VAGAL TONE IN THE LOWER APES (Macaques)

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I. A. Arshavskii, O. T. Vakhidova, S. I. Enikeeva, and D. U. Ermatova

Laboratory of the Physiology and Pathology of Aging (Head – Professor I. A. Arshavskii), Institute of Normal and Pathological Physiology (Director – Active Member AMN SSSR V. V. Parin), AMN SSSR, Moscow
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Work in our laboratory has shown that the development of vagal tone and fall in heart rate during postnatal development are directly related to the fall in respiratory rate which occurs at this time. In those mammals in which in the postnatal period there is either a very small reduction or no fall in respiration rate vagal tone fails to develop, and the natural heart rate is slowed very little or not at all [2, 4-10]. Our observations (I. A. Arshavskii and S. I. Enikeeva) on the respiration rate in the lower and man-like apes were carried out at various times in the Moscow Zoo, at the Sukhumskaya Medical and Biological Station, AMN SSSR, and at the Durov Center. It was found that in the adult lower apes (baboons, macaques, capuchin monkeys and marmosets) the natural respiration rate was twice as high as in the man-like apes (chimpanzees, orang-utan). In the lower apes, in the postnatal period (first few days of life) the natural respiration rate did fall, but the reduction was not so marked or striking as in dogs, cats, hares, or, in particular, man. In the lower apes, at an early age the lower limit of the respiration rate coincided with the upper rate in adults.

In the present work we have set out to study the features of the tonic excitation of the vagal innervation in lower apes.

EXPERIMENTAL METHOD

The experiments were carried out on 11 macaque rhesus apes. One ape was two months, two were 3-3½ months, two were 5-6 months old, and six were adult. Initially, long-term observations were made on all the apes: the ECG was recorded (from the three standard leads), respiration was measured (electrical recording), and the EEG was recorded (frontal and parieto-occipital leads).

The EEG was used to determine the condition of the ape (whether at rest or alert). The recording was made in a special cage which restricted movement. After the long-term observations, other measurements were made in a short session in which measurements were made of arterial pressure, or of the ECG during stimulation of the peripheral or central end of the vagus.

EXPERIMENTAL RESULTS

In apes aged 2-3 months the natural respiration rate at rest varied from 40 to 60 per minute, while the natural heart rate ranged from 180 to 220 beats per minute; in 5-6 months old and in adult apes the corresponding figures were 35-55, and 160-220 beats per minute.

Respiration and heart rates were considered "natural" when recorded at rest, when the EEG was desynchronized (low amplitude and high-frequency activity).

According to N. I. Lagutina and A. A. Furacheva [11] in new-born baboons, hamadryads, and macaque rhesus monkeys the heart rate was 180-220 beats per minute, while in animals it was 140-180 per minute. The lower end of the rate range in new-born apes coincided with the upper limit in adults. The heart rate in the macaque rhesus

was somewhat higher, possibly because of the smaller size of the experimental animals used. The weight of our adult apes ranged from 4.5 to 6 kg.

It has been shown that in adult macaque rhesus monkeys at rest a high respiration rate is associated with a high heart rate, and that we therefore attempted to find out whether or not vagus tone was present. A subcutaneous or intraperitoneal injection of 0.05 mg/kg atropine (which blocks the transmission of vagal impulses to the heart of adult dogs) caused no change in the natural heart rate, nor did a dose even as high as 0.1-0.2 mg/kg. It is known that in adult dogs in which vagal tone is well marked the subcutaneous injection of 10 mg/kg morphine increases the tone of the vagal cardiac innervation, as shown by a reduction of the original rate and an increased respiratory cardiac arrhythmia.

The injection of 10, 20, or even 30 mg/kg morphine caused no change in respiration or cardiac rates in monkeys. Investigations by our laboratory colleagues have shown that adult dogs (from $2\frac{1}{2}$ -3 months onwards) respond to an injection of a sublethal dose of staphylococcus toxin by an initial bradycardia, which represents the anabloic phase of the reaction [3, 14, 15]. However in monkeys this dose caused no change in the natural heart rate nor did it cause any tachycardia.

In dogs, in the postnatal period the changeover from the right-sided ECG to the normal type is correlated with the development of vagal tone. E. I. Arshavskaya found the same effect in children [1]. We have shown that the right-sided ECG is present not only in monkeys of 2-3 months, but also in adults. Only in three adult monkeys (1 and 6 months old) was a normal ECG and a normal high heart rate recorded.

Finally the recording of comparatively high P and T waves is evidence of the regulation of the natural heart rate by tonic subsidiary influences from the sympathetic and not from vagal cardiac centers. In adult dogs the ratio of the amplitude of the R wave to that of the P and T waves (in lead II) is 2-3 times greater than the ratio in adult monkeys.

In acute experiments also, in all the monkeys investigated results were obtained which differed essentially from those recorded in adult dogs. In dogs when the peripheral end of the vagus was stimulated by an induction coil or by an electronic stimulator operating at 20-30 cycles somewhat above maximal stimulus, at first the heart is completely arrested and remains motionless for 20-50 seconds; subsequent stimulation causes a change to the atrioventricular rhythm. As atrial diastole continues this condition persists as long as the stimulation is maintained (in our experiments up to 1 h or more). In adult dogs the phenomenon of escape is not shown by a changeover to the sinu-atrial rhythm.

In all studies of monkeys in which supramaximal stimuli are applied to the peripheral end of the vagus the phenomenon of cardiac arrest observed in dogs does not occur (Fig. 1). As stimulation continues the heart responds by a negative chronotropic reaction and a sinu-atrial rhythm is established, not an atrioventricular rhythm as in dogs (Fig. 2).

As in young puppies at the time when cardiac activity is subordinate to sympathetic influence, in adult macaques during prolonged peripheral vagal stimulation the R wave either maintains its original amplitude or else falls very slightly.

As we have already said, in adult dogs during prolonged vagal stimulation the heart may continue to beat at the slow atrioventricular rate for up to 1 h or more. However in adult macaques under these conditions the sinu-atrial rate is not maintained for more than 3-5 min, and in some cases it lasts for a shorter time, and then returns to the original rate (see Fig. 1).

The effects of stimulation of the peripheral end of the vagus may be blocked by intravenous atropine. As the investigations by V. D. Rozanova on dogs at different ages [13] shows the blocking of atropine is more pronounced the greater the vagal tone. It is extremely small in young puppies, in which vagal tone is absent. In adult macaques the dose of atropine required to block the vagi is one tenth or less of that required for the adult dog.

If the central end of one of the vagi is stimulated in the macaque, in cases when a depressor (and not a pressor) response developed it was shown only by a drop in arterial pressure and there was no change of heart rate. A depressor response shown by a combined reduction of arterial pressure and a reduced heart rate occurred only in cases when stimulation of the central end of the vagus produced a reflex arrest or a considerable slowing of respiration.

The results obtained lead us to conclude that in the macaque rhesus during the postnatal period no excitability in the vagal cardiac center develops. The characteristics of nervous regulation of cardiac activity are the same for

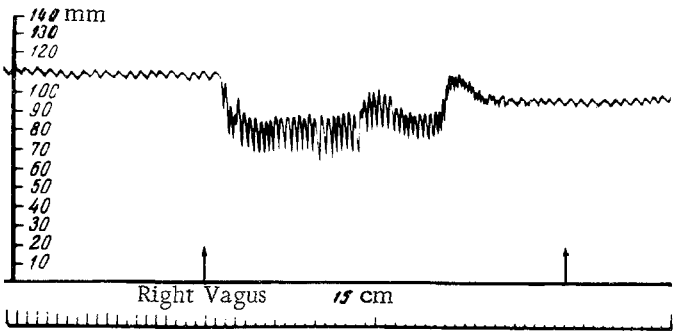

Fig. 1. Effect of stimulation from an induction coil applied to the peripheral end of the vagus in monkeys. Curves, top to bottom: arterial pressure in the carotid artery (mercury manometer); zero line; time marker (1 sec). The arrows indicate the onset and termination of stimulation.

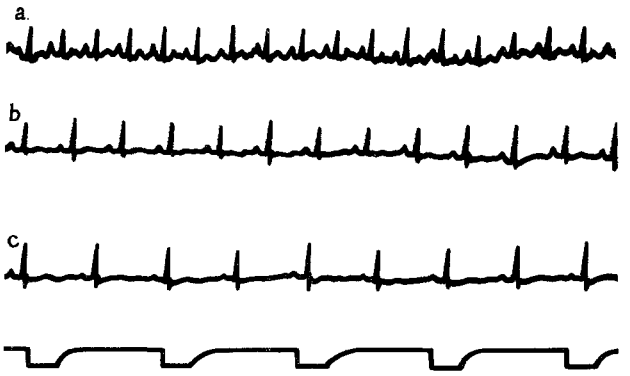

Fig. 2. Reaction of the heart of an adult monkey to stimulation of the peripheral end of the vagus by an induction coil. a) Original rate; b) stimulation of the peripheral end of the vagus (difference between coils 14 cm); c) stimulation of the peripheral end of the vagus (distance between coils 10 cm); stronger stimulation of the vagus: P waves reduced, amplitude of the R waves increased.

the lower apes (macaque rhesus) and animals like the rat, rabbit, and guinea pig in which no vagal tone develops during the postnatal period [12]. In this respect lower apes differ from dogs and hares. The differences are still more clearly shown when a comparison is made with the innervation of the human heart.

It is usually supposed that an experimental study of the functions of the different organs of the monkey, which is an animal resembling man closely in its organization, may be used in understanding the function of human organs. This idea has been applied to studies of nervous irregulation of cardiac activity in the lower apes [12]. The results we have obtained concerning vagal regulation of cardiac activity in the macaque rhesus have led us to reject such a view.

SUMMARY

During the postnatal period in lower monkeys vagal tone is absent. In the adult macaque the natural respiration rate is high and associated with it is a high heart rate regulated by sympathetic (not vagal) influence.

Nervous regulation of cardiac activity in the lower monkeys (macaque rhesus) in no way resembles that of such animals as the rat, rabbit, or guinea pig, in which vagal tone is absent during the postnatal period.

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