育成期および成熟期にある家畜の安静時心拍数と固有心拍数および自律神経緊張度の関係

誌名	Japanese journal of veterinary science
ISSN	00215295
著者	松井, 寛二 菅野, 茂
巻/号	51巻1号
掲載ページ	p. 29-34
発行年月	1989年2月

Relation of Intrinsic Heart Rate and Autonomic Nervous Tone to Resting Heart Rate in the Young and the Adult of Various Domestic Animals

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(Received 21 July 1988/Accepted 24 August 1988)

ABSTRACT. Intrinsic heart rate (IHR) and autonomic nervous tone (ANT) were measured using the young and the adult of horses, cows, pigs, goats and chickens in order to elucidate species differences in a decrease of resting heart rate (RHR) with growth or age. The IHR and ANT were estimated from the changes in heart rate after the administration of atropine and/or propranolol. The IHR in all species decreased progressively with an increase in body weight from young to adult, and moreover the ANT altered toward the direction of parasympathetic predominance by a decrease in sympathetic tone and/or an increase in parasympathetic tone. The decrease of the RHR with growth resulted from a decrease in the IHR primarily and from a parasympathetic predominance in the ANT secondarily. A considerable species difference existed in the alteration of the ANT.—KEY WORDS: autonomic nervous tone, domestic animals, intrinsic heart rate, resting heart rate.

Jpn. J. Vet. Sci. 51(1): 29–34, 1989

In general, heart rate is modulated by both the intrinsic heart rate (IHR) and the autonomic nervous tone (ANT). With regard to domestic animals, a decrease in heart rate with growth or age has been reported in horse [7], cattle [5, 7, 11], sheep [12], pig [4] and chicken [10]. Regrettably, however, little is known on both the IHR and ANT which could modulate the decrease in the heart rate.

The IHR and ANT are able to be determined using autonomic blockade as proposed by Jose [2], Walsh [14] and Sturkie and Chillseyzn [10]. Recently, we have studied the relationship between T-wave amplitude on ECG and the ANT, analyzing the responses of heart rate and T-wave amplitude to autonomic blockade in adult domestic animals [6]. These experiments are performed in several adult animals and to our knowledge, few similar studies have been performed in young animals or both young and adult animals.

In the present study, the RHR, IHR and ANT were measured in both the young and the adult of horses, cows, pigs, goats and chickens, to elucidate species differences in age-related control mechanisms of the heart rate from a comparative biological standpoint.

MATERIALS AND METHODS

The animals used for the present investigation were reared under ordinary conditions in the Animal Husbandry Experiment Station of the University of Tokyo. Numbers of animals, age and body weight are shown in Table 1. The young of the horse, cow, pig and goat was about one month of age, that of the chicken was about 1.5 month of age. Heart rate was determined by records of electrocardiogram. The electrocardiograms in all the species were recorded in A-B lead, i.e. a bipolar lead along the longitudinal heart axis. This lead is basically similar to a base-apex lead induced by Detweiler and Patterson [1]. The position of

Table 1. Age and body weight of the animals used in this study

Species	Number of animals		Age and body weight			
			Young		Adult	
	Young[a)]	Adult[b)]	Days	Kg	Years	Kg
Horse[c)]	5	6	27–47	58.0±10.1[h)]	6–10	265.6±20.7
Cow[d)]	7	6	30–45	74.3± 3.0	2– 8	575.0±49.9
Pig[e)]	6	7	30–35	8.9± 0.7	1.5–3.5	231.7±11.0
Goat[f)]	5	6	23–30	4.4± 0.1	3– 8	28.4± 1.2
Chicken[g)]	6	6	45–50	0.67±0.03	0.8–1.0	2.48±0.07

a), b) Both youngs and adults were females and the same strain.
c) Shetland pony and Japanese native horse.
d) Holstein cow.
e) Hybrid (LD or LDH).
f) Shiba goat (Japanese miniature native goat).
g) Commercial layer.
h) mean±S.E.

the electrodes in various domestic animals is defined by Japanese Association of Animal Electrocardiography [8].

Selective blockade of parasympathetic (muscarinic) and sympathetic (beta-adrenergic) nerves was accomplished with the injection of atropine sulphate (Sigma Chemicals) and propranolol (Inderal; Sigma Chemicals), respectively. Drugs were injected into the jugular vein of horses, cows and goats, ear vein of pigs or wing vein of chickens. A single injection of atropine and propranolol, and a simultaneous injection of both drugs at the same dose as a single injection were carried out intravenously. Dosage of atropine (mg/Kg) was 0.04 to 0.08 in horse, 0.1 in cow and pig, 0.3 in goat and chicken as the same dosage as previous report [6]. Dosage of propranolol (mg/Kg) was 0.2 to 0.6 in horse, 0.5 in cow, 1.0 in pig and goat and 0.4 in chicken. The experiment was carried out under unanesthetized conditions. The animals were hold at a resting state through the experiment by the bridle (horse, cow and goat), in the stall (adult pig), in the small pen (young pig) and by tying the wings and legs (chicken).

The measurements of RHR, IHR and ANT were performed according to our previous report [6]. Comparisons between youngs and adults were analyzed by Student's t-test. Differences between means were considered to be statistically significant when the P value was less than 0.05. A part of the data on the adults obtained was published previously on the subject of the relationship between T-wave amplitude and ANT [6].

RESULTS

The results for the heart rate obtained are summarized in Table 2. The RHR and IHR in all species were significantly lower in the adult animals than in the young ones. The RHR in the young and the adult of horses and cows were lower than the IHR, whereas the RHR in the young and the adult of chickens and pigs were higher than the IHR. On the other hand, the RHR in young goats was close to the IHR and the RHR in adult goats was lower than the IHR. The percent change in (RHR-IHR)/IHR was negative in the young and the adult of horses and cows, and positive in the young and the adult of chickens. The value in pig was barely

Table 2. Differences between young and adult in resting heart rate (RHR) and intrinsic heart rate (IHR) of several animal species

Species	RHR (beats/min)		IHR (beats/min)		(RHR-IHR)/IHR (% change)	
	Young	Adult	Young	Adult	Young	Adult
Horse	74.6± 4.4	41.8± 1.8**	123.6± 5.9	95.5±10.2*	−37.9± 4.4	−54.7±3.9*
Cow	81.4± 3.1	60.7± 3.9**	105.0± 3.2	74.0± 1.4**	−22.1± 3.6	−17.7±5.9
Pig	201.5±22.4	114.6± 7.2**	185.3± 4.8	108.9± 3.0**	+ 8.1±10.6	+ 4.8±4.8
Goat	142.0± 4.3	80.2± 5.2**	140.6± 7.6	117.1± 3.4**	+ 1.2± 4.7	−30.8±5.5**
Chicken	398.4±14.3	357.0±15.6**	297.8±12.3	253.4±17.0**	+33.9± 2.1	+41.7±5.3

Each value represents a mean±S.E. of 5 to 7 animals.
* and ** indicate significant differences between young and adult (*=P<0.05, **=P<0.01).

positive in the young and the adult. The value in goats varied from little positive in the young to large negative in the adult.

Fig. 1 shows changes in the ANT from young to adult. In adult horses, cows and goats, parasympathetic tone increased remarkably as compared with the young ones and moreover sympathetic tone decreased. In chicken, sympathetic tone remained in the adult in the same magnitude as in the young, while parasympathetic tone was not seen in the young but became to exist slightly in the adult. In pigs, both sympathetic and parasympathetic tone decreased from young to adult. The young and the adult in horses and cows showed parasympathetic predominance, whereas those in pigs and chickens showed sympathetic predominance. On the other hand, goats converted from sympathetic predominance in the young to parasympathetic predominance in the adult.

Fig. 2 shows the relationship between IHR or RHR and body weight. The IHR and RHR decreased with increasing body weight regardless of species difference. When the 10 data obtained were located to a straight line in both logarithmic scales, the slope of the regression lines was negative; the equation for the lines was $IHR=253.4\ BW^{-0.1852}$ ($r=-0.938$, $p<0.001$, $n=10$); $RHR=320.4\ BW^{-0.2937}$ ($r=-0.885$, $p<0.001$, $n=10$). The relationship between the IHR and RHR as shown by arrows in Fig. 2 reversed with increasing body weight. This change was similar to an alteration in the ANT as shown in Fig. 1.

DISCUSSION

Generally the heart rate in mammals is inversely proportional to body size [9]. Our previous reports indicated that the fetal heart rate in horses and cows progressively decreased with the advance of gestational age, but the heart rate immediately after birth remarkably increased to much higher level than at the end of gestation and reached gradually the respective adult heart rate level at about 4 to 5 months of age [7]. The heart rate level in hatched chick becomes to be highest at 2 and 4 weeks of age, and then decreases with advancing age [10].

Heart rate is regulated by intrinsic (or myogenic) and extrinsic (or neurohumoral) mechanism. Intrinsic cardiac rhythm of the sinus node (or IHR) and extrinsic mechanism (the sympathetic and parasympathetic activities or ANT) can be estimated approximately by pharmacological denervations [2, 3, 6, 10, 14]. The ANT at rest in the adult of horses, cows, pigs, goats and chickens [6], in

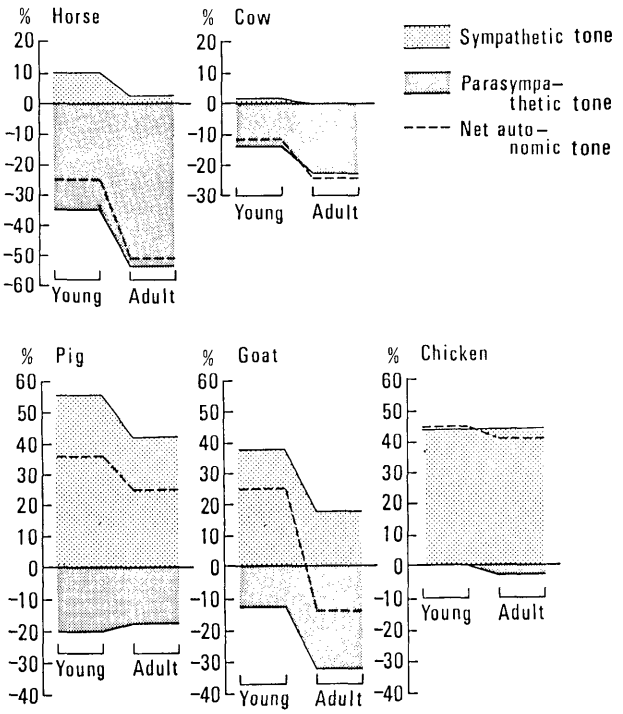

Fig. 1. Sympathetic, parasympathetic and net autonomic tone at a resting state in the young and the adult of several animal species. Values (%) show percent changes from the IHR. Data are expressed as mean of 5 to 7 animals.

the young of pigs [4], in the newborn and the adult of sheep [13, 15] and in the young of chicken [10] has been studied. However, there have been few reports about the relationship among the RHR, IHR and ANT in both the young and the adult period. It is of much interest to examine differences in age-related control mechanism of the heart rate from a comparative biological standpoint.

As shown in Fig. 2, the relationship between log IHR and log body weight was shown by a straight line with the negative slope. The result suggests that the decrease in the IHR is primarily related to a decrease in the RHR because the IHR in any species progressively decreases with the increase of body weight. It is known that there is a negative correlationship between the IHR and age or body weight in human [3], cow [5] and pig [4]. On the other hand, Fig. 1 also indicates that the ANT, in any species, shifts to the direction of parasympathetic predominance by a decrease in sympathetic tone and/or an increase in parasympathetic tone and that a considerable species difference exists fatefully in the alteration of the ANT. These results suggest that the alteration of the ANT is secondarily related to the decrease in the RHR. It may be explained that, as shown in Fig. 2, the amount of dispersion in the RHR to body weight is larger than that in the IHR because the RHR is modulated by both the IHR and ANT.

In Table 2, the values of percent change in (RHR-IHR)/IHR in horses and goats significantly decreased from young to adult, but those in cows, pigs and chickens did not change significantly. We consider that the

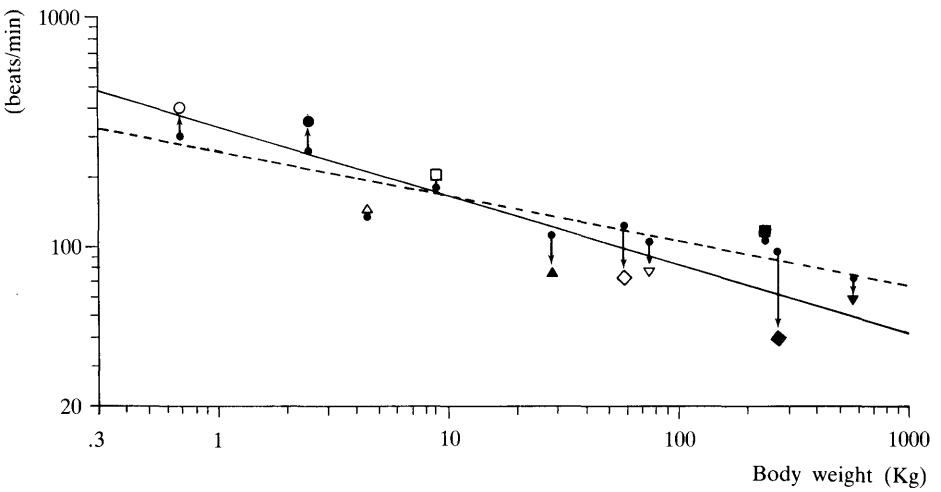

Fig. 2. Relationship between IHR or RHR and body weight in various animals. Data are expressed as mean of 5 to 7 animals and plotted on logarithmic coordinates. Open and solid marks represent the RHR in the young and the adult, respectively. ○: Chicken, □: Pig, △: Goat, ◇: Horse, ▽: Cow. Small solid circles represent the IHR at the same time and each arrow upwards and downwards shows differences between the IHR and the RHR. Solid straight line shows regression line between the RHR and body weight (BW: Kg), and broken straight line shows regression line between the IHR and body weight. The equation for the lines was $IHR=253.4\ BW^{-0.1852}$ ($r=-0.938$, $p<0.001$, $n=10$); $RHR=320.4\ BW^{-0.2937}$ ($r=-0.885$, $p<0.001$, $n=10$).

negative value might be related to parasympathetic predominance, whereas the positive one to sympathetic predominance. It is suggested that the decrease in the RHR in horses, goats is strongly influenced by the alteration of the ANT as well as the decrease in the IHR, whereas that in cows, pigs and chicken is little influenced by the alteration of the ANT.

Thus, it was presumed that the decrease in the RHR with growth or age resulted from the decrease in the IHR primarily and the parasympathetic predominance secondarily and that a considerable species difference existed in the alteration of the ANT.

ACKNOWLEDGEMENTS. The authors thank the members of the Animal Husbandry Experiment Station, the University of Tokyo for their support on this experiment. This work was supported in part by Grant-in-Aid (No. 61760254) from the Scientific Research Fund on the Ministry of Education, Science and Culture, Japan.

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要　約

育成期および成熟期にある家畜の安静時心拍数と固有心拍数および自律神経緊張度の関係：松井寛二・菅野茂[1)]（東京大学農学部附属牧場，[1)]家畜環境生理学教室）——育成期および成熟期のウマ，ウシ，ブタ，ヤギおよびニワトリを用いて，安静時心拍数と固有心拍数および自律神経緊張度の相互関係を調べ，成長にともなう心拍数減少にみられる動物種差の原因について考察を加えた．固有心拍数と自律神経緊張度はアトロピンとプロプラノロール投与後の心拍数を用いて算出した．安静時心拍数と固有心拍数はいずれの動物においても育成期から成熟期にかけて減少し，また自律神経緊張度は交感神経緊張度の減少あるいは副交感神経緊張度の増加という型で副交感神経緊張優位の方向に推移した．成長にともなう安静時心拍数の減少にはまず固有心拍数の減少が，ついで副交感神経緊張度の優勢化が深く関わっており，とくに自律神経緊張度の推移の面で著しい動物種差が認められた．