

Methods of measuring body temperature in cattle – a review

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Summary

Monitoring body temperature in cattle is crucial for assessing animal health and for the early detection of physiological disorders. Changes in body temperature may signal infections, environmental stress or metabolic problems, making temperature measurement a vital element of herd management and disease prevention. The aim of this study was to present and compare methods used for measuring temperature in cattle. The paper reviews traditional contact techniques, primarily rectal measurement, as well as modern solutions using non-contact technologies and automated monitoring systems. Particular attention was paid to infrared thermography and electronic sensors that enable continuous, real-time temperature measurement. The analysis indicates that the implementation of modern methods allows health anomalies to be detected more rapidly, reduces animal stress and improves the efficiency of cattle-production management.

Keywords: temperature measurement, old and new methods, advantages and disadvantages, cattle

Internal body temperature in cattle is a key physiological indicator, reflecting the intensity of metabolic processes and the efficiency of thermoregulatory mechanisms. The maintenance of thermal homeostasis within a strictly defined range (usually 38.0-39.0°C in adult animals) is essential for the proper functioning of the organism. Any fluctuations outside physiological norms constitute an important diagnostic signal, which may indicate stress responses, the adverse influence of environmental factors or developing disease conditions.

In modern livestock production systems, regular monitoring of body temperature is becoming an indispensable element of health and welfare management strategies for the herd. Early detection of deviations from the norm allows sick animals to be identified quickly, limiting the spread of infection and minimizing economic losses. Over the years, measurement methodology has evolved from traditional rectal

examinations using mercury thermometers, through electronic replacements, towards non-contact and automatic technologies. Although rectal measurement remains the reference standard, alternative solutions such as infrared thermography (IRT) and implantable sensors are gaining increasing importance, enabling animals to be monitored in real time without disrupting their natural behavior.

Physiology of thermoregulation

Maintaining an appropriate body temperature is one of the key conditions for the proper functioning of living organisms (48). Homeothermic organisms maintain a constant temperature through continuous heat production and the dissipation of excess heat (44). This process is subject to both central and peripheral control. The superior central thermoregulatory centre is located in the brain, in the region of the lateral hypothalamic nuclei (18, 32). In the anterior part of this

organ, which contains the preoptic area, there are heat-sensitive receptors and less numerous cold-sensitive receptors. This region is responsible for receiving stimuli associated with increased temperature and for generating impulses that increase heat loss from the body. Peripherally, temperature regulation is mediated by thermoreceptors in the skin, which predominantly detect decreases in temperature. Impulses generated in these thermoreceptors reach the posterior hypothalamus, triggering the appropriate response (15).

Cattle are moderately resistant to elevated air temperature. In cows, signs of hyperthermia usually become apparent at ambient temperatures in the low to mid-twenties celsius and are accompanied by an abrupt fall in production. They are a direct consequence of disruption of the relatively narrow balance between heat production and heat loss (17). In bulls, in turn, prolonged hyperthermia may cause a deterioration in semen parameters (30).

Elevated body temperature is most often associated with the body's response to endogenous pyrogens, intended to support defense mechanisms. These include, among others, microorganisms or their toxins, which cause cells to release cytokines. Together with the blood, they reach the brain, affecting the preoptic area of the hypothalamus, adjusting the thermoregulatory centre to a higher temperature (17) and thereby ensuring full control over the developing inflammatory process. In such cases, an increase in internal body temperature may be an early warning signal of adverse weather pressure or disturbed homeostasis under unfavorable zoohygienic conditions. Both in the case of early infection and increased environmental pressure, it requires careful monitoring, possible pharmacological support or zoohygienic correction. Any further undesirable rise in temperature, regardless of its origin, may lead to a breakdown of regulatory mechanisms and the need for immediate, targeted veterinary intervention.

Methods of temperature measurement

Measurement of body temperature is one of the more important veterinary procedures performed during clinical examination of a patient. It provides important information about the animal's general health status and about the presence of inflammatory processes caused by bacterial or viral infection (57, 60). It also enables disturbances of homeostasis to be detected before clinical signs appear, which allows treatment to be introduced earlier and thus improves the profitability of breeding (16). In reproductive supervision, body temperature measurement is also used to detect oestrus and to monitor postpartum metritis (9).

Many methods and devices are currently available for measuring internal body temperature, ranging from traditional mercury thermometers (now increasingly rare), through widely used electronic thermometers, to modern technologies using infrared radiation.

Each of these methods has specific advantages and limitations that should be considered when selecting an appropriate solution. An optimal measuring device should ensure safety for both the person performing the examination and the animal, and should also be easy to use, require a short measurement time and be resistant to the influence of external factors (8). In recent years, the importance of non-invasive methods has also increased, which is associated with efforts to improve animal welfare (16, 20).

Contact methods

Until the end of the first decade of the twenty-first century, the mercury thermometer was the most commonly used instrument for measuring body temperature (55). It consisted of a reservoir containing mercury, a capillary with a scale and a glass casing. Its mechanism of action was based on the phenomenon of liquid expansion: as temperature increased, mercury moved along the calibrated capillary. To prevent the mercury from suddenly returning to the reservoir, a constriction was used between the reservoir and the capillary, which ensured the stability of the temperature reading. After examination, the thermometer had to be shaken down so that the mercury returned to the reservoir and another measurement could be taken. The mercury thermometer was inexpensive, simple to use and highly accurate, but it also had significant limitations (21). One of the main reasons was that it contained toxic mercury, as a result of which such thermometers were withdrawn from use in many countries and in the European Union (57). Other reasons include the relatively long measurement time (2-3 minutes) and the fragility of the construction, which created a risk of damage to the instrument during use (19).

The role of mercury thermometers is being taken over by environmentally friendly mercury-free gallium thermometers. They contain galinstan, a mixture of tin, gallium and indium, whose physicochemical properties are similar to those of mercury (5). A study conducted in cattle of various breeds and ages showed a high degree of correlation and close agreement between temperature measurements obtained with mercury and galinstan thermometers. These findings indicate that gallium thermometers may be a good and safe alternative to mercury thermometers (57).

Electronic (digital) thermometers are readily used in cattle veterinary practice, among other reasons because of their speed of operation and safety. They are based on temperature-sensitive electrical sensors, such as thermistors, which contain metal oxide. These sensors measure changes in electrical resistance, allowing temperature to be determined precisely (19, 68). The completion of measurement, depending on the device model, is indicated by the appearance of the measurement result on the display or by an audible signal (9). The advantages of electronic thermometers include

high accuracy and a short measurement time (19). The disadvantage is the risk of an incorrect reading when the tip of the thermometer does not remain in continuous contact with the mucosa of the examined site (12).

Temperature measurement at different body sites

Among the possible methods of measuring body temperature in cattle, measurements may be taken in the rectum, vagina, auditory canal, medial canthus of the eye and on the body surface. Modern methods of monitoring body temperature in cows include the subcutaneous implantation or placement of wireless thermometers in body tissues. The exact functioning of these methods is described in section 3.3.

The rectum (RT) is the most frequently chosen site for measuring body temperature in cattle. This preference results from its low invasiveness, easy access, high repeatability of results and the wide range of available measuring devices (41, 71). The disadvantage of this method is the need to restrain the animal, which increases its stress level and also creates a risk of injury for the person performing the examination (8). Contact methods, including electronic thermometers, are most often used for temperature measurement. To reduce irritation of the mucosa, a lubricant, for example petroleum jelly, may be applied (12). The thermometer should be inserted as deeply as possible (approximately 11 cm), because placing it too shallowly may falsify the result by about 0.4°C. Measurement accuracy may also depend on the angle of insertion of the thermometer, the physiological status of the animal and the presence of air or faeces in the rectum. The housing system and the frequency and method of milking may also exert some influence (27).

An alternative site for temperature measurement in females is the vagina (71). For this purpose, intra-vaginal measuring devices equipped with a special, usually plastic, sun-shaped (59) or T-shaped housing are used to prevent the device from falling out. They are placed in the vaginal cavity manually or with an applicator (29) to a depth of approximately 20 cm (41). These devices can be programmed to perform measurements several times a day, which helps limit the effect of circadian fluctuations in body temperature (71). Continuous measurement of vaginal temperature (VT) may also be used to estimate the time of calving, although this remains the subject of research. Approximately 24–48 hours before parturition, a decrease in temperature is observed, enabling the breeder to increase supervision of the animal and potentially to intervene more effectively during calving (3, 10). In most cases, the measuring device is expelled from the vagina under the pressure of the foetus being delivered (29). This creates a risk of its being lost, especially if the device is expelled onto bedding and not noticed by the staff (38). A study conducted in young Angus heifers (41) showed a high correlation between rectal

and vaginal temperature. However, vaginal temperature measurement may be more accurate than rectal measurement. Factors influencing this include, among others, greater blood flow through the vaginal walls (31) and the absence of faeces, which may affect the accuracy of rectal measurement (38). Nevertheless, this method also has disadvantages: if the measuring device is introduced too abruptly or incorrectly, damage to the mucosa, inflammation (38) or perforation of the vaginal wall (29) may occur.

Another site for measuring body temperature in animals is the auditory canal (13, 14). In this case, measurement involves introducing an electronic sensor into the external auditory canal in such a way that it remains in contact with the tympanic membrane. It can be performed using a tympanic thermometer (50) or an implanted sensor that enables temperature to be monitored over time (13). In cattle, the auditory canal is relatively long and runs almost vertically (35). At its end is the tympanic membrane, located close to the hypothalamus. Because of this anatomical relationship, tympanic membrane temperature is regarded as a good reflection of hypothalamic temperature, which is important for the interpretation of measurement results (61). Other advantages of this method include the speed of measurement and the safety of the procedure, which reduces stress in the animals examined (16). Before the device is introduced, the hair inside the auditory canal should be shortened and excess cerumen removed to allow the reader to be implanted safely (61). When a long-term sensor is used, it should be placed at a depth of approximately 12 cm from the base of the ear, and the auditory canal should be secured so as to prevent the device from falling out or the results from being disturbed (6). In a study conducted in the late 1990s, body temperature measured in the area of the tympanic membrane using commercial tympanic thermometers was assessed, and the results obtained were compared with rectal temperature measured with a mercury thermometer (50). The temperature values obtained from the tympanic membrane were consistently lower in the animals examined than temperatures measured in the rectum. However, they should not be regarded as measurement error, but rather as the natural temperature of this body region, while rectal temperature may additionally be influenced by external factors (45). This method therefore constitutes a valuable supplement to the available techniques for monitoring body temperature in animals.

The ventral surface of the tail in cattle is commonly associated with the site for blood collection. Over the last decade, however, specialized sensors have been developed that enable temperature to be measured at the ventral tail base (ST), and these have found wide application in dairy-cattle breeding (46). Measurement in this region is associated with the course of the median caudal artery (39) and the high correlation between ST

values and rectal temperature (47). The device is placed on the midline of the tail a few centimeters above the anus and is fixed with a bandage and a Velcro strap, often additionally secured with an elastic bandage to ensure stability and appropriate adherence to the skin. The sensor is covered with polyurethane gel to reduce the risk of skin damage (23, 38, 46, 62). The device enables continuous temperature measurement, allowing internal temperature to be assessed while limiting error resulting from circadian fluctuations in body temperature. The possibility of continuous temperature control means that this method is useful, among other things, for monitoring the oestrous cycle (46), estimating the time of calving (23, 38) and diagnosing fever in calves (62). Its main advantages include low invasiveness and minimal discomfort for the animal compared with traditional methods. It should be emphasized, however, that seasonal variability in ST values may significantly affect the interpretation of the results obtained (46). Temperature measurement on the ventral surface of the tail is a valuable addition to standard methods of assessing body temperature, particularly in the context of continuous monitoring, but it should not be regarded as their full substitute.

Modern technologies

Thermal imaging (IRT) is a simple, non-invasive method of temperature measurement that is safe both for animals and for those carrying out the examination. It consists of measuring the body's surface temperature by detecting infrared (thermal) radiation emitted by the organism. Detectors located in thermal-imaging cameras record the radiation and convert its energy into an electrical signal. This signal is then amplified and processed into digital data corresponding to the temperature of the examined object. On this basis, a color map is generated showing the temperature distribution on the surface of the examined body area (43). As is widely known, physiological processes occurring in tissues influence their temperature, mainly through regulation of blood flow; for example, increased blood flow during inflammatory processes causes increased heat dissipation (34). However, blood flow in a tissue may be reduced because of local pain, oedema or vascular thrombosis, which is visible on the thermogram as an area of lower temperature. It is worth noting that the popular forehead thermometer also operates on the basis of infrared (IR) radiation detection. It is not, however, a classic thermal-imaging camera. It has found wide application in medicine, but in veterinary medicine it is used only rarely. In our practice, we used it to measure vaginal temperature during insemination. Measured in this way, the temperature was 38.9°C and was 0.1°C lower than when examined at the same site using a forehead thermometer. In broader studies conducted in cattle, it was used to measure body-surface temperature at two defined sites in the frontal and

temporal regions of the facial part of the skull. These studies demonstrated some usefulness of this method for rapid determination of body temperature, but the authors do not recommend its use as a substitute for a clinical thermometer (49).

Thermal imaging has been used in the diagnosis of diseases in many animal species (40). In dairy cattle, it is used mainly for the diagnosis of mastitis. A healthy animal is characterized by a symmetrical temperature distribution; therefore, by examining symmetrical body parts, the operator is able to locate an area of increased temperature. Elevated udder surface temperature (in this case above 31.25°C) correlated with a significant increase in the somatic cell count in milk, which indicates subclinical or clinical inflammation of the mammary gland. It is assumed that if udder temperature is below 31.24°C, the health status of the mammary gland in cows can be regarded as very good (36). In cattle, IRT has been used to detect oestrus, monitor pregnancy and assess the breeding suitability of bulls. At the end of the previous century, Lunstra et al. (42) examined scrotal temperature in bulls. They observed that males with an abnormal temperature distribution had a lower conception rate. There is considerable controversy regarding the indirect diagnosis of pregnancy using this method. Some authors claim that thermography does not allow reliable diagnosis of pregnancy (22), whereas others have used it successfully (7). The use of thermography to detect oestrus in cows may improve pregnancy rates by detecting both regular and silent oestrus as well as ovulation (66). Studies serving this purpose are based on the analysis of changes in body and vaginal temperature, which increases three days before ovulation (54). Breed differences are worth noting; for example, in Holstein cows examined in Australia, a decrease in vulval and muzzle temperature was observed 48 hours before ovulation, followed by an increase 24 hours before ovulation (64). In Braford cows, a decrease in vulval skin temperature was also found in the pre-oestrous period (58). The use of thermography for non-invasive assessment of stress has also been reported (65).

Thermal imaging has also been used to examine the temperature of the medial canthus of the eye (IRT-Eye). In this case, the maximum eye-temperature values were analyzed as an indicator of the response of cows exposed to heat stress (11, 61, 63). The results obtained indicate that the temperature at the eye canthus was significantly higher during the period of exposure of animals to high external temperatures and was also significantly correlated with rumen temperature (25, 34).

Thermographic images may indicate changes in blood flow associated with an increase in body temperature resulting from stressful environmental conditions. Suggested measurement sites have included, among others, the areas of the eyes, neck, muzzle, ribs,

rump, flank, abdomen, thigh, shank, udder or limbs, with the choice of the specific region depending on the species of animal examined (45). The need for caution has been emphasized when taking images in sunlight or under conditions of high humidity and wind, and when photographing dirty surfaces, because in such situations the camera records the temperature of the heated skin or surface rather than the actual body temperature (34). When analyzing a thermogram, attention should be paid to the possibility that certain anatomical structures may be in contact with one another, which can cause a local increase in temperature resulting from direct contact between two body surfaces that differ in temperature. A good example is the area of the udder adjacent to the medial surface of the thigh, where the temperature may be higher for this reason.

Although monitoring body temperature by means of IRT (infrared thermometry), owing to its convenience and non-contact nature, has been extensively studied, assessment of temperature based solely on infrared-radiation measurements is not a complete substitute for direct assessment of core body temperature (CBT). In addition, errors may arise both from incorrect use of the equipment and from the device itself, limiting the ability of IRT to provide accurate estimates of core temperature under various conditions (21).

An Automatic Measurement System for Cattle's Surface Temperature (AMSCST) has also been developed. A specially designed shell adapted to the anatomy of the pelvic limb was used for temperature measurement. This system was compared with temperature measurements taken using a thermometer, demonstrating a high correlation between the results obtained (37).

A newer technology for measuring temperature in cattle is the use of subcutaneously implanted temperature sensors and wireless thermometers. Depending on the system, these devices can transmit information on the animal's body temperature and may be combined with environmental measurements, such as ambient temperature and humidity, to support interpretation of thermal changes. Data from implantable or wearable sensors can be integrated with animal-identification systems and analyzed as part of precision-livestock-management platforms, providing information for breeders and veterinary surgeons (16, 28).

Temperature boluses are a method intended for continuous monitoring of changes in internal body temperature (26). The device, which contains a heat sensor, is enclosed in a casing made of materials resistant to moisture and enzymes, most often polyoxymethylene (69). They are introduced orally using an applicator (70), after which they enter the rumen and reticulum. Their length is approximately 10 cm, and their mass ranges around 100 g for adult cattle and 50 g for calves (26, 33, 67). They are equipped with a temperature sensor, a battery and a data-transmission module,

which enables continuous monitoring of changes in the body's internal temperature (1). The devices use various data-transmission technologies, including low-power radio links (69) and Bluetooth. In order for measurement data to be transmitted to the database, the animal must be within range of the receiving device. Otherwise, the bolus stores data for several days, depending on the model (4). In cattle, the heat generated during fermentation processes in the rumen accounts for approximately 8% of total body heat production; therefore, temperature at this site may be about 1°C higher than rectal measurements (70). This relationship should be taken into account when analyzing the results. The accuracy of temperature measurements using temperature boluses is $\pm 0.25^{\circ}\text{C}$ relative to the true value, while precision is $\pm 0.05^{\circ}\text{C}$ across the entire measurement range, indicating high repeatability of the results obtained (33). Measurements may be disturbed, among other things, by water intake, which causes a short-term decrease in rumen temperature (69). This technology makes it possible to determine the individual temperature of each animal, allowing rapid detection of an animal whose body temperature deviates from the accepted norm. Its use also reduces the need for manual temperature measurement, decreases staff workload and increases the effectiveness of herd-health monitoring (1). From the point of view of animal welfare, boluses may represent an optimal solution because their administration is non-invasive, they do not cause discomfort to the animal, and their presence in the rumen can be long-term (70).

Temperature-measurement devices can now be supplemented with wireless implantable thermometers, which are surgically implanted in various sites of the animal's body. Iwasaki et al. (28) conducted an experiment comparing the results of temperature measurement at different body sites using these thermometers. The measurement sites were: base of the ear, withers, flank, inner wall of the flank region of the abdominal cavity, base of the tail, groin, abdominal cavity, axilla, and the internal ventromedial wall of the abdominal cavity. It was shown that devices placed in the abdominal cavity had lower transmission quality and poorer agreement with the reference temperature (RT). The best results were obtained for the flank region, where both intra-abdominal and subcutaneous measurements reflected deep body temperature well. Among intra-abdominal locations, measurements in the abdominal cavity and in the flank wall showed high agreement with RT. Among subcutaneous locations, the base of the tail proved most effective, being characterized by high transmission efficiency and good correlation with RT. In summary, the results obtained indicate that long-term temperature monitoring in cows is possible using wireless thermometers, particularly when they are placed subcutaneously in locations that ensure high accuracy and measurement stability (28).

Factors affecting the quality of readings

Depending on the method used, there are a number of factors that influence the sensitivity and accuracy of measurement (2). Their type depends on the method applied. When measuring rectal temperature using a thermometer, the depth of insertion is of greatest importance, whereas the degree of contact with the rectal mucosa and the angle of insertion are of lesser importance (51). The site of temperature measurement is also significant; temperature measured in the anal canal is the most stable, whereas temperature measured inside the auditory canal, on the skin surface or in subcutaneous tissue is more susceptible to the influence of external temperature. The interpretation of the results obtained is also affected by numerous physiological and environmental factors, such as the phase of the reproductive cycle, physical exertion and stress level. For example, stress may cause a transient increase in body temperature, referred to as psychogenic hyperthermia (2, 53). This phenomenon may be induced, among other factors, by a change in environment, isolation from the herd or restraint of the animal. Circadian rhythm should also be taken into account when measurements are performed. For this reason, among others, examination should, as far as possible, be carried out at the same times of day (56).

In the case of non-contact methods such as thermography, factors that disturb the reading of the true temperature include ambient temperature, sunlight, humidity, and wind strength and direction (11, 64). Measurement of rumen temperature may depend on current feed-intake activity, the intensity of fermentation, and the quantity and temperature of water ingested (52). With regard to thermometers attached to the body surface, a certain drawback may be hair covering the skin, which can make them difficult to attach and, consequently, may cause them to detach. In this case too, ambient temperature may be of considerable importance (24).

Summary

Despite the development of modern methods for monitoring body temperature, including continuous-measurement techniques and thermal imaging, correct interpretation of the results obtained in relation to the physiological and pathophysiological mechanisms of thermoregulation is becoming crucial. In particular, it is important to distinguish fever from hyperthermia, and also to recognize hypothermia, as these are distinct pathophysiological entities. Rectal temperature measurement remains the most accurate and reference method in animals, despite certain limitations related to stress and the technique of performance. Nevertheless, appropriate use of alternative measurement methods may have a positive effect on improving welfare and may facilitate herd monitoring.

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