the chick embryo and the rat foetus.

The formation of the heart in vertebrates varied with species from an incomplete heart to a complete one. The conduction system of the heart was investigated morphologically and functionally in detail in man. In any other species of vertebrates, however, no studies on the relationship between the electrocardiographical characteristics and the distribution of specific cardiac muscles were performed. Several papers have been published to deal with the functional approach to the heart in a given species of vertebrates. Few reports, however, have been made from a comparative electrocardiographical point of view. In the previous paper [9] comparative electrocardiographical studies were done on the activation time in each part of the heart in vertebrates. In the present paper, the wave forms of the QRS complex in the electrocardiograms of several vertebrates were investigated from above-mentioned point of view.

Materials and Methods

The species of vertebrates used for the present investigation were the following twenty:

Primates: man (Japanese), monkey (Rhesus monkey, Marmoset)

Ungulata: Ruminants

cattle (Japanese Black), goat (Japanese native)

Non-ruminants

horse (Thoroughbred), pig (Landrace)

Carnivora: dog (mongrel), cat (hybrid)

Lagomorpha: rabbit (Japanese White)

Rodentia: rat (Wistar strain), mouse (JCL-ICR stock)

Aves: fowl (White Leghorn hybrid), quail (Japanese)

Reptilia: alligator (caiman)

Amphibia: newt (*Triturus pyrrhagaster*), frog (*Rana nigromaculata*)

Pisces: carp (*Cyprinus carpio*), shark (*Triakis scyllia*), ray (*Urolophus aurantiacus*)

The wave forms of electrocardiograms are altered by the relationships between the positions of electrodes and the localization of the heart in the thoracic cavity. In order to compare them among many species of animals, electrodes must be placed in the same position in relation to the heart.

In the present investigation, electrocardiograms of A-B lead were recorded in all the species of

animals used. The A-B lead was unified as a common bipolar lead by the Japanese Association of Animal Electrocardiography in 1968. It was a bipolar lead along the longitudinal heart axis. One electrode was placed at the apex as the positive one, and the other at the base of the heart as the negative one.

Electrocardiograms were recorded in all the animal species under the unanesthetized and no restrained condition except a few species which were under mild anesthesia and restrained conditions.

In several species of animals, especially in poikilothermic animals, electrodes were placed near the heart under the open chest condition.

Electrocardiograms were recorded by the electrocardiograph and the direct recording apparatus for a cathode-ray oscilloscope. The two recording methods were employed, because the present subjects showed a heart rate varying from several to several hundred per minute. They were applied to the following animal species.

Electrocardiograph: man, monkey, marmoset, cattle, pig, goat, horse, dog, cat, shark and ray.

Direct recording apparatus for a cathode-ray oscilloscope: rabbit, rat, mouse, fowl, quail, alligator, newt, frog and carp.

The paper speed was set at 50, 200 or 500 mm per second, so that all deflections might be recorded distinctly.

Results

The electrocardiograms of Primates are indicated in Fig. 1. The electrocardiogram of man recorded by the second limb lead for man is the same as that recorded by A-B lead for other animals, because electrodes are placed along the longitudinal heart axis in both leads. In the electrocardiograms of man, rhesus monkeys and marmosets, the P wave and T wave were positive, and the QRS complexes identified as the Rs or qRs type. The Carnivora presented the same characteristics of the wave forms as the Primates (Fig. 2).

The electrocardiograms of Lagomorpha and Rodentia are indicated in Fig. 3. Both animals exhibited positive P wave and T wave. The QRS complexes, however, the RS type in the former animals, and the Rs

Fig. 1. Electrocardiograms of Primates

Fig. 2. Electrocardiograms of Carnivora

Fig. 3. Electrocardiograms of Lagomorpha and Rodentia

type in the latter.

The deflections of the QRS complexes in the Ungulata were different from those in any other mammalian species (Fig. 4), regardless of the classification of ruminants and non-ruminants. The P and T wave of the Ungulata were also positive like those of any other mammal. The QRS complexes of those animals, however, were the rS type which was superior to the negative deflection.

Electrocardiograms of the Aves are shown in Fig. 5. The P and T wave of birds were positive. The deflection of the QRS complex was the rS or QS type in the Aves as in the Ungulata.

In the Fig. 6, the electrocardiograms of Reptilia and Amphibia are indicated. The P wave in them were positive. The deflections of the QRS complex were the Rs type. The T wave of a given animal was positive and/or negative.

Fig. 7 showed the electrocardiograms of several species of Pisces. The P and T wave in them were positive. The deflections of the QRS complex were the Rs type. The heart rates of the poikilothermic animals were affected remarkably with ambient temperature. Especially in the Pisces, bradycardia appeared when the temperature of the intrapericardiac cavity was low. Ex-

amples of bradycardia are given in electrocardiograms shown in Fig. 7. In the electrocardiograms of shark and ray, remarkable notches were recognized in the ST segment.

Fig. 4. Electrocardiograms of Ungulata

Fig. 5. Electrocardiograms of Aves

Fig. 6. Electrocardiograms of Reptilia and Amphibia

Fig. 7. Electrocardiograms of Pisces

Discussion

The electrocardiogram indicates the sum of electrical activities of the two kinds of cardiac muscles. The one kind is the specific cardiac muscle and the other the proper cardiac muscle. The deflections of the QRS complex in an electrocardiogram are designated the main vector of the ventricular exciting process. The direction of the main vector is related to the distribution of specific cardiac muscle in the ventricle. Therefore, it is possible to discuss the conductive direction in the ventricle on the basis of the polarity of deflections.

From the electrocardiographical characteristics of dogs, monkeys and man [3, 4, 11], it is reasonable to assume that these species may show the similar distribution of specific cardiac muscle in the ventricles, although few reports have been published on such distribution [6, 7, 14].

The longitudinal length of the heart is greater in the Ungulater with the sharp apex than in any other vertebrate species, although the free wall of the left ventricle is voluminous and the wall of its apex relatively thin. Some investigators reported the conduction system of the Ungulata [1, 2, 10,

14]. It is presumed that there may be a difference in the distribution of Purkinje fibers in the ventricle between the ungulate animals and any other mammalian species. From the electrocardiographical characteristics of the avian heart, it is assumed that the distribution of Purkinje fibers in the avian ventricle may resemble that in the ungulate ventricle.

The homothermic animals, such as Mammalia and Aves, have a complete heart composed of two auricles and two ventricles. On the contrary, the poikilothermic animals, such as Reptilia and Amphibia, have an incomplete heart composed of two auricles and one ventricle. There is a difference in the blood circulatory system between the homothermic and poikilothermic animals. The fundamental properties of the conduction system of the heart are the same in the homothermic animals as in the poikilothermic ones [9]. Because the deflections of the QRS complexes are manifested in the same type in the homothermic animals, except the Ungulata and the Aves, it follows that the main vectors of conduction in the ventricles of those animals proceed in the same direction.

The notch appearing in the ST segment

Fig. 8. Phylogenical situations of vertebrates and wave-forms of QRS-complexes for a given species

Class	Order	Family	ECG Pattern
Chondrichthyes	Elasmobranchia	Shark Ray	Rs
Osteichthyes	Teleostei	Carp	
Amphibia	Urodela	Newt	
	Anura	Frog	
Reptilia	Crocodylia	Caiman	rS
Aves	Galliformes	Quail Fowl	
	Artiodactyla	Pig Cattle Goat	
	Perissodactyla	Horse	
Mammalia	Carnivora	Dog Cat	Rs (RS)
	Rodentia	Rat Mouse	
	Lagomorpha	Rabbit	
	Primates	Monkey Man	

Fig. 9. Electrocardiograms of rat foetuses during their several developmental stages

of the Chondrichthyes, the so-called Bd wave (conal depolarization complex), was considered to be the action potential of the conus arteriosus [13]. It is assumed that the structure of the conus arteriosus is analogous to that of the dorsal vessels of insects from which is led an action potential [12]. The C wave, so-called first by Paff et al. (1975) and identified as the activity of the conus arteriosus, appeared in 72-hour chick embryos [8]. From these findings, it is presumed that the electrocardiogram of the Chondrichthyes may present an intermediate pattern between the invertebrate and the vertebrate.

The type of the QRS complex in the

vertebrates are arranged phylogenically in the following manner: $Rs \rightarrow RS \rightarrow rS$ or Rs (Fig. 8). The shifting process of the QRS complex types was demonstrated ontogenically in chick embryos [5]. The shifting was expressed in the order of $Rs \rightarrow RS \rightarrow rS$ types after the appearance of action potential on the 5th day of incubation, without any relation to the morphological completion of the heart. Furthermore, the shifting process of QRS complex deflection in the rat foetus started from the Rs type on the 14th day of conception. The adult Rs type appeared on the 19th day after the transient RS type was seen on the 16th day (Fig. 9).

From these results, it is concluded that

the primitive type of the QRS complex in the vertebrates may be mostly the Rs type ontogenically, and that the same process may be traced in all the species of vertebrates up to the RS type. Subsequently, however, the deflection of the QRS complex reaches a final pattern of rS and/or Rs (qRs) type depending on the animal species. It should be noted that the shifting process of deflection of the QRS complex phylogenically arranged is recapitulated in the ontogenical process.

The formation of four chambers is completed earlier than the appearance of the adult type of QRS complex in the chick embryos, as well as in the rat foetus. Therefore, it is assumed that the shifting process of deflection of the QRS complex may be concerned with the development of specific cardiac muscle or with the activating procedure in the conduction system of the heart.

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