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Increase of skin temperature prior to parturition in mares

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A B S T R A C T

Prediction of impending foaling is highly desirable as early intervention may improve mare and foal outcomes. However, monitoring the peripartum mare is a time-consuming challenge for breeders and many foaling prediction systems have limitations. "Heating up" of the mare is empirically used by breeders as a sign of upcoming parturition in mares. The purpose of this study was to investigate if an increase in skin temperature shortly before parturition is detectable and to determine whether such physiological changes could be an additional valuable parameter to predict foaling. For that, 56 foalings of 14 Warmblood mares, 5 Arabian mares, 27 Thoroughbred mares, and 2 mares of other breeds were analyzed in this 2-year-study. Eight mares were monitored in both years. Mares were between 4 and 22 years old (average: 10 ± 5.5 years) and the mean pregnancy length was 342 days (±9 days), resulting in 14 births from primiparous mares and 42 multiparous mares. For monitoring the periparturient mares, the Piavet® system (Piavita AG, Zurich, Switzerland) was fixed daily when the mares had returned from the field between 4:00 and 6:00 p.m. and collected the next morning between 6:30 and 7:30 a.m. until the time of foaling. Nocturnal rhythms of the skin temperature with the highest values at the start of measurements and a nadir at 6:00 a.m. were observed. On the foaling night, we found a rise in skin temperature starting on average around 90 min prepartum. Skin temperatures recorded at 50 min before parturition and at each 5 min time point until rupture of the allantochorion were significantly higher ($p < 0.05$) than the mean temperatures measured in the 5 nights before parturition at the same time, reaching a difference of approximately 0.5 °C. There was a significant effect of parity ($p = 0.04$) on skin temperature during the last hours before foaling where primiparous mares showed a higher mean temperature than uni- or pluriparous mares as early as from 180 min on before parturition. In conclusion, our study shows an increase in skin temperature in most mares within 90 min before birth. Using new biomechanical and digital technologies, this finding could generate an additional potential parameter for the detection of impending parturition. However, skin temperature cannot be used as the only predictive diagnostic of impending parturition in the absence of other parameters.

1. Introduction

In 90% of foalings in domestic mares, no human intervention is necessary. However, when problems at this time point arise the consequences may result in the death of the mare or the foal. Besides ethical and emotional aspects, this is also associated with a large financial risk. Early intervention may improve mare and foal outcomes. It is therefore highly desirable to attend and if needed to assist parturition of the mare [1,2], necessitating the best prediction of the event as possible. This is complicated by the highly variable gestation duration in mares which can be anywhere between 320 and 360 days [1,3,4]. As the majority of mares foal at night when environmental stimuli are minimal [5,6], the monitoring in the prepartum phase is a laborious challenge for breeders.

Physical observation of readiness for parturition such as waxing of the udder, relaxation of the sacro-sciatic and other pelvic ligaments, and increased vulvar length are subtle and very variable among mares [7,8]. In addition, evaluation of mammary secretion

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focusing on electrolytes or pH gives good negative predictive values and is more beneficial in predicting when the mare would not foal [8,9]. Summarizing the mentioned observations of clinical signs may indicate the day of foaling but provide no information on the actual onset of parturition. Only shortly before an upcoming birth and due to rotation of the foal and uterine contractions, reliable characteristic signs of the first stage of parturition can be observed such as sweating of the mare, restlessness, signs of colic, showing the flehmen response, frequent switching of the tail, and milk squirt from the teats [4,10,11]. However, not all mares display all these signs.

There are several foaling alarm systems commercially available that are based on behavioral changes such as pedometer, accelerometer, electrodes that detect an increase in humidity when the mare starts to sweat, or probes that register lateral recumbency. Most of these alarm systems are fraught with considerable uncertainty, and false alarms are common [4,12]. Thus, transponder-based systems which are sutured to the vulva are more sensitive but invasive and announce alarm only in an advanced stage of the birth when the foal enters the birth canal [8]. Recently, alterations in physiological values prepartum and changes indicative of parturition have gained increasing attention [13].

In mammals, including horses, many physiologic processes display 24-h rhythms that are regulated by the circadian system and vary during the day, having both endogenous and exogenous influences [14–16]. For example, circadian rhythmicity of body temperature is well documented in farm animals and horses, because of the relative ease of monitoring [17]. Some studies indicate that, even if the physiological background is unknown, body temperature could be a valuable parameter to predict an upcoming onset of parturition as a pronounced drop in body temperature can be detected up to 3 h before and during foaling using rectal temperature measurements or implanted temperature sensor microchips [10,18]. However, changes might be missed if measurements are not taken very frequently [10,11,13].

As far as we know, skin temperature prepartum as a potential indicator of upcoming foaling is not yet described in the literature. In cattle, it was shown that ventral tail base surface temperature decreases in the hours before parturition [19]. Likewise, mean body surface temperature (BTS) measured at the neck on peripartum ewes was lower on the day of parturition compared to the days before [19]. However, the authors also documented in the same study an increase in BTS shortly before parturition [19].

The purpose of the present study was to investigate if an increase in skin temperature shortly before parturition in mares is detectable and to determine whether such physiological changes could be an additional valuable parameter to predict foaling.

2. Material and methods

2.1. Animals

The experiments were performed during the foaling seasons 2020 and 2021 from February to June and 83 periparturient cases were monitored. Finally, 56 foalings in Warmblood mares, 5 Arabian mares and 2 mares of other breed from the Haupt-und Landgestüt Marbach/Germany, and 27 Thoroughbred mares from Gestüt Fährhof in Sottrum/Germany were analyzed. Eight mares were monitored in both years. 27 foalings had to be excluded due to reasons like foaling during the day in the field ($n = 5$; 6.0%), insufficient data recording before the onset of foaling ($n = 10$; 12.0%), or poor measurement quality caused by the displacement of the girth and the recording device due to movement such as repeated standing up and lying down of the mare or rolling in the box ($n = 12$; 14.5%).

The mares included in the study were between 4 and 22 years old (average: 10 ± 5.5 years) and the mean pregnancy length was 342 days (±9 days), resulting in 14 births from primiparous and 42 from multiparous mares (Haupt-und Landgestüt Marbach: $n = 8$ and 18, respectively; Gestüt Fährhof: $n = 6$ and 24, respectively). The late pregnant mares were stabled in single boxes overnight, with daily access to the field in groups. At both the Gestüt Fährhof and the Haupt-und Landgestüt Marbach, the horses were fed twice daily with hay and grain in their boxes. The experiment was approved by the Animal Health and Welfare Commission (Permission no. VD3550) and strictly followed institutional guidelines for humane animal treatment.

2.2. Experimental design

Measurements in each mare were individually started as soon as they were stabled in single foaling boxes, the latter based on the presence of characteristic signs of readiness for parturition, e.g. enlargement of the udder, slight filling of the teats, and taking into account the calculated date of birth (335 days). From this date, the measuring device was fixed daily when the mares had returned from the field between 4:00 and 6:00 p.m. and collected the next morning between 6:30 and 7.30 a.m. until the time of foaling. Measurements were stopped after placental expulsion. Routine stud farm management was not changed. At the Gestüt Fährhof, a night guard was present, whereas at the Haupt-und Landgestüt Marbach the system Foalert® (Foalert inc., Willow Tarn, USA) was used in parallel. At both stud farms, simple foaling assistance was performed if considered necessary. No clinically complicated dystocia was observed in our study.

2.3. Monitoring system

For monitoring the periparturient mares, the Piavet® system (Piavita AG, Zurich, Switzerland) was used. The Piavet measuring device is attached to a belt that holds it in place on the left side of the horse's thorax. For the measurement of the skin temperature, a sensor (TMP117 High-Accuracy, Low-Power, Digital Temperature Sensor, with SMBus™- and I2C-Compatible Interface, Texas Instruments, Dallas, USA) is embedded in the device which lies directly on the surface of the skin (Fig. 1). The TMP117, validated according to ASTM E1112 and ISO 80601 requirements for electronic patient thermometers, provides a 16-bit temperature result with a resolution of 0.0078 °C and an accuracy of up to ±0.1 °C across the temperature range of −20 °C–50 °C. Skin temperature in degrees Celsius was recorded every second.

2.4. Statistical analysis

Statistical analysis was performed using the software NCSS 2020 [21]. After a preliminary visualization of the data, the first hour of every daily measurement was removed because the device sensor needs time to warm up to skin temperature. As 5 min time intervals were sufficient to illustrate temperature variations, mean temperatures every 5 min were calculated. Since every mare foaled at a different clock time, time intervals were standardized to the foaling hour (foaling defined as rupture of the allantochorion and depicted as time interval 0). Then, the 5-min mean temperatures were in turn averaged across all 5 nights before parturition to render the mean skin temperature before parturition for each mare every 5 min. The dataset was structured in a 'long-format' with the mean of the 5 nights followed by the skin temperature on the parturition night. To be able to compare these two time periods, a binary variable 'night' was coded to distinguish the parturition night data from previous nights' data.

Fig. 1. Piavet® system.

The evolution of the skin temperature over time (preprocessed as described above) was visualized with line plots for each mare separately and with box-plots pooling all mares at each 5-min interval. Data distribution was analyzed using Normality tests (Shapiro-Wilk and Wilcoxon rank-sum tests) and then expressed as means ± SD. Boxplots were expressed as median, first and third quartile, and the whiskers were calculated as 1.5xIQR.

A mixed linear model (full model with 1-way interaction terms) using the NCSS 'Repeated Measures Analysis of Variance' procedure was calculated setting skin temperature as the outcome variable, mare number as a subject variable, and night and time interval as within-variables. Changes in skin temperature during the 180 min before parturition were analyzed. In 11 foalings (19.6%) data from less than 180 min of measurement was available, but at least from 70 min (see Supplementary Fig. S1 and S2). Finally, the influence of season (first vs second year of the study), month of parturition, time of birth, breed, age and status (primi-vs pluriparous) of the mare was evaluated by running additional models introducing these variables (all at the level of the subject mare) one at a time as between factors. From that, season, time of birth, and age of the mares were excluded as confounding variables ($p = 0.90$, $p = 0.64$ and $p = 0.55$, respectively). In a following analysis of the increase of skin temperature within the 90 min before delivery in relation to the month of parturition and the breed of the mares using a General Linear Model, these two variables were also shown to not influence during this time period ($p = 0.33$ and $p = 0.10$, respectively). The level of significance was set at 0.05.

3. Results

The measured mean skin temperature overnight during the 5 nights before parturition was 31.6 °C ± 1.3 °C. Nocturnal rhythms were observed with the highest values at the start of measurements (e.g. measured mean skin temperature at 7:00 p.m.: 32.62 °C ± 0.96 °C) and a nadir at 6:00 a.m. (measured mean skin temperature 30.69 °C ± 1.20 °C) (Fig. 2).

All analyzed foalings took place between 6:43 p.m. and 7:22 a.m. Fig. 3 illustrates the changes in mean skin temperature measured during the 180 min before and 60 min after parturition, compared with the mean skin temperature measured during the 5 nights before at the same time sets. Measured mean skin temperatures on the foaling night recorded at 50 min before parturition and at each 5 min time point until rupture of the allantochorion were significantly higher ($p < 0.05$) than the mean temperatures measured during the 5 nights before parturition at the same time.

The individual increase of skin temperature of each mare started on average around 90 min prepartum: in this time window, the lowest mean prepartum value was measured 90 min before (32.00 °C ± 1.07 °C) and the highest 5 min before, resulting in 0.51 °C higher (32.51 °C ± 0.80 °C) parturition, followed by a rapid decrease. This observed increase varied strongly between the individual mares: A significant rise in measured skin temperature of a minimum of 0.5 °C in this time period could be observed in 40/56 foalings at different times (71.4%; individual line charts of all foalings see Supplementary Fig. S3) whereas this was not the case in the remaining 16 foalings.

In addition, there was a significant effect of parity ($p = 0.04$) on skin temperature during the 3 h before foaling (Fig. 4). Primiparous mares showed in the foaling night a higher mean temperature than uni- or pluriparous mares as early as 180 min on before parturition compared to the 5 nights before at the same time. The lowest measured mean skin temperatures (32.51 °C ± 1.49 °C) in the group of primiparous mares were found 75 min prepartum and the highest (32.83 °C ± 1.10 °C) 15 min prepartum.

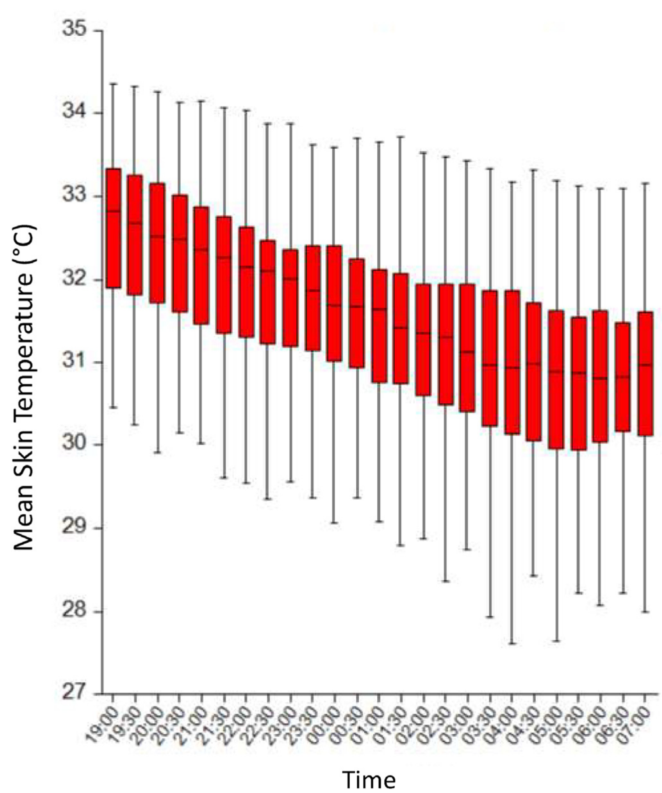

Fig. 2. Mean skin temperature every 30 min (in °C) over the five nights before the foaling night.

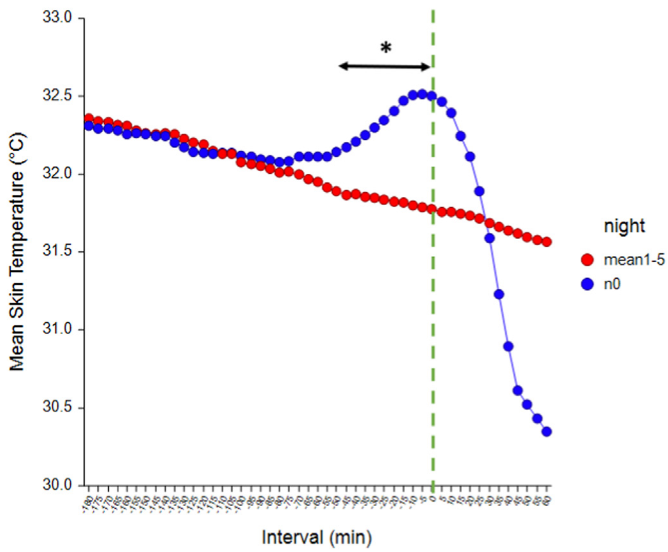

Fig. 3. Changes in mean skin temperature (5 min intervals, in °C) during the 180 min before parturition and up to 60 min after parturition in the foaling night (n0), compared to the mean skin temperatures in the five nights before (mean 1–5) at each time set. The time point of rupture of the allantochorion was set as 0 (dashed green line). Values under the arrow with the symbol * added as superscript differ significantly between the nights. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4. Discussion

In this study, we found a rise in measured skin temperature in the last 90 min prepartum in foaling mares. Compared to the average of the 5 nights before the foaling night, this observation was significant from around 50 min before parturition until 5 min before the rupture of the allantochorion (approximately 0.5 °C). Skin temperature also showed typical variation across the night with higher values in the early evening, a constant decrease overnight, and a nadir in the early morning. Thus, on the foaling night, this decreasing nocturnal trend was overruled. Before 90 min, no significant difference in skin temperatures compared to those in the 5 nights before foaling was observed. This may indicate that measurements of skin temperature are less useful as an early predictor for the onset of parturition compared to the body temperature where a failure of the normal evening temperature rise is an indicator for foaling in the same night already 12 h before parturition [11,22]. Besides physiological causes leading to this assumption, skin temperature might be influenced by other factors in particular the environmental temperature but also body condition, hair coat, exercise, and tissue perfusion [23–25]. Indeed, high variability of skin temperature between individuals (27–35 °C) was observed in our study population, most likely due to a wide variation in external temperature, as the study took place over two seasons from January to June.

However, using a standardized within design with intra-individual observations over a short time period of 6 days each, mentioned variables potentially influencing skin temperature like the month of foaling, body condition, hair coat, and exercise can be excluded as confounding factors in our results. Nevertheless, due to the relatively high individual variation of the time point of onset and the degree of measured skin temperature rise before parturition observed in our study cohort as well as considering other potential fluctuations of the skin temperature in the pre-partum period of mares there exists a clear fallibility when using skin temperature changes in the absence of other parameters as predictive diagnostic of impending parturition.

In contrast to our observations in mares, in ewes, a comparable study by Nabenishi & Yamazaki [20] showed a decrease in surface temperature at the upper neck on the day preceding parturition compared to the same time the days before, followed by a slight increase of neck temperature just before parturition, which was not further analyzed by the respective authors. In mammalian species, most of the hormones involved in parturition are probably common but it was hypothesized that the timing and quantitative significance of prepartum endocrinological processes show some variations in the individual species [13,26,27]. In cattle, a decrease in body temperature prepartum is associated with a decrease in progesterone concentration and is a reliable predictor of calving [13]. In horses, this fall in maternal progestogen levels 48–24 h prepartum activates lactogenesis and causes the final change in milk composition but correlates only loosely with the described decrease in body temperature prepartum [26,28]. Moreover, initiation of parturition in horses does not require such a pronounced decrease in progestins as described in cattle but activation of uterotonic hormones, such as prostaglandins and oxytocin [29–31].

'Heating up' of the mare before foaling is well known among

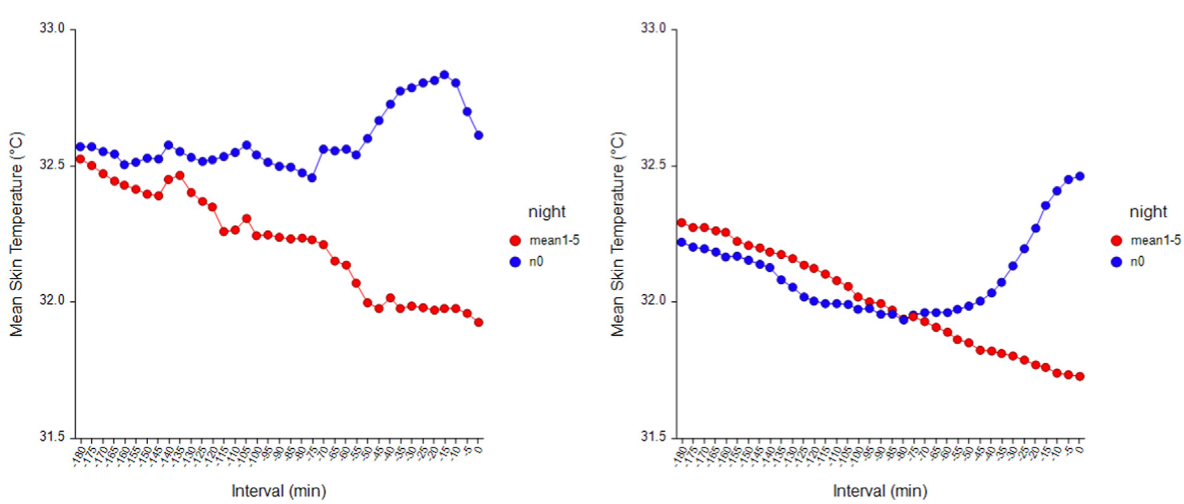

Fig. 4. Change in mean skin temperature (5 min intervals) of the last 180 min until parturition in the night of foaling (n0), compared to the mean skin temperatures in the 5 nights before (mean 1–5) at the same time set in (A) primiparous and (B) uni- or pluriparous mares. The time point of rupture of the allantochorion was set as 0.

breeders and empiric observations suggest that shortly before parturition most of the mares' neck, shoulders, or flanks feel warm followed by the next stage where a damp or general sweat may occur [4]. Under normal circumstances, the temperature of the skin is approximately 5 °C lower than the body core. Evaporation plays an important role in balancing internal and external temperatures. Also, changes in tissue perfusion and blood flow lead to skin temperature differences [32,33]. The main stimuli causing activity and sweating of the body surface glands in the horse are increased environmental temperatures and exercise. In addition, pharmacological studies suggest that equine sweat glands are under predominantly adrenergic control and that vascular changes might also affect sweat discharge [34,35]. The release of maternal prostaglandin $F_{2\alpha}$ starts to increase during the first stage of labor, and a massive release during the second stage of labor before foaling and during the delivery of the foal is well described [26,30,36]. Such prostaglandins are produced by the uteroplacental tissues and involved in the main physiological events i.e., cervical dilatation, rupture of the allantochorion, and uterine contractility [29,36,37]. In horses, it is well documented that $PGF_{2\alpha}$ leads to stimulation of the body surface glands by increased cutaneous blood flow [38,39]. Thus, we hypothesize that our findings of an increase in surface temperature before foaling might also be related to elevated prostaglandin levels. Finally, the marked fall of skin temperature observed immediately after parturition is attributable to pronounced sweating, which occurs at this stage. However, our hypotheses should be tested in further studies including parallel analysis of hormonal concentrations, and behavioral observations as well as the detailed recording of sweating.

In addition, we found a significant effect of the mares' parity on skin temperature before foaling. We hypothesize that the higher surface temperatures of primiparous mares compared to uni- or pluriparous mares in the last 3 h before parturition is due to reinforced discomfort and increased restlessness. Higher locomotor activity one to 2 h prepartum [3] is well documented in horses. Also in bovines, primiparous periparturient dairy cows showed a higher activity level before parturition than multiparous [40–42]. Furthermore, several studies indicate that gestational length, placental anatomical development, and metabolic function differ in the gestation of primiparous mares from that in multiparous mares [42,43]. Also, these hypotheses have to be further elaborated in the horse.

Despite substantial efforts to acquire a large sample of animals and carry out the experiments under standard conditions, some biases cannot be excluded. Major limitations of this clinical field study were the availability of the mares only at night, and multiple heterogeneous variables like breed, age, reproductive history, hair coat as well as different management routines by the studs. However, we did consider these variables in our within-study design and analysis as best as possible. In addition, data from 27 mares had to be eliminated a posteriori from the experiments for reasons such as too few data for comparative measurements or bad quality due to displacement of the sensor.

In this study, we used a commercial high precision digital temperature sensor designed for high accuracy temperature measurement (±0.1 °C) around human body temperature. However, the sensor has previously not been validated in horses by comparison with other technologies e.g. thermography. Therefore, we only focused on and interpreted observed temperature changes but not absolute values in our results. Skin temperature is also dependent on the outside temperature [23,24], and this varied greatly between January and June. Moreover, the outside temperature during the night decreases, which further complicates a comparison of absolute skin temperatures at different times of the night. The fact that not all mares start sweating at the same time and to the same extent also makes analysis difficult. Further studies would be necessary including recording of stable temperature and humidity as well as sweating for more detailed results.

5. Conclusions

In conclusion, physiological observations give useful supplementary information for upcoming parturition. While “heating up” is used as an important empirical parameter by many breeders, it has, to the best of our knowledge, not been studied in detail. Our study is the first one that shows an increase in skin temperature that starts 90 min before and culminates at parturition, and this increase was more pronounced in primiparous mares. Using new biomechanical and digital technologies, this finding could lead to further improvements in tools for the detection of impending parturition. However, skin temperature cannot be used as the only predictive diagnostic of impending parturition in the absence of other parameters.

Authors’ declaration of interest

No conflicts of interest have been declared. The work received no financial assistance from the manufacturer of the Piavet system.

CRediT authorship contribution statement

Antonia Müller: Methodology, Investigation, Data curation, Writing – original draft. **Stefan Glüge:** Prosessing of the raw data, Validation. **Beatriz Vidondo:** Validation, Formal analysis. **Anna Wróbel:** Prosessing of the raw data. **Thomas Ott:** Prosessing of the raw data. **Harald Sieme:** Conceptualization, Methodology. **Dominik Burger:** Conceptualization, Methodology, Writing – review & editing, Supervision.

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Appendix B. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.theriogenology.2022.07.007.

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