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Parturition in horses is dominated by parasympathetic activity of the autonomous nervous system

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ABSTRACT

External and internal stressors prolong parturition in different species. At parturition, sympathoadrenal activation should be avoided because an increased sympathetic tone may cause uterine atonia via β_2-receptors. We hypothesized that at physiological parturition, horses are under parasympathetic dominance, and stress-response mechanisms are not activated during delivery of the foal. To evaluate stress responses, heart rate, heart rate variability, catecholamines, and cortisol were analyzed in mares (n = 17) throughout foaling. Heart rate decreased from 2 hours before (51 ± 1 beats/minute) to 2 hours after delivery (41 ± 2 beats/minute; $P < 0.05$). Heart rate variability variables, standard deviation of the beat-to-beat interval, and root mean square of successive beat-to-beat differences, changed over time ($P < 0.05$) with the highest values within 15 minutes after delivery. The number of mares with atrioventricular blocks and the number of atrioventricular blocks per mare increased over time ($P < 0.01$) and were significantly elevated from 15 minutes before to 45 minutes after birth of the foal. Salivary cortisol concentrations increased to a maximum at 30 minutes after delivery (25.0 ± 3.4 ng/mL; $P < 0.01$). Plasma epinephrine and norepinephrine concentrations showed significant fluctuations from rupture of the allantochorion to expulsion of the fetal membranes ($P < 0.01$) but were not markedly elevated at any time. In conclusion, mares give birth under high parasympathetic tone. Cortisol release during and after foaling is most likely part of the endocrine pathways regulating parturition and not a labor-associated stress response.

1. Introduction

The mechanisms for maintenance of pregnancy and the characteristics of parturition clearly differ between species. In horses, length of gestation is highly variable and, in contrast to ruminants and pigs, foaling takes place in the presence of still high progestin concentrations [1]. Once initiated, equine parturition proceeds rapidly. The expulsive phase of foaling should be completed after a maximum of 20 to 30 minutes and is often finished within half of that time [2]. Endocrine changes during labor thus occur within a very small time window and are difficult to differentiate. The regulation of labor in horses is, therefore, discussed at least in part controversially [3–5], and further studies are warranted.

Rapid expulsion of the foal requires powerful and coordinated myometrial and abdominal contractions. Stressors such as environmental disturbance prolong parturition and impair rapid delivery of the newborn in rats [6] and pigs [7]. In mares, parturition only takes place

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Table 1
Number of mares (n) from which data were obtained for different parameters from 120 minutes before to 120 minutes after delivery of the foal.

Time relative to end of second stage of labor (min)	−120	−90	−60	−30	−15	−5	+5	+15	+30	+60	+90	+120
Heart rate	9	10	10	11	11	11	11	11	11	11	11	11
AV blocks	9	10	10	11	11	11	11	11	11	11	11	11
HRV	7	8	8	9	9	—	—	9	9	9	9	9
Cortisol	—	—	—	—	—	—	17	17	17	17	17	17

Abbreviations: AV, atrioventricular; HRV, heart rate variability.

when the environment is perceived as safe. This is illustrated by the fact that in domestic horses, up to 90% of foals are born during the night, i.e., at a time of minimal disturbance in the stable [8].

Stress caused by labor has been mostly studied in women (reviewed by [9]). Pain or stress induces an immediate release of catecholamines from the adrenal medulla. In women, maternal sympathoadrenal activation during labor can be attenuated by adequate pain management [10]. Increased sympathoadrenal activity prepares the body for a "fight-or-flight" reaction. At the level of the myometrium, sympathetic activation of uterine β_2-receptors causes myometrial relaxation as shown in humans and rats [11,12]. In humans, this is mimicked by the administration of β_2-adrenergic stimulants to postpone parturition and treat preterm labor [11,12]. In cattle, the β_2-adrenergic drug, clenbuterol is used to facilitate obstetrical manipulations [13]. Although such clinical use is uncommon in mares, clenbuterol decreases uterine tone at all stages of equine pregnancy [14]. Stress responses during parturition should be avoided because endogenous activation of β_2-receptors may cause uterine atonia.

Increased sympathetic activity in response to acute stressors is not only reflected by catecholamine release but can also be evaluated by heart rate (HR) and heart rate variability (HRV) analysis. Heart rate variability, i.e., short-term fluctuations in HR, is based on the antagonistic oscillatory influences of the sympathetic and parasympathetic branch of the autonomic nervous system on the sinus node of the heart. Heart rate variability represents the fine tuning of the beat-to-beat (RR) control mechanisms and increases during dominance of the parasympathetic branch of the autonomous nervous system. In general, decreases in the HRV variables, standard deviation of RR interval (SDRR) and root mean square of successive RR differences (RMSSDs), reflect sympathetic dominance, whereas increased values indicate parasympathetic dominance [15].

Stressful stimuli increase cortisol release from the adrenal cortex. Non–protein-bound cortisol rapidly diffuses into saliva, and salivary cortisol mirrors changes of free cortisol in blood plasma [16]. Saliva can be collected easily and stress-free from horses of all ages without the need to restrain the animal [1,17,18]. Increased cortisol release and decreased HRV indicate stress responses in horses [19,20].

Horses respond to potentially dangerous situations with an immediate flight reaction [21]. In domesticated horses, also anthropogenic challenges such as equestrian training [18,19], transport [20,22], or weaning of foals [17] increase cortisol release and HR and decrease HRV. On the other hand, the extremely rapid delivery of the foal requires the absence of sympathoadrenal activity and thus activation of β_2-receptors at least during the expulsive phase of labor.

We hypothesized that at physiological parturition, horses are under parasympathetic dominance and stress-response mechanisms are not activated during delivery of the foal. To evaluate sympathoadrenal and adrenocortical activation at physiological, undisturbed foaling, we have analyzed HR and HRV, plasma catecholamines, and salivary cortisol concentration in parturient mares throughout delivery of their foals. For comparison, HR, HRV, and cortisol concentration were also studied in nonpregnant mares.

2. Materials and methods

2.1. Animals

For this study, a total of 17 late-pregnant Warmblood brood mares (*Equus caballus*) with singleton pregnancies from the Brandenburg State Stud at Neustadt (Dosse), Germany, were available. Mares were between 4 and 15 years of age (7.1 ± 0.8 years). All mares and their foals were healthy throughout the study. Horses were fed oats and hay twice daily. Mineral supplements and water were freely available at all times. The horses were housed in group stables on straw with daily access to an outdoor paddock. Approximately 15 days before the calculated day of parturition, mares were separated into single boxes and were left in the foaling unit until 5 days after birth of their foal. In the foaling unit, mares were observed 24 hours per day from outside their box and without disturbing the animal. Average gestation length calculated from the day of ovulation was 337.5 ± 1.8 days. In all mares, parturition took place between 8:00 PM and

Table 2
Number of mares from which blood were collected at individual time points from rupture of the allantochorion until the end of second stage of labor and from birth of the foal until passage of the fetal membranes.

Time (min)	Rupture of allantochorion	+10	+20	Birth of foal	+10	+20	+30	+40	+50	+60	+70	+80	+90	−5.9 ± 0.7	Passage of fetal membranes
Mares (n)	10	5	1	10	9	6	4	3	1	1	1	1	1	10	10

The last two samples are aligned to the time of expulsion of the fetal membranes. Differing n numbers are due to differences in the duration of labor between mares.

10:00 AM. All foalings were observed but no obstetrical intervention was needed. Nonpregnant mares (n = 7; age, 9.0 ± 1.3 years; range, 6–15 years) were stabled at the same location and kept and fed identically to the foaling mares.

2.2. Experimental design and sample collection

Mares in the foaling unit were regularly examined for clinical signs of impending parturition. When parturition appeared close, ECG recordings were started and continued throughout foaling until 2 hours thereafter. Recordings of the cardiac RR interval were used for analysis of HR and HRV. In all mares, saliva for cortisol analysis was collected immediately after birth of the foal and 15, 30, 60, and 120 minutes thereafter (Table 1). In the nonpregnant mares, four saliva samples were taken at 30-minute intervals starting at 6:00 AM. Collection of saliva for cortisol analysis was performed as described [19]. A cotton roll (Salivette for cortisol analysis; Sarstedt, Nürmbrecht-Rommelsdorf, Germany) was grasped with a surgical clamp and gently inserted into the mouth of the horse onto its tongue. The cotton roll was left in place for 1 minute until it was well moistened. Horses were made familiar with saliva collection before the experiment and before and also during the study, saliva collection was at all times well tolerated by all horses, and no restraint was needed. After collection, samples were centrifuged at 1000 × *g* for 10 minutes, and at least 1 mL of saliva was obtained and frozen at −20 °C until analysis.

In a subgroup of mares (n = 10; age, 4–15 years; mean, 7.1 ± 1.3 years; gestational length, 336.7 ± 2.6 days), blood was collected for analysis of epinephrine and norepinephrine concentrations. In these mares, the colostrum was checked twice daily (6:00 AM, 6:00 PM) with commercial test strips (Merckoquant 10025; Merck, Darmstadt, Germany) for changes in calcium concentration [23]. By the time four of four of the control fields were positive, a catheter (Milacath; Mila International, Florence, KY, USA) was placed into one of the mares' jugular veins. During the second stage of labor (time from rupture of the allantochorion until birth of the foal), blood samples were taken at 10-minute intervals. Immediately after delivery, another blood sample was collected, and sampling was continued at 10-minute intervals throughout the third stage of labor (time from birth of the foal until passage of the placenta). The last blood sample was taken immediately after passage of the placenta. Depending on the duration of the second and third stage of labor, one to three and three to 12 blood samples, respectively, were taken per mare (Table 2). For sample collection, chilled heparinized tubes (Vacuette; Greiner, Kremsmünster, Austria) were used. Immediately after blood collection, samples were placed on ice and centrifuged (4 °C; 1000 × *g*; 20 minutes). After centrifugation plasma was decanted and plugged into liquid nitrogen (−196 °C) until analysis. The study was approved by the competent authority for animal experimentation in Brandenburg State, Germany (Landesamt für Umwelt, Gesundheit und Verbraucherschutz, license number V3-2347-14-2011).

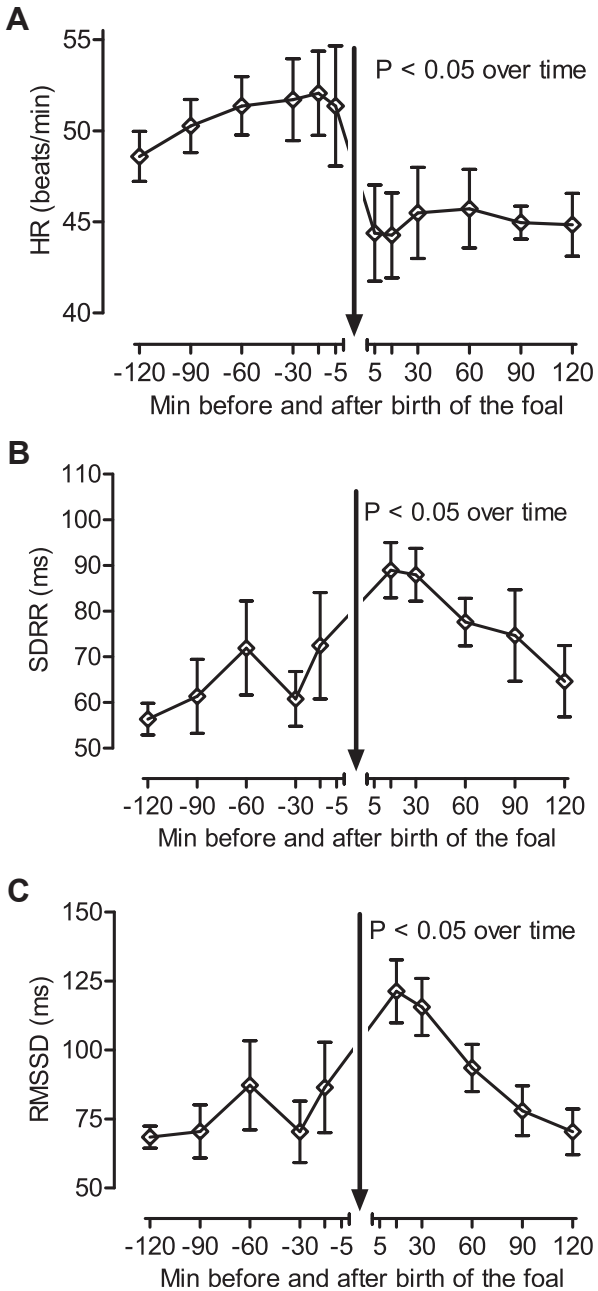

Fig. 1. (A) Heart rate (n = 11) and HRV (n = 9) variables, (B) SDRR, and (C) RMSSD in mares from 120 minutes before to 120 minutes after birth of the foal (arrow), values are means ± SEM. HRV, heart rate variability; RMSSD, root mean square of successive RR difference; RR, beat-to-beat; SDRR, standard deviation of the RR interval; SEM, standard error of the mean.

2.3. HR, HRV, and cardiac arrhythmias

All ECG recordings were made with the Televet 100 system (version 4.1.3; Engel Engineering, Offenbach am Main, Germany) as described [1,24]. Electrodes were positioned as for fetomaternal ECG recordings and left in place after parturition to obtain a continuous maternal ECG. Data from the Televet 100 were transferred to a

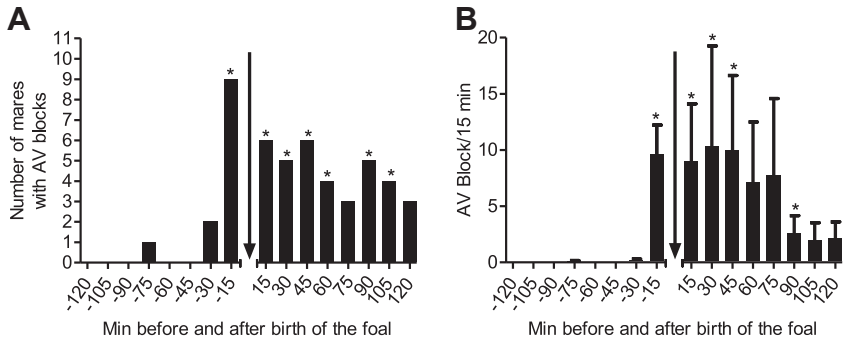

Fig. 2. (A) Number of mares with AV blocks and (B) number of AV blocks per mare during 15-minute time intervals from 120 minutes before to 120 minutes after birth of the foal (arrow; n = 11); Data for times marked (*) differ significantly from data 120 minute before delivery (Wilcoxon test; $P < 0.05$); for (B) values are means ± SEM. AV, atrioventricular; SEM, standard error of the mean.

laptop computer via Bluetooth. For analysis, maternal ECG was checked visually for the presence of cardiac arrhythmias. The last 2 hours before and the first 2 hours after delivery of the foal were subdivided into 15-minute intervals, and all arrhythmias were counted for each mare.

The Televet 100 recorded the RR intervals in milliseconds (ms). Following established procedures, data were detrended. In addition, an artifact correction was made as in previous studies on horses [19,20,22]. From the RR intervals, HR and the HRV variables, SDRR and RMSSD, were calculated using the Kubios HRV Software (version 2.1, Biomedical Signal Analysis Group, Department of Applied Physics, University of Kuopio, Finland).

Heart rate and HRV were always calculated for 5-minute intervals starting at 120, 90, 60, 30, 15, and 5 minutes before delivery and at 5, 15, 30, 60, 90, and 120 minutes after birth of the foal. If the 5-minute intervals contained atrioventricular (AV) blocks, the window for analysis was moved maximally 5 minutes (e.g., starting at 115 minutes instead of 120 minutes before delivery) because the presence of AV blocks may bias HRV results. From all 5-minute intervals, HR was determined, whereas for HRV analysis, the last 5-minute interval before and the first 5-minute interval after delivery were omitted because of the presence of AV blocks in the majority of mares.

From the 17 mares, no ECG recordings were made in six mares because either the two available Televet recorders were in use on other mares at the same time or the first sign of labor was already rupture of the allantochorion so that the Televet device could not be positioned in time. In two mares, recordings were started delayed. In two of the remaining mares, due to a high incidence of AV blocks, HRV could not be reliably calculated and thus for these mares, only HR data were included (Table 1). In the nonpregnant mares, recordings were made for 100 minutes from 6:00 to 7:40 AM and 5-minute intervals starting at 0, 30, 60, and 90 minutes were analyzed.

2.4. Hormone analysis

Salivary cortisol concentrations were determined with an enzyme immunoassay established in our laboratory as described [20]. The antiserum cross-reacts with several cortisol metabolites, and values have to be interpreted as cortisol immunoreactivity. The intra-assay and interassay coefficients of variation were 5.0% and 6.7%, respectively, and the minimal detectable concentration was 0.3 pg per well.

Analysis of epinephrine and norepinephrine concentrations was performed by ELISA after extraction from plasma using a cis-diol–specific affinity gel (2-CAT ELISA; Labor Diagnostika Nord, Nordhorn, Germany) as described in [25] validated for equine plasma in our laboratory. For both epinephrine and norepinephrine, increasing dilutions of plasma showed good parallelism to the standard curve, and recovery of standard added to plasma was 95% for epinephrine and 99% for norepinephrine. For epinephrine, the intra-assay coefficient of variation calculated from variations of all sample duplicates was 3%. The interassay coefficient of variation (n = 3 assays) was 6% and 4%, respectively, for plasma with a high (29.0 ng/mL) and medium (7.7 ng/mL) concentration and the minimal detectable concentration calculated as 2 standard deviation from zero binding was 20 pg per well. For norepinephrine, the intra-assay coefficient of variation was 3%, the interassay coefficient of variation (n = 3) was 14% and 25%, respectively, for high (143.1 ng/mL) and medium (38.2 ng/mL) pool plasma, and the minimal detectable concentration was 60 pg per well.

2.5. Statistical analysis

For statistical analysis, the SPSS statistics program (version 20; IBM, Armonk, NY, USA) was used. All data were normally distributed (Kolmogorov–Smirnov test). Changes over time were analyzed using a general linear model for repeated measures. The occurrence and distribution of AV blocks was analyzed by nonparametric tests (Friedman test for comparisons between multiple time points and Wilcoxon test for comparison between two time points). A P-value less than 0.05 was considered significant. All values given are means ± standard error of mean.

3. Results

3.1. Clinical findings

The time from rupture of the allantochorion until the foal was born (second stage of labor) lasted 13.4 ± 1.4 minutes,

and passage of the fetal membranes (third stage of labor) was completed within 23 to 118 minutes (45.1 ± 7.9 minutes) after delivery of the foal. All foals were checked clinically and were found to be mature and healthy. Foals were standing for the first time at 38.0 ± 4.4 minutes after delivery and mean time until the first suckling of the foal at the mares' udder was 84.3 ± 7.4 minutes after delivery.

3.2. HR, HRV, and AV blocks

Maternal HR decreased significantly from 120 minutes before to 120 minutes after delivery of the foal ($P < 0.05$; Fig. 1A). Heart rate was the highest 15 minutes before the end of the second stage of labor (52 ± 2 beats/min) and declined to a minimum at 15 minutes after birth of the foal (41 ± 2 beats/min; Fig. 1A). As for HR, the HRV variables, SDRR and RMSSD, changed significantly over time from 120 minutes before to 120 minutes after birth of the foal ($P < 0.05$). The highest values were reached within the first 15 minutes after delivery of the foal (SDRR, 94.6 ± 6.2 ms; RMSSD, 131.7 ± 11.9 ms) and SDRR and RMSSD decreased significantly thereafter until 120 minutes after delivery ($P < 0.05$; Fig. 1B, C).

The only cardiac arrhythmias in the mares' ECG were the second-degree AV blocks. The number of mares that showed AV blocks increased over time ($P < 0.01$). During the 15-minute interval starting at 120 minutes prepartum, no mare showed any AV blocks. The number of mares with AV blocks increased thereafter and was significantly elevated during the time intervals starting at 15 minutes prepartum and 15, 30, 45, and 90 minutes postpartum ($P < 0.05$; Fig. 2A). Within 15 minutes before birth of the foal in nine of 11 mares, AV blocks were found, whereas only in two mares, no AV blocks occurred at this time. Mares showed AV blocks in 3 ± 1 of the 15-minute intervals between 120 minutes before and 120 minutes after birth of the foal. Only one mare showed no AV block at any time. Also, the number of AV blocks per mare increased significantly ($P < 0.01$). Compared with the 120-minute prepartum interval, where no AV blocks were present in any mare, the number of AV blocks per mare was significantly increased during the intervals beginning at 15 minutes prepartum and to 15, 30, 45, 60, 90, and 105 minutes postpartum ($P < 0.05$; Figs. 2B and 3A–D).

In nonpregnant mares, during the recording time, neither HR nor HRV changed, and no AV blocks were detected (Fig. 4A–C).

3.3. Salivary cortisol

Salivary cortisol concentration in mares was 14.4 ± 1.4 ng/mL immediately after birth of the foal and increased thereafter to a maximum of 25.0 ± 3.4 ng/mL at 30 minutes postpartum. Cortisol concentrations then decreased to 7.1 ± 1.0 ng/mL at 120 minutes after delivery ($P < 0.01$; Fig. 5). Salivary cortisol concentrations in nonpregnant mares were below 1 ng/mL at all times and did not change significantly during the 90-minute sampling period (Fig. 4D).

3.4. Catecholamines

Epinephrine and norepinephrine concentrations in plasma changed significantly from rupture of the allantochorion to expulsion of the fetal membranes ($P < 0.01$; Fig. 6). The highest epinephrine concentrations were measured at rupture of the allantochorion (142 ± 19 pg/mL) and decreased to 119 ± 21 pg/mL at the end of the second stage of labor and 84 ± 13 pg/mL after expulsion of the fetal membranes. Norepinephrine showed the highest values toward the end of the second stage of labor (379 ± 31 pg/mL), whereas lower concentrations were found at rupture of the allantochorion (240 ± 33 pg/mL) and expulsion of the fetal membranes (243 ± 24 pg/mL).

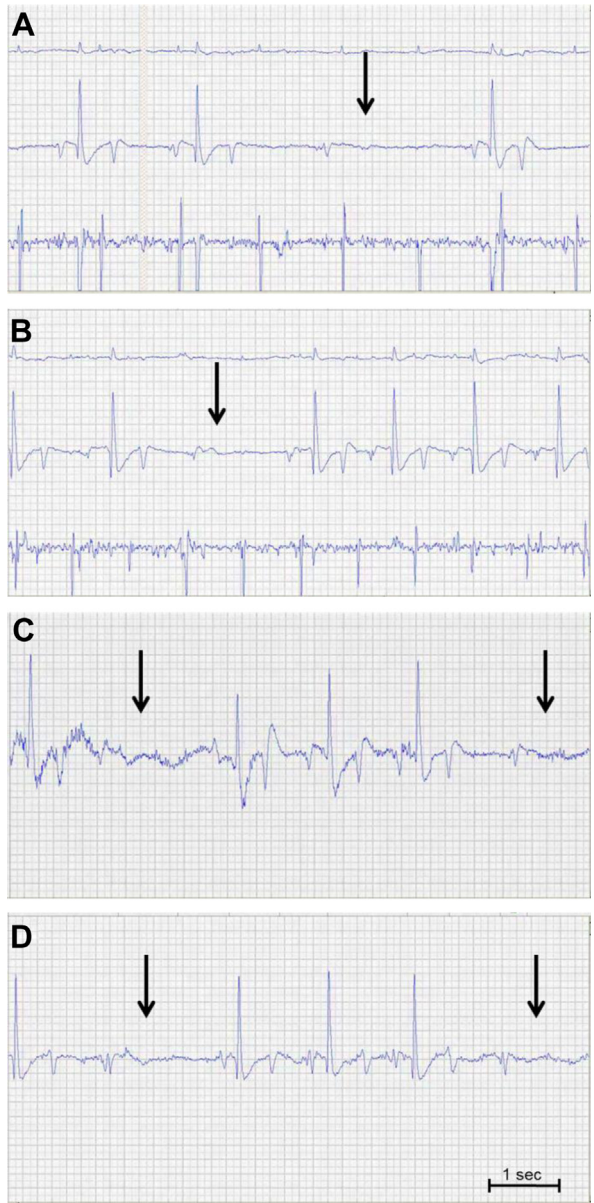

Fig. 3. ECG recordings with AV blocks from individual mares (A) 70 minutes, (B) 13 minutes before birth of the foal, (C) 1 minute, and (D) 9 minutes after birth of the foal; (A, B) fetus mode, upper line: combined fetomaternal signal, middle line: maternal signal, lower line: fetal signal, (C, D) single lead mode, maternal signal only; gain 40 mm/mV, feed 50 mm/s; arrows indicate AV blocks. AV, atrioventricular.

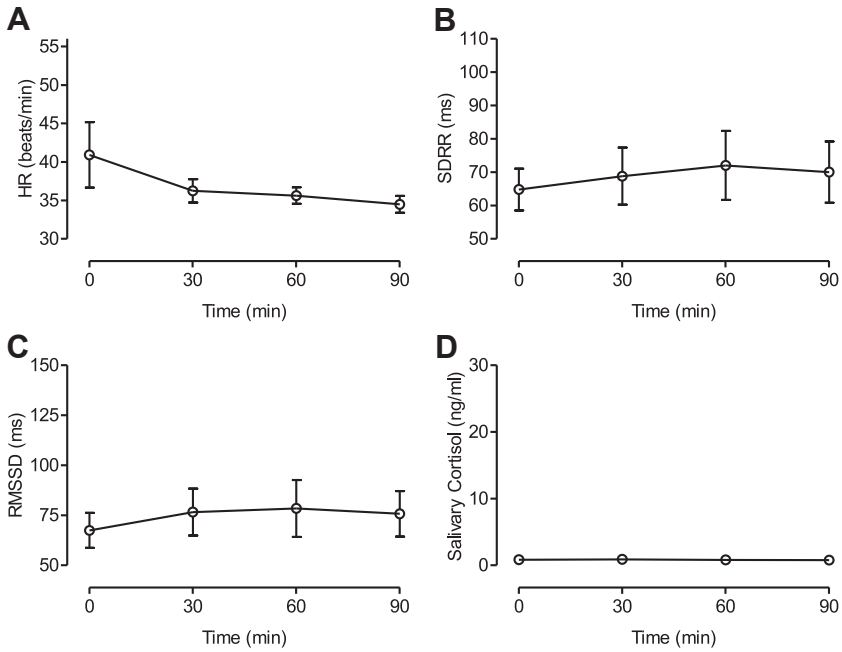

Fig. 4. (A) Heart rate and HRV variables, (B) SDRR, (C) RMSSD, and (D) salivary cortisol concentration in nonpregnant mares over a 90-minute recording time. None of the parameters changes over time were significant. HRV, heart rate variability; RMSSD, root mean square of successive RR difference; RR, beat-to-beat; SDRR, standard deviation of the RR interval.

Atrioventricular blocks occurred primarily at times of either low or decreasing plasma norepinephrine concentrations. Individual curves for representative mares are shown in Figure 7.

4. Discussion

This study demonstrates for the first time that horses give birth under reduced sympathetic and high parasympathetic tone. The short and pronounced expulsive phase of physiological parturition in mares is thus characterized by a state of relaxation and not as might have been expected associated with a stress response. This is mainly indicated by a high incidence of second-degree AV blocks and marked increases in the time domain HRV variables, SDRR and RMSSD. At rest and during low intensity exercise, horses show high parasympathetic activity and in resting horses, occasional second-degree AV blocks are physiological [26]. These AV blocks have no effect on the physical capacity of healthy horses and, with an increase in sympathetic tone, resolve during exercise [27]. Although labor would be assumed to constitute a strenuous process comparable to exercise, in foaling mares labor was not associated with a resolution but on the contrary with an increased induction of AV blocks, indicating a marked

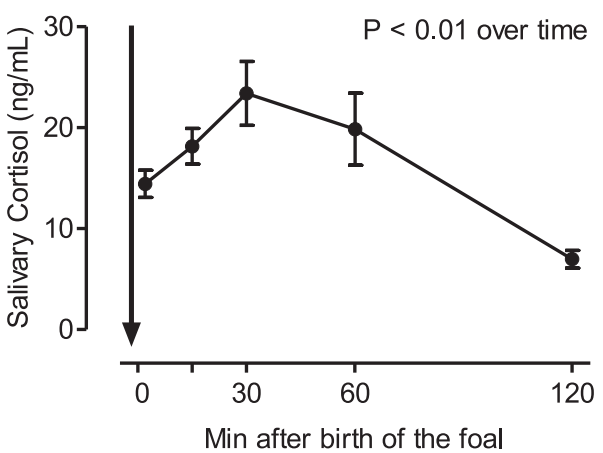

Fig. 5. Salivary cortisol concentrations in mares (n = 17) from birth of the foal (arrow) until 120 minutes thereafter, values are means ± SEM. SEM, standard error of the mean.

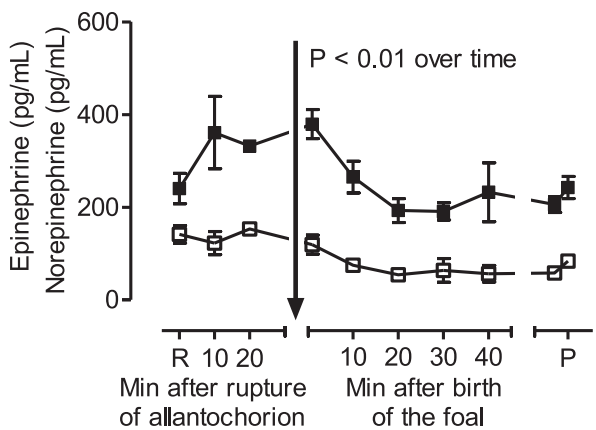

Fig. 6. Plasma concentrations of epinephrine (□) and norepinephrine (■) in mares from rupture of the allantochorion (R) to birth of the foal (arrow) and passage of fetal membranes (P). The last two samples are aligned to the time of expulsion of the fetal membranes (n = 3–10; see Table 2); values are means ± SEM. SEM, standard error of the mean.

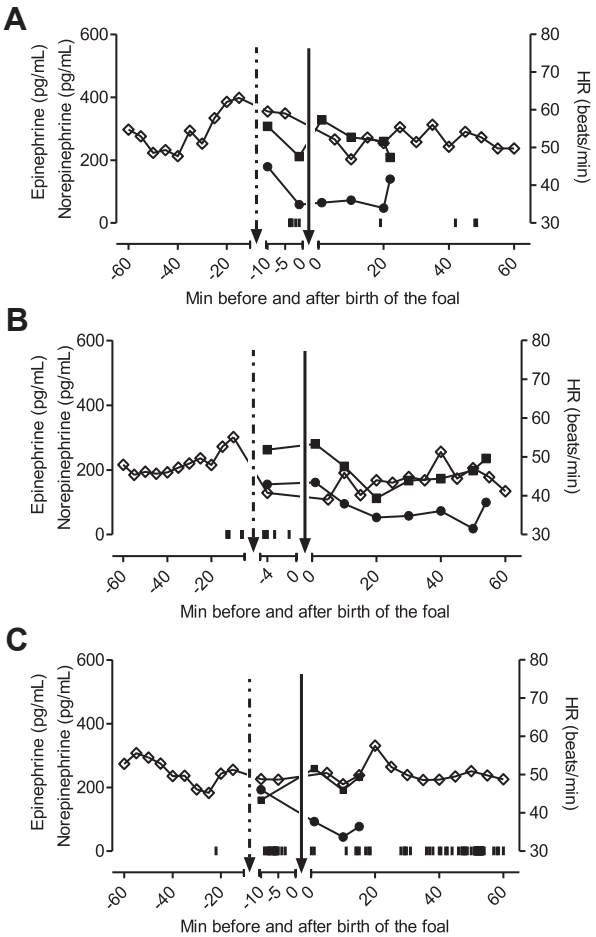

Fig. 7. Concentrations of epinephrine (•) and norepinephrine (■) in plasma, HR (◇), and occurrence of AV blocks (I) in individual mares from 60 minutes before rupture of the allantochorion (interrupted line arrow); to birth of the foal (continuous line arrow) and 60 minutes thereafter. Note the differences in duration of second stage labor between mares. AV, atrioventricular; HR, heart rate.

increase in parasympathetic tone. This interpretation is further supported by an increase in HRV during and after expulsion of the foal, leading to maximal values for the HRV variables, SDRR and RMSSD, at 15 minutes after birth of the foal and a rapid decline thereafter. An increase in HRV is indicative of increased parasympathetic or reduced sympathetic activity or a combination of both with RMSSD being more specific for parasympathetic activity [15]. Both HRV variables reached peak values shortly after delivery of the foal and also the occurrence of AV blocks persisted into this period, demonstrating parasympathetic dominance not only during expulsion of the foal but also immediately after foaling. The parasympathetic branch of the autonomous nervous system has stimulatory effects on myometrial contractility in rats [28,29]. High parasympathetic tone thus may also enhance labor in parturient mares.

In the mares, catecholamines were determined at different stages of parturition only and thus concentrations cannot be compared with values from the same mares earlier in pregnancy. Although norepinephrine concentrations were slightly higher during expulsion of the foal than thereafter, concentrations of catecholamines in foaling mares were still in the same range as in horses at rest measured with the same assay system [25] and below concentrations found in acute or chronically ill horses [30]. In contrast in women, catecholamine release is clearly elevated during delivery compared with resting adults [10]. The AV blocks in parturient mares occurred mostly at times when catecholamine concentrations were either low or declining in the individual mare, again indicating parasympathetic rather than sympathetic dominance.

Cortisol, but not HRV starts to increase in foaling mares 1 to 2 days before parturition [1] and—as found in the present study—reaches its maximum about 30 minutes after birth of the foal. The antepartum increase in maternal cortisol concentration [1] coincides with an increased cortisol release in the fetal circulation [31]. The rise is therefore unlikely to be a stress response but part of the endocrine pathways initiating parturition. Maximum cortisol release occurred 30 minutes after foaling and thus not in association with labor. Even if cortisol release at foaling includes a stress-induced component, this takes place after and not during foaling. However, the maximum values in both HRV variables and high incidence of AV blocks at that time do not indicate a maternal stress situation.

Throughout equine gestation, maternal HR increases because of adaptation of the cardiovascular system to the increasing demands of the fetus but during foaling itself HR remains at the same level as in late-pregnant mares [1,32]. The present data show that immediately after expulsion of the foal, maternal HR decreases to levels as in nonpregnant horses. The mean HR of mares during foaling is far below HR in horses during stressful situations such as weaning [17], equestrian performances [18], or strenuous exercise with HRs exceeding 200 beats/min [33]. Thus, undisturbed parturition apparently is neither a stressful nor a strenuous process in horses. Rapid delivery may be in part enabled by an altered pain threshold during labor due to increased endorphinergic activity as has been found in parturient rats [34]. An endorphin-mediated increase in nociceptive threshold as an endogenous defense against labor pain has also been suggested in pigs [35]. Labor-associated β-endorphin release into plasma exists in humans [36] and rats [37] but apparently not in cattle [38]; however, it has not been studied in horses so far.

Horses are a prey species and respond to dangerous and threatening situations with immediate escape. Foaling most often occurs during night when the environment is perceived as quiet and safe [8], but it cannot be excluded that nocturnal parturition is driven by melatonin that may enhance uterine contractions as suggested for humans [39]. Results of the present study do neither totally exclude that horses can give birth also under stressful conditions nor do they prove that mares can withhold parturition on purpose. However, data strongly suggest that high parasympathetic and/or low sympathetic activity is a prerequisite for the onset of physiological foaling.

In rats and pigs as polytocous species, parturition *per se* takes longer than in horses and can be prolonged or

interrupted by environmental disturbance [6,7]. Parturition in horses has to be very fast because survival time of the foal is limited after rupture of the allantochorion. Thus, although we suggest that a pronounced nonstress situation is a prerequisite for the onset of foaling, once the second stage labor has started, it has to be finished within a short time. A state of marked myometrial relaxation during the last 2 to 4 hours preceding parturition followed by an abrupt increase in myometrial activity only shortly before delivery of the foal [3] supports this interpretation. A massive release of PGF2α and oxytocin occurs immediately before and during the second stage of labor only [4,5]. At this time, the foal has entered the birth canal and rapid foaling is stimulated most likely via Ferguson's reflex. Uterine-type oxytocin receptor gene expression has been found in all chambers of the rat heart. Receptor mRNA levels in the atria were higher than in the ventricles and oxytocin reduced HR in isolated atria from perfused rat hearts [40]. In agreement with these findings, expulsion of the foal was associated with a sudden and pronounced oxytocin release in previous experiments [5] and coincided with the occurrence of AV blocks in the present study. Besides its effects on uterine contractions, oxytocin may have negative chronotropic effects and thus contribute at least in part to the occurrence of AV blocks in parturient mares.

4.1. Conclusions

The horse, as a species responding to external challenges with a flight response and with pronounced sympathoadrenal activity physiologically, gives birth in a state of marked relaxation and high parasympathetic tone.

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