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Review

Daily Variation of Body Temperature: An Analysis of Influencing Physiological Conditions

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Abstract: The evaluation of thermoregulation in homeothermic animals is important for their health assessment. Body temperature is influenced by the circadian rhythm, which, through certain signals, is regulated by the suprachiasmatic nucleus. Temperature is collected by various methods; to reduce the invasiveness of rectal temperature sampling, considered the most accurate, infrared thermography has been used. The aim of the present review was to describe the circadian variability of average body temperature in several domestic animal species. In addition to variations due to the circadian rhythm, a number of conditions that can influence body temperature have also been studied. One example of this is exercise, which occurs in the case of domestic animals such as horses, dogs, and donkeys. In particular, it has been analysed in athletic horses, where, following intense exercise, the circadian rhythm of temperature is altered. The daily temperature variation during pregnancy and the neonatal period was also analysed. The circadian rhythm of temperature is influenced by the gestational period of sheep and goats, but this is affected differently depending on the type of species. The same is true for the neonatal period, in kids, lambs, and cattle, where the circadian rhythm is established at different times.

Keywords: circadian rhythm; homeothermia; domestic animals; rectal temperature

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1. Introduction

Homeothermic animals are those capable of maintaining a temperature despite the external environment [1]. The measurement of body temperature is important in clinical practice as it can be helpful in assessing clinical conditions.

Thermoregulation is an important physiological process; this depends on involuntary effectors that, through the activation of thermoreceptors, certain responses such as heat generation and dissipation are carried out. This is conducted in most domestic animals by certain organs, such as metabolic heat sources (liver, heart), that are located away from the skin, where heat is dissipated [2,3].

The circadian rhythm, endogenously generated, has the characteristic of being omnipresent and affecting both physiology and behaviour [2]. This is regulated by the suprachiasmatic nucleus (SCN), located in the hypothalamus, via neural and hormonal signals [4,5]. The circadian rhythm is responsible for several physiological mechanisms that are greatly influenced. Coordinated processes include locomotor activity, urinary excretion, hormone secretion, heart rate, heart pressure, and temperature [6] (Figure 1). The circadian rhythm can be divided into four phases, including robustness, amplitude, acrophase (peak time), and mean level (or mesore) [2]. Among the parameters controlled by the circadian rhythm, along with the thermoregulatory system, is body temperature. Based on its variations, it is considered a basic physiological parameter of every animal, which is also important for assessing health conditions and energy metabolism [7]. The evaluation of the animal's

temperature is extremely important; in general, it is possible to measure body temperature, and it has been since the 1800s that measured temperature repetitions have been carried out [1]. For data collection, the most accurate method is considered to be the rectal method, despite being invasive [1,8,9]. Body temperature can undergo various variations due to the influence of some environmental factors such as humidity, solar radiation, and ambient temperature [10]. The circadian rhythm of body temperature (Tb) is regulated by maternal rhythms before birth, while after birth, it varies between species. After birth, in lambs and foals, fluctuations in body temperature are detected one week after birth. In primates, on the other hand, rhythms of Tb are detectable from the second postnatal week or later [11]. The process of temperature regulation and oscillation is known as thermoregulation. In thermoregulation, the hypothalamus has the function of regulating heat loss and heat production to maintain a stable temperature range for each species. When the homeostasis regulated precisely by the various thermoregulatory mechanisms is altered, fever can be encountered. Fever is an acute phase response that the body may generate following an infection or systemic inflammation. The rise in temperature triggers neurological, endocrine, immunological, and metabolic changes in order to limit the body's damage [3]. Although some of these physiological processes are valid for all organisms, there are variables that must be taken into account and that vary between animals, including the accumulation of fat, fur, and the number of sweat glands and their functionality [12]. The homeostatic regulation of body temperature is a fundamental physiological process that ensures the stability of the immune system in birds and mammals. Secondly, the thermoregulatory system is a complete system that utilises behavioural and autonomic processes in integration with other physiological systems, including the cardiovascular system, including the implementation of vasodilation and vasoconstriction, or the digestive system with the production of saliva [13]. The aim of this study was to understand how the circadian rhythm of mean body temperature varies in different domestic species and by which conditions it is influenced (Figure 2).

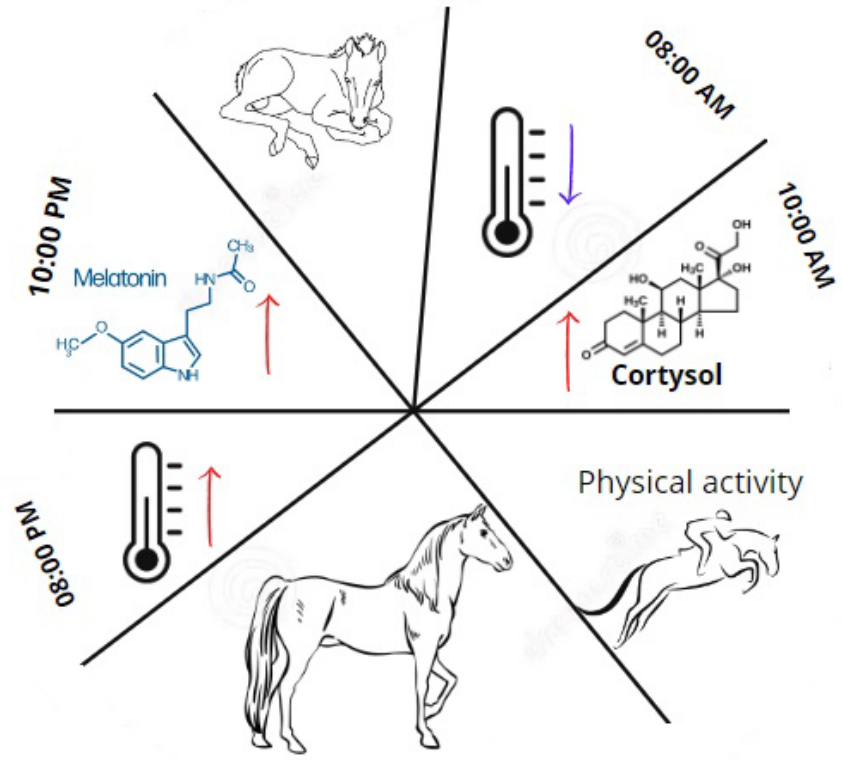


Figure 1. The circadian rhythm of some of the most important parameters in horses and how they are influenced. Acrophase times were specified.

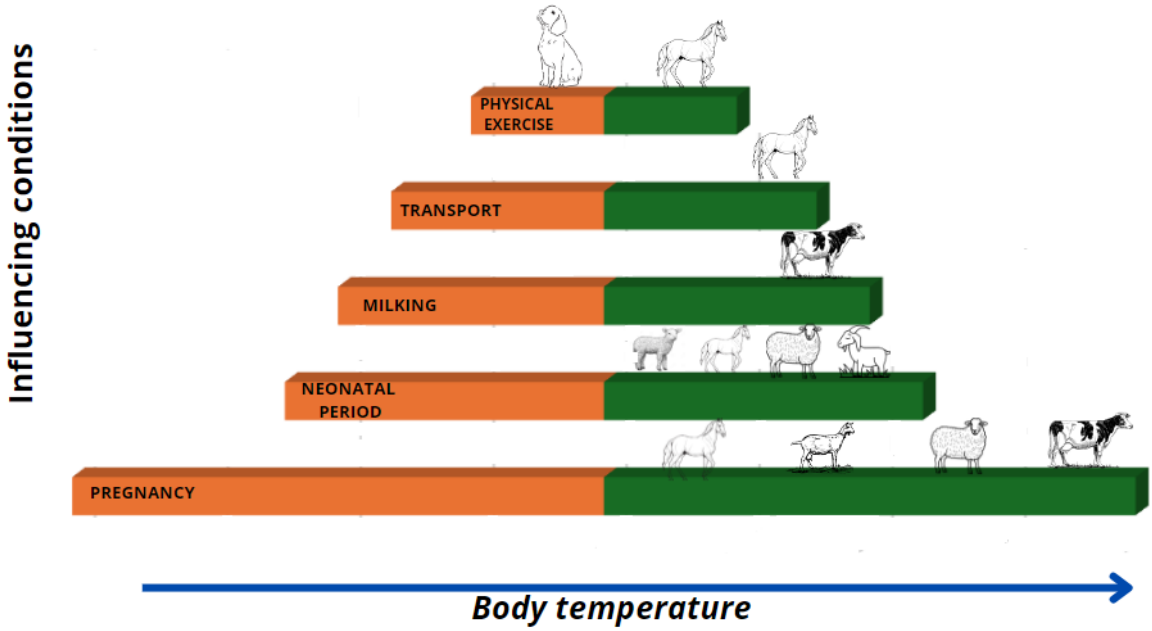


Figure 2. Graphical representation of the circadian rhythm variation due to different conditions of body temperature in different domestic species.

2. Materials and Methods

In writing this review, the aim was to identify which factors influenced the circadian rhythm of temperature. Initially, we wanted to present the circadian rhythm and then focus on the different factors that could alter the circadian rhythm, such as physiological ones such as pregnancy, lactation, or the neonatal period, and non-physiological ones such as transport or exercise. The literature search for this review was conducted on a number of scientific search engines, such as Google Scholar and PubMed, using a number of keywords, including, for example, 'circadian rhythm', 'domestic animals', 'temperature', 'exercise', and 'transport'. We proceeded by means of a search that first analysed the most current sources, noting in fact that few research groups have worked on how the circadian rhythm of temperature is affected in recent years. Subsequently, we focused on works that may be somewhat outdated, but which allowed us to understand the state of the art and how this topic can still be relevant and important for the health of domestic animals. The articles selected were those that provided the most information about the various phases related to the circadian rhythm (mean level, amplitude, acrophase, and robustness), as it was believed that they could provide important insight into how the circadian rhythm of temperature was actually affected. Articles that were deemed repetitive or did not provide anything new to the review were excluded.

2.1. Main Characteristics of Circadian Rhythms

Circadian and annual rhythms, to be defined as such, must be based on certain fundamental characteristics and coordinate certain physiological and behavioural phenomena. The fundamental time signal is certainly light, which has the function of synchronising circadian rhythms with the 24 h period of the earth's rotation, often tying the various physiological functions to the solar day [14,15]. The important aspect of the circadian rhythm is that it plays a role in influencing the natural environment, modifying and mediating, e.g., reproduction [16]. The circadian clock, through transcription-transduction feedback loops, is coordinated by a set of genes. A primary negative feedback loop is established involving the Clock/Npas2, Bmal1, Period1 (Per1), Per2, Cryptochrome1 (Cry1), and Cry2. In general, every mammalian cell has rhythmic gene expression that coordinates the various biological functions, ensuring that they take place at the most favourable time of day. The heterodimeric transcription factor CLOCK:BMAL1 is known as the master transcription

factor, as it rhythmically binds to DNA to activate the rhythmic transcription of the fundamental clock genes Period (Per1, Per2, Per3), Cryptochrome (Cry1 and Cry2), Rev-erb (Rev-erbα and Rev-erbβ), and Ror (Rorα, Rorβ and Rorγ) [17].

2.2. Daily Rhythmicity of Body Temperature

The circadian rhythmicity of body temperature in animals maintained in a light-dark cycle is characterised by four parameters:

- The mean level, like the mean of any set of data.
- The amplitude refers to the different values (range) of the body temperature excursion in a cycle.
- The time of the daily peak is defined as the acrophase.
- Robustness describes the way in which the rhythm takes on a regularity [2].

The circadian rhythm of temperature can vary slightly from species to species, which also influences the range and timing of the acrophase (Table 1).

Table 1. Daily variations of the body temperature rhythm of some species of domestic animals.

Species	Place of Collection	Mean Temperature	Oscillation Range	Acrophase	References
Equus caballus	rectum	38.0	0.4	15:00	[18]
	rectum	37.4	0.3	20:00	[19]
	rectum	38.2	0.4	23:00	[20]
	rectum	38.4	0.7	14:00	[2]
	rectum	37.4	1.0	12:00	[21]
	rectum	37.4	0.3	19:00	[22]
Ovis aries	carotidy artery	38.7	1.0	18:00	[23]
	intraperitoneal	39.3	0.3	14:00	[24]
Ovis aries (lambs)	rumen	39.5	0.4	19:00	[1]
Bos taurus	vagina	38.6	0.5	18:00	[25]
	udder	38.9	0.5	22:00	[26]
	rectum	38.3	1.4	14:00	[5]
	retina	38.1	0.4	10:00	[27]
Capra hircus	rectum	38.8	0.2	14:00	[13]
Capra hircus	rectum	38.4	0.4	19:00	[28]
Capra hircus	rectum	38.4	0.5	19:00	[22]
Canis familiaris	rectum	39.1	0.5	11:00	[13]
	rectum	38.7	0.7	11:00	[29]
	rectum	39.0	0.8	11:00	[30]

Refinetti et al. [2] show that in some domestic animals, such as dogs and horses, body temperature is influenced by the switching on of lights. It was noted that the temperature rose very gradually, but the peak, particularly in horses, was reached after the light was switched off and after several hours.

3. Some Factors Affecting Body Temperature and Its Circadian Rhythm

The circadian rhythm related to body temperature has been extensively studied and has been suggested as a useful tool for the assessment of health and energy metabolism in mammals [5]. Although body temperature is regulated by the circadian rhythm, it can also be influenced by considerable physiological factors, including pregnancy and/or the neonatal period. Its assessment is therefore also considered important in diagnosing pregnancy, and after birth, it also serves to understand how the pup is acclimatising to life outside the womb [31]. Among the factors that may influence the circadian rhythm of body temperature is the frequency of milking. Indeed, Kendall et al. [32] showed that cows milked twice compared to those milked only once experienced an increase in circadian temperature rhythm. This occurred between 4 p.m. and midnight. Some lactating cows, on the other hand, showed a diphasic circadian temperature rhythm with a twelve-hour

period, especially when milking, regardless of the number of milkings, took place in the evening [33]. Among the non-physiological practices that can influence temperature is certainly transport. Transport is the process in which animals are grouped and loaded at the place of origin and then unloaded at the place of destination [34]. The most stress-related factors are certainly the confinement, the size in which the animal is placed, and the duration and direction of the journey [35]. Several studies [36,37] show that the conditions of transport or its timing can cause injuries, respiratory or gastrointestinal diseases, and immune system disorders. The onset of an inflammatory condition, which may therefore precede any pathologies affecting the systems, can be verified during and after transport by measuring temperature [38]. Stress stimulates the syndromic pathway of the autonomic nervous system, and the temperature regulation point is altered [39]. Padalino et al. [35] report the effects of increased temperature in a group of 26 156 horses transported 880 km. The results show that the temperature measured at the beginning and end of the journey and during storage increased from 37.0 °C to 37.9 °C. An increase in temperature also occurred in pigs after measurement after transport [40]. These showed an increase of approximately 2 °C (30.94 ± 0.24 °C vs. 32.52 ± 0.24 °C) at the time of loading. To avoid this, the impact could be diminished and the stress reduced if preconditioning conditions were implemented prior to transport [36]. Preconditioning management involves weaning, castration, ear labelling, vaccination, and fitting [37].

3.1. Circadian Rhythm of Temperature following Exercise

The temperature, generally, is divided into internal body temperature and outer shell temperature. In horses, the body temperature (T_C) must be around 37.4–38 °C, while the outer coat temperature is most influenced by various central thermoregulatory processes. The shell temperature consists of intramuscular temperature, subcutaneous temperature, and skin surface temperature. For this reason, temperature varies in different parts of the body. In addition to those mentioned, there are several areas where temperature can be taken, e.g., shoulder temperature, right atrial blood temperature, and central venous blood temperature [41]. The horse can be considered an extraordinary athlete, which is precisely why it can be used as a model organism for intense exercise. [1]. Certainly, it must be considered that exercise is, from a physiological point of view, an inefficient mechanism; in fact, it refers to a process during which an excessive amount of chemical energy is produced that is converted into heat energy [42]. This can alter homeostasis and affect the health and even the performance of the athletic horse [43]. During exercise, the animal needs and can make use of efficient physiological systems. In particular, metabolic changes, which also vary with the type of exercise, can influence catabolic reactions in order to maintain a correct ATP concentration and high O_2 consumption [44]. This will result in an increased transport of oxygen, water, electrolytes, nutrients, and hormones to the muscles involved in exercise. In addition, as a result of an increase in thermoregulatory mechanisms, an increase in heart rate and blood pressure is also detected [1,45]. The resulting heat in the horse is made up of three basic components, namely the animal's basal metabolism, muscular metabolism, and finally a part of the heat due to digestion [46]. There is a substantial difference between the heat and, therefore, energy production of a horse at rest or during exercise [47]. For example, as exercise increases, the amount of energy produced is released in the form of heat. Heat is then dissipated from the skin surface by certain processes, including evaporation [48]. The speed of heat removal depends on the speed of heat transfer, via the blood vessels, to the surface of the body. Vasodilation allows more blood to flow through the arteriole, diffusing heat through the superficial capillaries. If vasodilation is not sufficient, sweating begins [49,50]. Sweating can lead to fluid and electrolyte losses; a severe loss of electrolytes can cause dehydration, which will clearly impair the athlete's physical performance [51]. It is also necessary to understand what methods are used to measure temperature in domestic animals; in fact, we refer to thermistors, thermocouples, thermometers, and infrared thermography (IRT). Of these, the most commonly used are definitely thermometers, and the use of infrared thermography

is widely practiced. As far as infrared thermography is concerned, it is important to say that it is a non-invasive method that requires short distances and can make use of good sensitivity. Infrared thermography, through certain physical laws and surface capabilities, has the ability to measure the infrared radiation emitted by the subject. For this reason, a camera is used to measure thermal radiation and body temperature, through which images with different colours and temperatures are obtained [4,7,52]. In addition to measuring body temperature, infrared thermography can also be used to measure the temperature of the eye, which is a perfect area for accurate temperature measurement as it is hairless [53]. The measurement of eye temperature becomes important to evaluate, as changes in eye temperature are correlated with the onset of stressful factors for several species, including horses, cattle. A relationship has been noted between increased temperature detected with IRT and hypothalamic-pituitary-adrenal activity and a consequent release of cortisol [50]. The use of the thermal imaging camera is considered innovative, as it reduces the risk of infection and stress caused, for example, by manipulation, as it is not necessary to touch the subject [54,55]. The latter is used to measure infrared radiation by creating maps of the temperature produced by the mammal [56]. Regarding the influence of operation on temperature, according to Piccione et al. [5], temperature changes during exercise and is also influenced by the time of exercise. In fact, it appears that the temperature increases more in the afternoon. In fact, the surface temperature (ST) increases during exercise; there is a small difference between the body and the surface temperature of 8 °C at rest and 4 °C during exercise. Other studies [57], on the other hand, show that the temperature increased without immediately returning to the control parameters. In fact, for this study, nine horses were used, whose temperature was always taken in the early morning hours (6:00 a.m.) once every week. The temperature was measured in certain areas of the body, such as the fore and hind limbs and the back. Compared to these areas, the results show an increase of approximately 12.3 °C, of which the lowest temperature was 6.9 °C to 19.2 °C. In addition to the time of day, the temperature also tends to vary depending on the type of work being done. In fact, as shown in [48], if a medium-sized horse (500 kg) performed moderate work for 60 min, the temperature would rise and increase by approximately 15–18 °C. During a running activity, on the other hand, for a horse of the same size but an activity considered shorter, the temperature would increase by only 5 °C. However, this can negatively affect homeostasis and, thus, the animal's metabolism and performance. For this not to happen, the temperature increase should be a maximum of 2 °C. There must therefore be a balance between heat dissipation and temperature maintenance [46]. With respect to the above, some work using an infrared camera confirmed an increase in skin temperature in correlation with training intensity. Studies [46,58] show that athletic Thoroughbred horses have a specific daily rhythm of activity in temperature regulation. This is also confirmed by actograms, which show activity in most cases during the day. With respect to the daily rhythmicity of body temperature, Piccione et al. [20] report that a daily rhythmicity of body temperature was found in considered athletic horses considered. In particular, the results show a 24 h peak in the periodograms about a twice-daily measurement. The measurement was taken one hour before the exercise and two hours after the end of the exercise; the temperature was also taken during the rest day (considered a control). Compared to the control, the temperature showed an increase of 0.7 °C during the exercise but then returned to the rest day values two hours after the end of the exercise. In relation to the above, the rectal temperature measured during the resting day reflected the circadian oscillation of the temperature, which varied due to exercise. A further article by Piccione et al. [20] confirms a robust daily temperature rhythm in athletic horses. According to a comparison, the daily temperature rhythm was influenced by exercise; the temperature was found to increase compared to sedentary horses. In a comparison of sedentary horses, athletic horses, and athletic horses two weeks after exercise, Piccione et al. [59] show that all groups, despite exercise, maintain the circadian temperature rhythm unchanged, showing nocturnal acrophase between 22:04 and 22:48. Dogs can also be considered valuable study models for understanding temperature variation in the daily rhythm. With respect to

physical activity, in some dogs (especially beagles), the temperature tended to rise as a result of increased locomotor activity, particularly at 10 o'clock. It was found that thereafter, the temperature decreased by 1 degree for approximately one hour in the controlled environment [60]. Zanghi et al. [61] collected data in which temperature was measured at 9:00, 11:30, 12:30, and 2:30 to understand how it varied according to exercise and daily rhythm. Measurements were taken at the same time in the rectum, in the ear, and in the eye, so that the diurnal fluctuation could be more accurate. The experiment was conducted on two different breeds: beagles and Labradors. An increase in temperature was observed with respect to exercise, the greatest increase being found at 11:30 in the morning. Immediately after exercise, an increase in temperature of 2 °C was found both in the rectum and in the ear and eye measurements. The same was found by Rizzo et al. [50], who noted an increase in temperature, particularly rectal temperature. This appears to be due to an increase in muscle activity to which the dogs were subjected through various high-intensity exercises on the treadmill. Although the physical activity of donkeys is not often emphasised, it may be important to understand the effect this has on temperature and how it affects the circadian rhythm. Despite the development of modern transport and thus the use of modern technology, donkeys are still used for transport in some parts of the world [62]. They were therefore studied [63] by dividing them into two groups, one of which carried the load and trekked, and a second group that only trekked. The results from this study report a greater increase in both temperatures (rectal and body) in the weight-carrying and trekking groups than in the trekking-only group. This is because weight-bearing generates more heat, involving the activities of various skeletal muscles. With respect to circadian rhythm variation, a difference between rectal and body temperature was noted. In fact, the amplitude was different between the two analysed groups; in fact, the amplitude of the rectal temperature was greater in the group of animals subjected only to trekking than in the group subjected to transport and trekking [64]. Regarding body temperature, however, the two groups do not differ in amplitude. The acrophase in donkeys, probably due to the difference in heat produced [65], occurred later in the group of animals involved in load and trekking transport than in the other analysed group.

3.2. Use of Non-Invasive Instruments for Temperature Measurement

Although methods of measuring rectal temperature are particularly accurate, a device known as the Ibutton was used to measure daily ruminal temperature trends. This device is capable of measuring the circadian rhythm of temperature continuously in different animal species, such as sheep [66]. It can be interesting, however, to understand circadian variations in rumen temperature, and to do so, these devices can be useful. Measuring rumen temperature can be useful for assessing core temperature regulation. In the case of ruminants, heat is produced in the gut during bacterial fermentation, with an optimal temperature for rumen microbial fermentation to take place [67]. It was noted that the temperature of the rumen varied, only decreasing at different times of the day. It was noted that this temperature tended to decrease when the animals ingested liquids, particularly water. An average temperature of 39.6 °C was generally observed, with a range from 37.8 °C to 40.4 °C [68]. The acrophase, on the other hand, was noted to be during the night, due to the fact that rumination occurs more during the night hours [69]. The Ibutton instrument was also used to assess the temperature of the ewes after lambing. A decrease in body temperature was noted in ewes before lambing and an increase in temperature up to 24 h later [70]. From what has been said, it can certainly be deduced that the placement of this instrument, which can be positioned under the tail, is also considered useful in preventing childbirth and being able to manage it better. In addition, measurement using the Ibutton is considered less invasive than the common skin temperature measurement [71].

3.3. Daily Variation of Body Temperature during the Gestation and Neonatal Period

In some animals, such as cattle and goats, it is important to assess body temperature, which has an important circadian rhythm. In this case, the temperature has a circadian

rhythm with a minimum in the morning and a maximum in the late afternoon [72]. The rotation of the Earth and its orbit around the sun cause a photoperiod, so an alternation of light and dark is the main environmental signal regulating circadian clocks and influencing circadian rhythms in organisms. In view of the above, certain physiological mechanisms, especially in female pets, such as pregnancy and lactation, alter circadian clocks and daily rhythms [73]. The above influences metabolism and consequently mammary development and lactation, particularly improved nutrient partitioning to support physiological needs during reproduction [74]. For the assessment of circadian body temperature rhythms in the goat, a 24 h measurement was taken. Measurements were taken three weeks before birth, three weeks after birth, and finally five weeks after birth. Every day, over a 24 h period, rectal temperatures in the goats were measured six times every four hours [75]. In the present study [65], in the third week before delivery, the circadian rhythm of body temperature was affected, the latter being higher in the long duration photoperiod (16 h light and 8 h dark) than in the short duration photoperiod (8 h light and 16 h dark), with a difference of 39.6 $\pm$ 0.06 and 39.3 $\pm$ 0.1 °C. At five weeks postpartum, the postpartum temperature was higher in the long-day photoperiod than in the short-day photoperiod, showing temperatures of 40.1 $\pm$ 0.15 and 39.7 $\pm$ 0.1 °C, respectively. Also, during the pregnancy period, in the cattle, Suarez-Trujillo et al. [73] show an increasing increase in the circadian rhythms of temperature and, at the same time, cortisol and serotonin in cows that were exposed to 16 h of light and 8 h of darkness for 35 days until delivery. This is due to changes in underlying circadian rhythms, such as changes in sleep close to the calving days. This is important to maintain because any interruption or mismatch in the timing of the circadian clock can cause a reduction in body temperature adaptation and lead, in cattle, to an increase in the duration of gestation. In sheep, Abecia et al. [76] conducted a study, relating the average temperature at 24 h before parturition and after parturition. The results showed a decrease in temperature upon landing and an increase in temperature up to twenty-four hours after delivery. This has been found in several studies of, for example, sheep or cows, where a lower temperature before delivery was found to increase after delivery. In particular, the decrease was found in the rectal temperature or on the body surface of both sheep and cows (Figure 3). The assessment of body temperature associated with the oestrus cycle may also be interesting. According to measurements taken at dawn and dusk, the temperature at dawn was lower and had a greater range than at dusk. Robustness, on the other hand, was similar [5]. During the neonatal period, a difference must be made between species with respect to achieving and maintaining the circadian rhythm of temperature. In fact, calves do not show a rectal temperature rhythm. In lambs and kids, on the other hand, a temperature rhythm is observed from the very beginning. It was noted that when a temperature rhythm was reached, the rectal temperature was higher in kids. In lambs, a different expression of the temperature rhythm was observed by Giannetto et al. [22], even in animals born on the same day. This was caused by a different development of the mechanisms underlying the circadian rhythm [2]. As far as single lambs are concerned, these show a temperature rhythm at the fifth or ninth hour after birth. The same was true for twins that did not, therefore, show similar rhythms (Figure 4). This obviously causes a delayed acrophase. The lambs' reaching the circadian temperature rhythm after about 10 days is confirmed by Piccione et al. [77]. The body temperature remained unchanged at sunrise but rose gradually at dusk and then reached the acrophase during the night. In cattle, according to the results analysed, a circadian body temperature rhythm starts to develop after nine days. A more complete rhythm, however, is established two months after birth. Animals kept under mild environmental conditions in Sicily (22–28 °C) showed an average body temperature of 38.3 °C and a range of 4 °C. The acrophase of the daily rhythm was about one hour before sunset. An increase in the daily range is believed to be due to a decrease in temperature at dawn [5]. As far as dogs are concerned, puppies show a circadian temperature rhythm that is established several days after birth. The results show that this rhythm is established as the circadian rhythm of body temperature before heart rate and respiratory rate; this rhythm is also not similar to

that of the mother. Four weeks after birth, the pups increase their temperature by about 0.6 and 1 °C; the increase is gradual, and there is less heat loss [11].

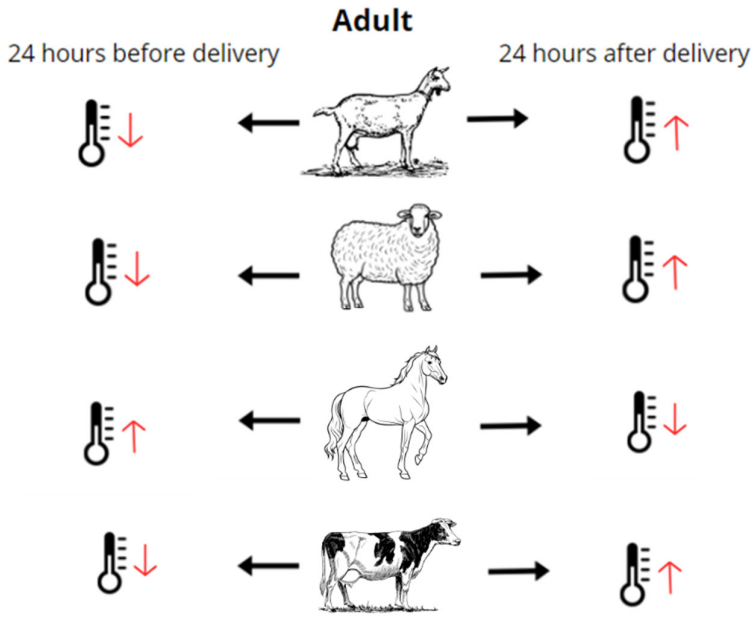


Figure 3. The circadian rhythm of temperature before and after 24 h after calving in goats and sheep.

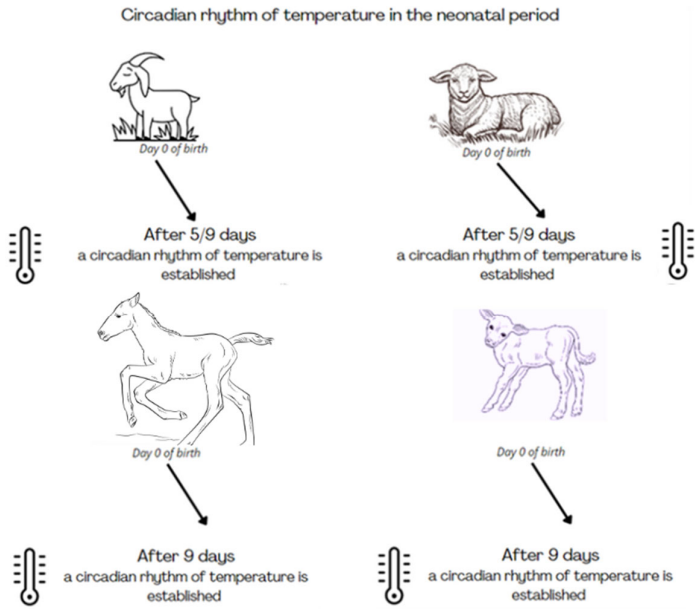


Figure 4. How and when the circadian temperature rhythm is established in kids, lambs, horses, and cattle.

4. Conclusions

In conclusion, we can say that the circadian rhythm of body temperature is an important parameter because it allows us to assess the health and maintenance of the body's homeostasis. The circadian rhythm of temperature in domestic animals such as sheep, goats, and horses is established from the first hours of life, but it can be modified by certain factors analysed in this work, such as more or less intense exercise or the gestation phase. In the bibliography, some of the works presenting variations in the circadian rhythm of temperature are very outdated, which is why it is proposed to continue investigating the circadian rhythm of temperature and what this may be influenced by, particularly with innovative methods such as infrared thermography.

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