Diurnal Variation in Dropped Beats in Horses with a Second Degree Atrioventricular Block

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(Received 1 June 1993/Accepted 16 September 1993)

Ten horses with a second degree atrioventricular block were examined whether the dropped beat (DB) shows a circadian rhythm and/or other periodicities. The results from the time-series analysis showed that most of horses had the circadian rhythm of DB with 22.2 ± 2.3 hr-period in addition to short-hour periodicities with 7.6 ± 1.3 h and 2.6 ± 1.1 h. Similarly, most of horses revealed the atrial rate (AR) circadian rhythm with 22.7 ± 3.6 h as well as 8.0 ± 1.4 h and 2.6 ± 1.0 h periodicities. These results suggested that the occurrence of DB was modulated by the central nervous system through the autonomic nervous activity.

Key words: diurnal variation, dropped beat, horse, second degree atrioventricular block

Jpn. J. Equine Sci. 4(1): 61-68, 1993

The horse has a higher incidence of cardiac arrhythmias at rest than any other domestic animals [7] and the prevalence of those arrhythmias may be greater than 25% [11]. The arrhythmia most commonly reported is a second degree atrioventricular (AV) block and its reported prevalence ranged from 12 to 18% [4, 11]. The dropped beats being characteristic feature of AV block, tend to occur when the resting heart rate is slow (less than 26 beats/min) [11] or the arterial blood pressure raises step-wise fashion over three or more ventricular beats [21]. Conversely, it has been reported that the dropped beats were reduced or abolished by atropine administration [7, 11], exercise [4], and paralyzing of the left vagosympathetic nerve [18]. Thus it is generally thought that AV block in the horse is a functional phenomenon resulting from the increase of vagal tone [4, 7]. Although the phase of breathing cycle may affect the AV conduction during an inspiratory phase via the inflation reflex of the

lung, the relationship between the occurrence of AV block and the respiratory phase seems to be complex [21]. Therefore, Detweiler pointed out that more detailed study is required to understand the genesis of this arrhythmia [4].

The horse has the circadian rhythm in heart rate [5, 16], and it is thought that the rhythm is apparently caused by the variation in autonomic nervous tone [16]. Then the frequency of AV block must also show the circadian rhythm if truly AV block is vagally induced. In humans [2, 9, 19, 23] and rats [13-15], it has been reported that the frequencies of AV block and bradyarrhythmias, in which are included sinoatrial block, sinus arrest and AV block, show circadian rhythms and these arrhythmias appear frequently during sleeping periods. Furthermore, it has been demonstrated that the suprachiasmatic nuclei of the hypothalamus generates the circadian rhythm in bradyarrhythmias in rats, that rhythm being abolished by the lesion of the

suprachiasmatic nuclei [15]. Therefore, it is important to examine whether the circadian rhythm can be observed in the frequency of dropped beats for understanding its genesis of the horse. In addition, it may be able to lead a new concept in the induction of AV block by comparing and collating the periodicities composed diurnal variation in this arrhythmia and the conceivable factors related to AV block by using the time-series analysis [22].

The purpose of this study is to investigate the occurrence of AV block for 24 hours and also the pattern of its diurnal variation by means of the maximum entropy spectral analysis, with special reference to find whether the circadian or other rhythmicities exist in the genesis of AV block in the horse.

Materials and Methods

Seven Thoroughbreds (3 males, 2 females, 2 geldings) and three Anglo-Arabs (2 females, one gelding), 4 to 15 years of age, were examined in this study (Table 1). They were previously confirmed to show Wenckebach type of AV block at rest. These horses were stabled in Equestrian Park and Equine Research Institute of the Japan Racing Association.

Electrocardiogram (ECG) was recorded continuously for 24 h with the aid of the

Table 1. Age, sex, breed and career as racehorse of the examined horses

Horse No.	Age	Sex	Breed	Career (age) as racehorse
1	5	Gelding	Thoroughbred	None
2	8	Female	Thoroughbred	None
3	10	Gelding	Anglo-Arab	None
4	11	Female	Anglo-Arab	None
5	15	Gelding	Thoroughbred	3-5
6	4	Female	Anglo-Arab	None
7	4	Female	Thoroughbred	3
8	7	Male	Thoroughbred	None
9	8	Male	Thoroughbred	3-6
10	14	Male	Thoroughbred	3-13

Holter ECG monitoring system equipped with a portable ECG tape recorder (SM-29, Fukuda Denshi Co., Ltd.). The ECG tape recorder was placed in a leather bag (25 cm × 50 cm) on the horse back, and the bag was fixed by the girth. The bipolar chest lead (nearly the A-B lead) was used for recording the ECG. The positive electrode was located under the girth at the left thorax along the horizontal line of the highest point of the olecranon. The negative and ground electrodes were located the left side of withers under the bag.

Horses were individually housed in standard stalls over 24 h and could move freely. Feeding times were 6:30 or 7:30 and 16:00 and water was given *ad libitum*. Sunrise and sunset times were from 5:05 to 6:16 and from 17:17 to 18:00.

After the recording, the tape was played

Fig. 1. An example of compressed electrocardiogram from a tape
Closed circles in figure show dropped beats.

back and the compressed ECG was printed out (Fig. 1). The numbers of dropped beats and P waves were counted manually and the total numbers of dropped beats and atrial rate during 24 h were determined. Furthermore, two time-series data on both the frequencies of dropped beats and atrial rate were provided on the basis of 5 minutes interval analysis. The pattern of diurnal variation in the frequency of dropped beats was estimated with the moving average method by 185 minutes interval. In addition, the periodicities composed diurnal variations of dropped beats and atrial rate were evaluated by the maximum entropy spectral analysis. In this spectral analysis, we must previously determine the order of autoregressive model that is to be fitted to the time-series data. It is known from experience that too short model order results in a highly smoothed estimate, whereas an excessive one introduces spurious detail into the spectrum. We have already examined the effect of order to analyzing the heart rate diurnal rhythms in a horse [23]. According to that study, the number of time series data (N)/2 for the estimate of over 6 h-period and N/5 for that of 1 h- to 6 h-period rhythm were adequate to the order of autoregressive model. Therefore we decided to use N/2 and N/5 as the order of autoregressive model in this study.

The relation between equine behavior and the frequencies of dropped beats was also investigated in two horses (No. 5 and No. 6, Table 1). Behaviors were classified into four states: feeding, drowsiness, lateral recumbency, and the other states. Drowsiness was a state that the head was down, the eyes partly closed and the lower lip relaxed [3].

Results

Table 2. Total numbers for 24 h of dropped beats and atrial rate

Horse No.	Dropped beats	Atrial rate
1	5	59688
2	62	50191
3	188	49677
4	618	48735
5	3116	52816
6	3397	45078
7	5233	49870
8	5236	50755
9	6428	47197
10	7149	54418
Low frequency group (No. 1-4)		
	218±240	52072±4428
High frequency group (No. 5-10)		
	5093±1463	50022±3165
(mean±S.D.)		

The total number of dropped beats and atrial rate ranged from 5 to 7149 beats/24 h and 45078 to 59688 beats/24 h, respectively, as presented in Table 2. The total number of dropped beats differed fairly in each horse, therefore the horses were grouped as two major groups with the low frequency of dropped beats (218±240 beats/24 h, No. 1-4) and the high frequency of dropped beats (5093±1463 beats/24 h, No. 5-10). In the total number of atrial rate during 24 h, however, no significant difference was observed between the low and high frequency groups, i.e., 52072±4428 beats/24 h versus 50022±3165 beats/24 h (Table 2).

Fig. 2 represents the diurnal variation in the frequency of dropped beats. In all horses of the high frequency group, the maximum number of dropped beats per 5 minutes, was over 30 beats. The time-series data of dropped beats in the high frequency group (No. 5-10) was employed to estimate the pattern of diurnal variation of dropped beats by the moving average method, whereas those in the low frequency group were not performed to avoid their excessive smoothing due to the scattered data. The results from the high frequency

Fig. 2. Diurnal variations of occurrence of dropped beats (/5 min)

Dotted lines are raw time-series data and solid lines are data after smoothing with moving average method.

Fig. 3. Power spectra estimated time-series data of dropped beats (DB) and atrial rate (AR) by maximum entropy spectral analysis with $N/2$ in order of autoregressive model
Solid lines are DB and dotted lines are AR.

group showed a clear diurnal variation of the occurrence of the dropped beats, the minimum frequency between 17:00 and 21:00 and the maximum frequency between 2:00 and 7:00. The three horses (No. 2-4) in the low frequency group seemed to have the same tending as shown in the high frequency group.

Figs. 3 and 4 depict the power spectra (model order, $N/2$ in Fig. 3; $N/5$ in Fig. 4) on diurnal variation of both dropped beats

and atrial rate, according to the maximum entropy spectral analysis, while Tables 3 and 4 show the summary results from those spectral analysis. The dropped beats of nine horses (excepting No. 1) and atrial rate of all horses revealed the long-hour period rhythmicities of 22.2 ± 2.3 h and 22.7 ± 3.6 h, respectively. The dropped beats of No. 1, however, failed to show such a long-hour periodicity, owing to the small number of its occurrence. In addition, the

Fig. 4. Power spectra estimated time-series data of dropped beats (DB) and atrial rate (AR) by maximum entropy spectral analysis with N/5 in order of autoregressive model. Solid lines are DB and dotted lines are AR.

Fig. 5. Relation between appearance of dropped beats (black : inner circle) and behaviors (outer circle) : feeding (dots), drowsiness (check), recumbency (stripe) and others (white).

short-hour periodicity with 7.6 ± 1.3 h and 8.0 ± 1.4 h were observed for dropped beats in four horses and for atrial rate in five horses. Besides these analysis, another maximum entropy spectral analysis (model order, N/5) exhibited 2.6 ± 1.1 h-periodicity in nine horses excepting No. 1. Although 2.6 h-period rhythm in dropped beats was also recognized in atrial rate of six horses, there was no coincidence in the spectral phases between the dropped beats and atrial rate in most of horses excepting No. 10.

Fig. 5 illustrates the relation between the behavior and the appearance of dropped

beats in two horses. The appearance of dropped beats increased in drowsiness state and decreased at feeding period.

Discussion

AV block in horses and training. As regards the relationship between the AV block and exercise, in humans, the heart block was found only during seasons of intensive training and could not be demonstrated, otherwise reduced, a few weeks after the training [12]. In the present study four horses in the high frequency group were career racehorses, but AV block was sustained even after the training had been stopped for a long period. Furthermore, six horses which were not career racehorses had the AV block (Tables 1 and 2). These results suggested that the cause of AV block in the horse is not able to be understood only by the increase of vagal tone related to race training.

The total number of dropped beats and atrial rate. The total number of dropped beats for 24 h differ individually in each horse and these horses were able to be classified into groups with the high and low fre-

Table 3. Periodicities of diurnal variations of dropped beats and atrial rate determined from Fig. 3

Horse No.	Dropped beats		Atrial rate	
1	—	7.9	27.7	9.2
2	23.7	—	16.6	—
3	23.7	—	18.5	—
4	23.7	—	23.7	—
5	23.7	—	23.7	—
6	18.5	—	23.7	8.3
7	20.8	—	20.8	—
8	18.5	8.7	23.7	8.7
9	23.7	5.7	27.7	5.7
10	23.7	7.9	20.8	8.3
mean	22.2	7.6	22.7	8.0
(SD)	(2.3)	(1.3)	(3.6)	(1.4)

Table 4. Periodicities of diurnal variations of dropped beats and atrial rate determined from Fig. 4

Horse No.	Dropped beats		Atrial rate	
1	—		2.2	
2	2.1		3.2	2.1
3	5.2, 3.6		1.5	
4	2.3, 1.6		4.6	2.1
5	3.0, 1.7		—	
6	1.9		—	
7	3.7, 1.7		3.3	
8	3.0		—	
9	2.0		—	
10	2.1		2.0	
mean $\pm$ SD	2.6 $\pm$ 1.1		2.6 $\pm$ 1.0	

quency of dropped beats. AV block can be commonly produced by the reflex vagal stimulation in humans [6]. The mechanism seems to be true also in horses: indeed, the AV block at the resting state was usually abolished by atropine treatment [7, 11] and paralyzing of the left vagosympathetic nerve [18]. Therefore, we previously considered that the vagal activity in the high frequency group of dropped beats may be higher than that in the low frequency group. The total number for 24 h of atrial rate in the high frequency group of dropped beats, however, did not differ from that in the low frequency group. As the intrinsic heart rate in adult horses was reported to be 95.5 ± 10.2 beats/min [10], the daily heart rate can be estimated to be approximately 140,000 beats. In the present study,

the total number of atrial rate was shown as 50,000 to 60,000 beats/24 h in all horses. Therefore, the autonomic nervous tone in both the low and high frequency groups were the same level with each other, and were, to a great extent, parasympathetically dominant through a whole day.

Diurnal variation of dropped beats and atrial rate. In horses, the highest heart rate occurs at approximately 18.00 h at lights off [5] and the lowest heart rate appears in the early morning [16]. In the present study, the atrial rate showed a similar pattern to above-mentioned reports and the dropped beats showed the mirror pattern of atrial rate diurnal variation that its frequency decreased toward the evening and increased in the early morning. The dropped beats, furthermore, indicated a clear circadian rhythm (22.2 ± 2.3 h-period rhythm) which was in accord with atrial rate circadian rhythm (22.7 ± 3.6 h) present in horses. In rats, it has been demonstrated that the bradyarrhythmia episodes, including AV block, showed the circadian rhythm [14] and its rhythm was closely associated with the oscillation mechanism by the suprachiasmatic nucleus (SCN) in the hypothalamus [15]. Therefore, our data and previous reports strongly suggest that circadian rhythms of both the dropped beats and the atrial rate in horses are originated from the central nervous system.

Ultradian rhythms of dropped beats and atrial rate. As for the diurnal variations in dropped beats and atrial rate, the ultradian rhythms consisted of 7.6 h (DB) and 8.0 h (AR), otherwise 2.6 h (DB, AR), were also observed in addition to the circadian rhythm described above. The 7.6 h or 8.0 h-period rhythm was almost coincident with the feeding intervals of daytime [22], which were 8.5 h and 9.5 h-period. In dogs, the 1.5 h [17], 1–2 h [8] and 2.6 ± 0.2 h

[1] -period rhythm have been observed in heart rate, mean arterial pressure, cardiac output, and total peripheral resistance. It might be assumed that the 2.6 h-period rhythm in dropped beats reflected the rhythmicity in the circulatory circulation control.

Furthermore, the dropped beats appeared frequently at the drowsiness state. Sleep is usually divided into at least two different states: slow-wave sleep (SWS) and paradoxical sleep (PS). During SWS, the parasympathetic tone increases, the sympathetic activity attenuates, and the cardiac and respiratory rates decrease as compared with those during wakefulness. Moreover, during PS, the mean cardiac and respiratory frequencies are slightly lower than those during SWS but the variabilities of those parameters increase more than during wakefulness and SWS. Then, it is known that the drowsiness in the horse is a light sleep state during SWS, and as a protective mechanism against predators. The prevalence of AV block enhances at the sleeping period in humans [2, 9, 19, 23]. The circadian rhythm in bradyarrhythmias, included AV block, is also related to the sleep state (PS) in rats and the oscillator of this rhythm is considered to be in the hypothalamus [14]. Therefore, we thought that the ultradian rhythms in dropped beats also reflect the activity of autonomic nervous modulated by the central nervous system.

Although the 2.6 h-period rhythm was obtained as mean period consisting the ultradian rhythm, there was no coincidence between the dropped beats and atrial rate in individual horse. It has been reported that there is a differential responsiveness by the sinus node and AV junction to the same autonomic maneuvers [20], and dropped beats could be produced by a

failure of the vagal activity to depress the discharge rate of the sinoatrial node [6]. This finding may lead a speculation that there is an inadequate sinus slowing to the decrease of AV conductivity in horses with AV block, and that the divergence in the ultradian rhythms in dropped beats and atrial rate indicates the existence of the mismatch of atrial rate and AV conduction.

In conclusion, it was elucidated the frequency of dropped beats and both the circadian rhythm (22.2 h-period) and ultradian rhythm with 2.6 h-periodicity in most of horse or with 7.6 h-periodicity in a few horses. The occurrence of dropped beats, moreover, was considered to be modulated by the central nervous system through the autonomic nervous activity. Furthermore, we speculate that the difference in the periodicities composed ultradian rhythm in the dropped beats and atrial rate, that is, the mismatch of atrial rate and AV conduction is one of causal factors to induce the AV block in horses.

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ウマの第2度房室ブロックにおける心室脱落の日内変動——山谷吉樹¹, 久保勝義², 天田明男², 佐藤 敬¹ (¹日本大学農獣医学部獣医外科学研究室 〒252 神奈川県藤沢市亀井野1866, ²日本中央競馬会競走馬総合研究所 〒154 東京都世田谷区弦巻5-27-7)

第2度房室ブロックを有する10頭のウマが、心室脱落(DB)の日内変動が概日リズムやその他の周期性を示すかどうかを検討するために供試された。DBおよび心房拍数(AR)の時系列データを解析した結果、DBには 22.2 ± 2.3 および 7.6 ± 1.3 と 2.6 ± 1.1 時間周期リズムが、ARには 22.7 ± 3.6 および 8.0 ± 1.4 と 2.6 ± 1.0 時間周期リズムが認められた。よって、DBの出現は中枢神経系により自律神経系を介して調節されていることが示唆された。