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Application of microchip and infrared thermography for monitoring body temperature of beef cattle kept on pasture

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ABSTRACT

The monitoring of body temperature is important for the diagnosis of the physiological state of the animal, being dependent on available methods and their applicability within production systems. This work evaluated techniques to monitor the body temperature of beef cattle kept on pasture and their ability to predict internal temperature. Twenty-three adult bovine females were monitored for six months, and collection data carried out in eleven campaigns (D0-D10) twelve days apart. During collections, the surface temperatures of ear base (ET, °C) and ocular globe (OGT, °C) were measured by infrared thermography, and the subcutaneous temperature (ST, °C) was measured with the use of transponder containing an implantable microchip. Rectal temperature (RT, °C) was considered as a reference for body temperature. Temperature and Humidity Index (THI), Black Globe Temperature and Humidity Index (BGHI) and Radiant Heat Load (RHL, W/m^2) were calculated. ET (33.32 ± 0.12 °C), ST (36.10 ± 0.07 °C), OGT (37.40 ± 0.06 °C) and RT (38.83 ± 0.03 °C) differed significantly ($P < 0.05$). There was positive correlation of RT with OGT (r = 0.392), ET (r = 0.264) and ST (r = 0.236) ($P < 0.05$). Considering the bioclimatic indicators, the highest magnitude correlations were observed between ET and THI (r = 0.71), ET and BGHI (r = 0.65), and ET and RHL (r = 0.48). The use of microchip represented a practical method, but with limited predictability. On the other hand, infrared thermography proved to be safe and non-invasive, presenting greater precision for inference of internal body temperature. ET was more influenced by meteorological conditions.

1. Introduction

Animal husbandry practices have been modernized to expand control of health in beef cattle production systems. Through the continuous monitoring of physiological variables of animals, it is possible to detect significant changes in their health and welfare (Barros et al., 2015). The accuracy of surveillance in animal production is dependent, among other factors, on the use of methods to identify diseased, injured or stressed animals and their execution by technicians and producers responsible for the activity. Among physiological parameters sensitive to stress and changes in the health status of animals, internal body temperature is the most reliable because it directly demonstrates situations of pyrexia, and the instantaneous condition of the animal homeothermic process. Monitoring the thermal status of animals is relevant, since heat stress results in an approximate loss of 2.5 billion dollars per year, only in the US livestock industry due to interference in performance indexes, mortality and lower reproductive efficiency (St.-Pierre et al., 2003). Since thermal stress increases internal body temperature (Srikandakumar and Johnson, 2004), this condition is identifiable, allowing the individualization of animals in discomfort and early decision making aimed at protecting animal health and productivity.

However, the use of body temperature monitoring as a tool for the diagnosis of animal physiological status depends on the methods available and their applicability under real conditions within the physical environments of production systems. In several countries, beef cattle activity is carried out in pasture areas. This makes the routine measurement of individual body temperature unfeasible, which is classically performed by clinical thermometry and requires animal

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displacement and physical restraint, demanding labor, and increasing the stress condition of the animal. Thus, it is assumed that for the effective monitoring of numerous herds, body temperature measurements would have to be performed frequently, at short intervals, and with the shortest possible management time. The need to collect animal temperature data, with attenuation of the management work and time spent led to the creation of different devices (Sellier et al., 2014). Older systems, in general, have been used in an invasive way and with low applicability outside research conditions. They were, therefore, systems that generated relevant but unpractical information for production environments. Intra-vaginal radio transmitters (Kyle et al., 1998), intrauricular thermistors connected to dataloggers (Mader et al., 2002), reticular bolus (Bewley et al., 2008) and rectal probes (Reuter et al., 2010) are among these systems.

On the other hand, the most recent systems for detecting body temperature use equipment for data acquisition by radiofrequency identification-RFID, being considered little invasive methods. Different models of transponders implanted via the subcutaneous route have been studied in domestic animals such as pigs (Lohse et al., 2010; Jara et al., 2016), horses (Marsh et al., 2008), goats (Torrao et al., 2011) and wild animals (Maxwell et al., 2016). Thus, technological innovations based on the use of electronic devices can increase the efficiency of beef cattle management. The technological advancement of microprocessors with RFID technology is a possible tool to be integrated into automation systems in animal management, compatible with the concept of precision livestock (Won et al., 2012; Stewart et al., 2017). In turn, the infrared thermography represents a non-invasive technology to measure body surface temperature changes and has been modernly used in veterinary medicine to monitor the health conditions of sheep (Pantoja et al., 2017), water buffaloes (Silva et al., 2018), dairy cows (Gianesella et al., 2018) and beef cattle (Romanello et al., 2018), and other species.

In this context, it is relevant to assess whether technological innovations that indicate subcutaneous or body surface temperatures are equally efficient for the remote monitoring of bovine body temperature. Acquiring reliable body temperature data using affordable and non-contact devices can represent the first step towards a complete automated system to monitor beef cattle health, in which autonomous gadgets could be used to monitor pasture-grazed animals. In this situation, the digital data acquisition additionally allows the immediate upload of images or datasets (the standard output of thermographs and RFID devices, respectively), the remote access and a decision-making loop in real time. The aim of this study was to evaluate the use of transponder-type electronic devices and infrared thermography in the monitoring of the internal body temperature of beef cattle kept in pasture and to correlate them with the clinical thermometry technique.

2. Material and methods

2.1. Location, climatic characterization, and experimental area

The experiment was carried out at Embrapa Pecuária Sudeste, São Carlos, Brazil (21° 57′42 ″S, 47° 50′28″ W, 860 masl). According to the Köeppen-Geiger classification, the local climate is Cwa, altitude tropical subtype (Köttek et al., 2006). The experimental area was composed of *Urochloa brizantha* pasture system (cv. Piatã) used in intensive rotational grazing.

2.2. Bioethics

The experiment was performed in accordance with current Brazilian laws, and all procedures performed were approved by the Ethics Committee of Experimental Animals Use (Protocol CEUA-CPPSE, Declaration 12_2014) and reported according to precepts of The Animals in Research: Reporting in Vivo Experiments Guidelines - ARRIVE (Kilkenny et al., 2010).

2.3. Animals, experimental period and adaptation

Twenty-three primiparous Canchim females (⅝ Charolese x ⅜ Zebu), aged 42.0 ± 0.3 months and weight of 477.0 ± 46.8 kg and body score of 3.5 at the beginning of the experiment (1–5 scale) were used (Houghton et al., 1990). The Canchim is a composite breed characterized by the white to yellow coat color, short hair, and pigmented skin. The experimental period occurred from January to June of 2017. Thirty days before the beginning of the experiment were used to adapt animals to environmental and management conditions.

2.4. Body temperature evaluations

Body temperature was measured using four different techniques: the infrared thermography technology used in two distinct anatomical regions, the RFID technology that is based on using the electronic transponder, and the clinical thermometry. Infrared thermography was used to obtain the surface temperatures of the ocular globe (OGT, °C) and ear base (ET, °C). The electronic transponder was implanted under the skin at the ear base to measure subcutaneous temperature (ST, °C). To make inferences about the effectiveness of techniques, the evaluation of rectal temperature (RT, °C), measured by clinical thermometry, was adopted as the standard technique ("gold standard"). Measurements were performed in eleven experimental daily campaigns (D0-D10), with a mean interval of twelve days between them. Data collections were always performed on the morning shift, from 08:00 a.m. to 11:00 a.m. (average time: 9:14 a.m.). For the measurements, animals were gently sent to a handling pen, adjacent to the pasture area. In the corral, they remained for 10 min in an area devoid of shading before the beginning of the measurements to avoid the influence of management and the facilities on the analyzed variables. Then each animal was individually contained in cattle crush sheltered from direct solar radiation and rain, and was immediately evaluated. Measurements were always in the following order: ST, OGT, ET, and RT. Only one technician performed all measurements and the order of entry of animals occurred randomly on all collection days.

2.4.1. Transponder-type electronic device

ST was evaluated using a transponder-type electronic device (Lifechip®, Destron Fearing, Saint Paul, USA), which consisted of a 2 × 12 mm bioglass device containing an onboard radio frequency microchip (134.2 kHz), with an unchanging 15-digit identification code. The transponders used were manufactured in accordance with International Standardization Organization-ISO standards (11784/11785) and with standards accepted by the United States Department of Agriculture-USDA (Gerber et al., 2012), with the incorporation of the Bio-Thermo technology to measure internal temperature as a differential. Transponders were implanted in the right ear base on its posterior face under the scutiform cartilage (Reid et al., 2012). The procedure was performed with the use of a special 12-gauge single use sterile syringe (Destron Fearing, Saint Paul, USA). The microchip implantation procedure occurred at D0, without the need for local anesthesia. The reading of transponders was carried out using a portable reader (Pocket Reader EX, Destron Fearing, Saint Paul, USA) at a distance of approximately 0.1 m. The reading was confirmed by a sound signal, followed by a visual signal on the LCD panel, in which the animal identification and the temperature recorded by the microchip were simultaneously displayed. The equipment had reading range capable of identifying temperatures between 0 and 50 °C, with temperatures below 33.0 °C being demonstrated as "temp below range" and above 43.0 °C as "temp above range".

2.4.2. Infrared thermography

Body surface temperatures were obtained by infrared thermography using portable thermograph (Testo 890, Testo AG, Lenzkirch, Germany) with detector of 640 × 480 pixels, fitted with 15° × 11° (40 mm) lens,

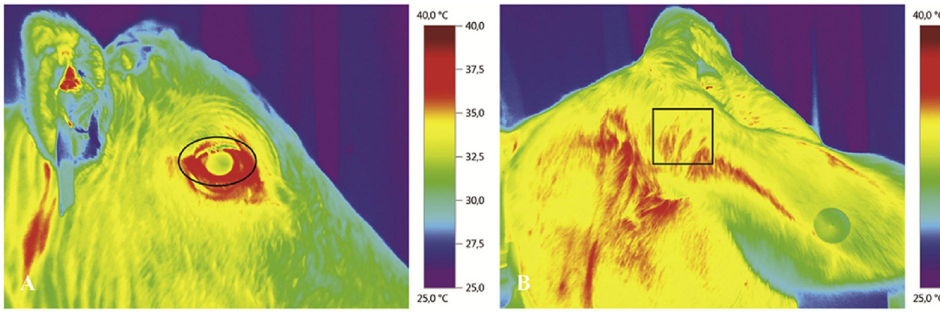

Fig. 1. Thermographic images demonstrating analysis of the surface temperature of ocular globe (a) and ear base (b) of bovine females. Parameterized for rainbow color palette and thermal scale from 25.0 to 40.0 °C.

thermal sensitivity < 40 mK (< 0.04 °C at 30 °C ambient temperature), temperature range from −20 to 350 °C, in the manual focus adjustment option. The emissivity adopted was 0.98 (Hoffmann et al., 2013). OGT and ET were obtained by thermographic images of the ocular globe and posterior ear regions, both on the right side. The procedure was performed with camera perpendicularly positioned to the anatomical area to be evaluated, at a distance of approximately 0.5 m (Pantoja et al., 2017). Any dirt present on the surface of the anatomical region to be studied was previously removed, aiming to increase the quality of measurements. The site used to acquire thermographic images was sheltered from rain and direct solar radiation to avoid possible environmental interference in results (Weschenfelder et al., 2013).

The analysis of thermograms was performed with the IRSoft version 4.0 software (Testo Ag, Lenzkirch, Germany). OGT was analyzed by elliptical tracing over the orbital region, including the ocular globe and approximately 10.0 mm from the ocular cavity (Fig. 1) in order to cover the lacrimal gland, considered sensitive to thermal changes. Maximum OGT values (hot spots) were recorded, as recommended for this type of analysis (Schaefer et al., 2007; Hoffmann et al., 2013). ET was obtained by rectangular tracing, delimiting the anatomical region of transponder implantation, and results were presented as the mean value of the analyzed area (Schmidt et al., 2013).

2.4.3. Clinical thermometry

RT was obtained by clinical thermometry using a digital thermometer (TS-101, Techline, São Paulo, Brazil), which was calibrated and previously certified according to standards of the National Institute of Metrology, Quality, and Technology of Brazil-INMETRO. The thermometer was inserted into the animal rectum after manual cleaning, being kept in contact with the internal rectal wall until temperature stabilization and device's sound signal emission. The instantaneous temperature presented on a liquid crystal screen was recorded and used as the reference of the animal's internal body temperature (Lee et al., 2016). The clinical instrument had a temperature range from 32.0 to 42.9 °C and a maximum error of ± 0.2 °C.

2.5. Meteorological variables and bioclimatic indicators

During days of data collection, air temperature (Ta, °C), black globe temperature (BGT, °C), relative air humidity (RH, %) and wind speed (WS, m/s) were permanently recorded in an automated meteorological station located 500 m from the experimental pasture system, set up in the outside area of the corral. Sensors were connected to a system with automatic data acquisition (CR3000 Micrologger®, Campbell Scientific, Logan, USA), programmed to perform readings every 5 s. Thus, the values of meteorological variables used corresponded to records made at the time the body temperatures of each animal were measured to allow a precise association between the current meteorological condition and the thermal state of the animal at the moment of evaluation.

From these data, the following climatological indicators of interest were calculated: Temperature and Humidity Index (THI, Thom, 1959), Black Globe Temperature and Humidity Index (BGHI, Buffington et al., 1981) and Radiant Heating Load (RHL, Esmay, 1978). THI was calculated by the formula:

$$THI = \left(0.8 \times Ta + \left(\frac{RH\%}{100}\right) \times (Ta - 14.4) + 46.4\right) \tag{1}$$

where Ta = air temperature (°C) and RH = relative air humidity (%). BGHI was obtained by the formula:

$$BGHI = BGT + 0.36 \times (DPT) + 41.5 \tag{2}$$

where BGT = black globe temperature and DPT = dew point temperature. The dew point temperature was calculated from the Tetens (1930) equation, as follows:

$$DPT = 237.3 \times \frac{\left[{}^{e^a}/_{0.6108}\right]}{7.5} - Log\left[\frac{e^a}{0.6108}\right]$$

where e_a is the partial vapor pressure. RHL (W/m^2) was obtained by the formula:

$$RHL = \sigma (T_m)^4 \tag{3}$$

where σ is the Stefan-Boltzman constant, 5.67×10^{-8} K^4 (W/m^2); T_m is the Average Radiant Temperature (W/m^2), obtained by the formula:

$$T_m = \sqrt[4]{2.51\sqrt{WS}\,(BGT - Ta) + \left(\frac{BGT}{100}\right)^4} \tag{4}$$

where: WS = wind speed (m/s); BGT = Black Globe Temperature (K) and Ta = air temperature (K). RHL was used to express the total radiation directly and indirectly received by animals.

2.6. Statistical analysis

SAS software (SAS, 2012) was used to perform data analysis. Descriptive statistics were performed using the UNIVARIATE procedure. The techniques were considered a source of variation for the analysis of variance using as the response variable the measured temperature. The general linear model (GLM) was used to this analysis, following the model:

$$Y_{ij} = \mu + Ti + eijk$$

where *Yij* denotes the response from the experimental unit (temperature), observed in the animal *i* and in the experimental day *j*, *T* is the fixed effect of technique, *eijk* is the residual term, including the random error, and *μ* is the overall mean.

Multiple comparisons between means of techniques were performed using the LSMEANS option, followed by the Tukey test. Pearson analysis was used to test correlations between body temperatures of the three techniques and the bioclimatic indicators considered (THI, BGHI, and RHL). The linear regression analysis between the reference/rectal temperature (RT) and the respective temperature obtained by the techniques evaluated (ET, OGT, ST) were also studied using CORR and

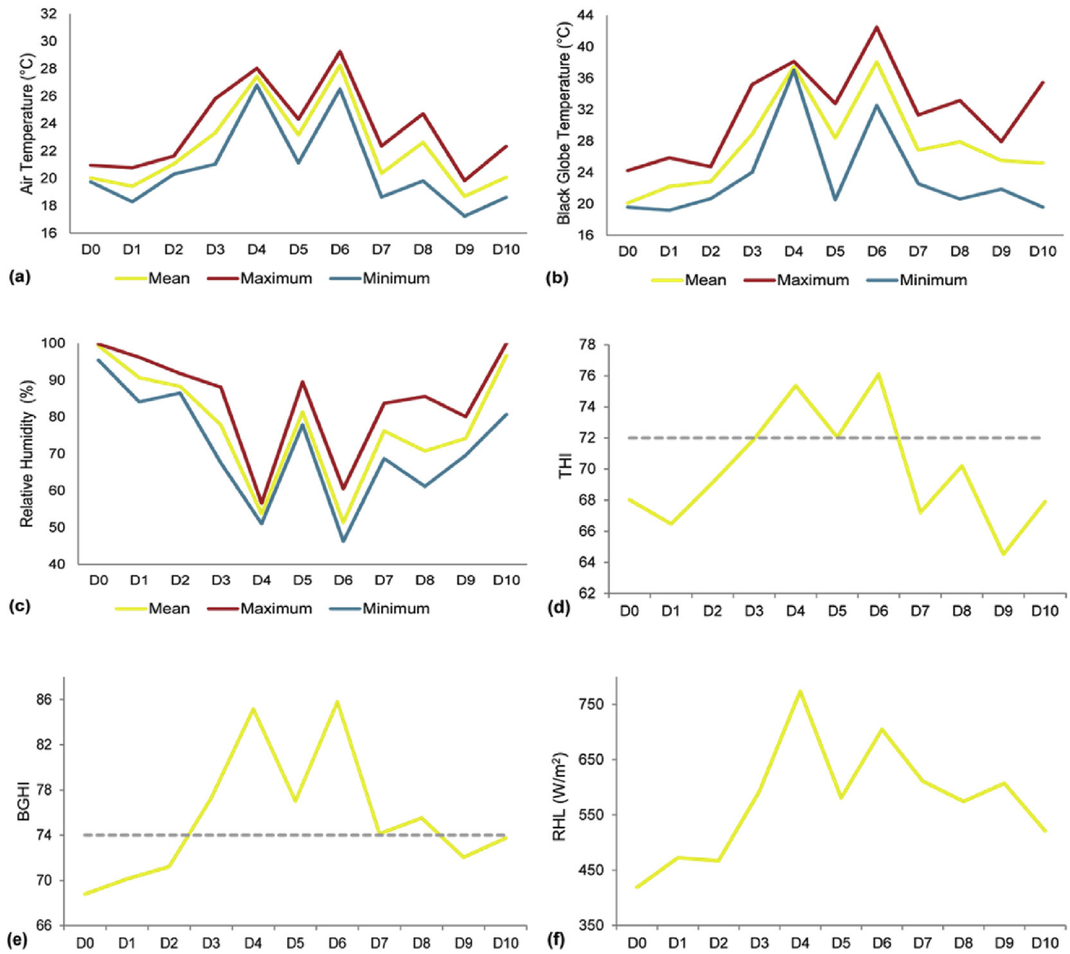

Fig. 2. Mean air temperature (a), black globe temperature (b), relative air humidity (c), Temperature and Humidity Index-THI (d), Black Globe Temperature and BGHI Humidity Index (e), and Radiant Hearing Load-RHL (f) values recorded in the evaluation periods of animals. Dashed lines indicate THI and BGHI reference values, above which animals exhibit thermal discomfort (Armstrong, 1994; Baêta and Souza, 2010).

REG procedures. For this purpose, the following model was adopted:

$$Y = a + b^{*}x + e$$

where Y is the reference/rectal temperature (RT), and x is the respective temperature obtained by the techniques evaluated (ET, OGT, ST), e is the residual term, including the random error of the model.

The significance level previously adopted for all analyses was 5%.

3. Results

Meteorological variables and bioclimatic indicators calculated for the different evaluation days are shown in Fig. 2. During management (08:00 a.m. to 11:00 a.m.), Ta ranged from 17.2 °C to 29.3 °C (mean of 22.23 ± 0.96 °C), BGT ranged from 19.2 to 42.5 °C (mean of 27.59 ± 1.73 °C) and HR ranged from 46.2 to 100.0% (mean of 78.23 ± 4.72%). The mean THI observed during the experimental period was 69, with a minimum of 62 and a maximum reaching 77. The BGHI presented mean of 75, with values between 67 and 90, while RHL presented a mean value of 576 W/m^2, ranging from 408 to 807 W/m^2.

The average of the animal's temperatures (Table 1) presented significant differences among techniques ($P < 0.05$). The interquartile range for the ST measurements was 1.7 °C, with large amplitude between the minimum and maximum values when compared to RT. Also, presented a high standard deviation of 1.12 °C, is only lower than the standard deviation presented by ET (1.82 °C). ST records showed intermediate values between OGT and ET measurements. The temperatures recorded by infrared thermography were significantly different. The amplitudes of interquartile ranges were between 1.1 and 2.4 °C for OGT and ET measurements, respectively. There was also an extensive range of data recorded between the minimum and maximum values when compared to RT.

Considering the climatologic indicators and mean body temperatures, the significant ($P < 0.05$) and highest magnitude correlations observed were between ET and THI (r = 0.71), ET and BGHI (r = 0.65), and ET and RHL (r = 0.48). OGT presented higher correlation with THI (r = 0.52), while ST had significant correlation with BGHI (r = 0.24). There was also a positive correlation but of smaller magnitude between RT and THI (r = 0.14).

The correlation coefficients of RT with the other evaluations indicated positive correlations with ET (r = 0.264), ST (r = 0.236), and OGT (r = 0.392) ($P < 0.05$). Among the techniques tested, ET and OGT showed the highest correlation (r = 0.71), with significant but lower correlations being observed between ST and OGT (r = 0.33), and ST and ET (r = 0.30) ($P < 0.05$). Body temperatures fluctuated among the different evaluation days, as can be observed in Fig. 3.

The linear regression equations generated to estimate RT, within the limits recorded in this study (min 37.5, max 40.6 °C), were determined by the following formulas: RT = 0.1905 × OGT + 31.70 (OGT: min. 33.6; max. 39.5 °C), r = 0.392; RT = 0.655 × ET + 36.64 (ET: min. 27.8; max. 37.5 °C), r = 0.264; RT = 0.09 × ST + 35.25 (ST: min. 33.0; max. 38.1 °C), r = 0.236 ($P < 0.05$). Associations between RT and ET, ST and OGT are graphically shown in Fig. 4.

Table 1
Descriptive statistics and comparison of mean values of ear (ET, ° C), subcutaneous (ST, ° C), ocular globe surface (OGT, ° C) and rectal (RT, ° C) temperatures measured in adult beef cattle kept on pasture (n = 245).

	ET	ST	OGT	RT
Mean ± SEM	33.32 ± 0.12[d]	36.10 ± 0.07[c]	37.40 ± 0.06[b]	38.83 ± 0.03[a]
Standard deviation	1.89	1.12	0.97	0.47
Minimum/maximum	27.80/37.50	33.00/38.10	33.60/39.50	37.50/40.60
Median	33.4	36.2	37.5	38.8
25 %-Quartile/75 %-Quartile	32.20/34.60	35.40/37.10	36.90/38.05	38.50/39.10
Interquartile range	2.4	1.7	1.15	0.6

SEM, standard error of the mean.
[a-d] Means with distinct letters are significantly different (P < 0.05).

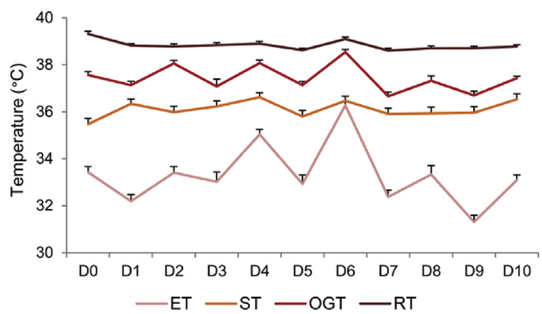

Fig. 3. Temperature variation profile of beef cattle (mean ± SEM; °C) measured by different techniques. ET: ear base surface temperature, ST: subcutaneous temperature, OGT: ocular globe surface temperature, and RT: rectal temperature.

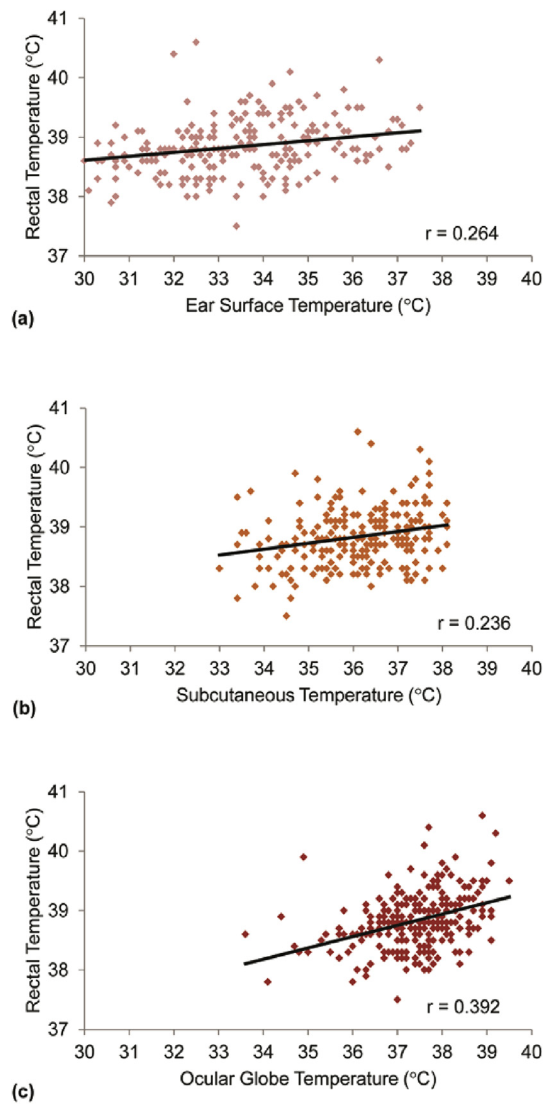

Fig. 4. Graphs of association between rectal temperature and ear base surface temperature (a), subcutaneous temperature (b), ocular globe surface temperature (c) of adult beef cattle kept in pasture. Solid lines show the trend line among temperature associations. r is the correlation coefficient.

4. Discussion

Body temperatures may vary depending on the different anatomical points, where they usually are measured (Taylor et al., 2014). The rectal temperature is the primary measure and considered as a reference to body temperature. For this reason, it is necessary to test its relationship with different body temperatures, identified by new methods to determine the reliability of the temperature monitoring modality (Adams et al., 2013; Jara et al., 2016; Lee et al., 2016). Developing a reliable and straightforward method to assess the body temperature of animals raised in the pasture that is associated with internal temperature is the key point to monitor the thermal condition of these animals. This kind of information acquisition could take part in an artificial intelligence model to monitor the thermal status or beef cattle, and compose a precision livestock farming strategy to support management strategies, that can lead to the reduction of farms environmental impact (Tullo et al., 2019). Indeed, providing thermal information is relevant to help the management of animals and the environment, and increase the productivity, since thermal distress impairs the optimal performance of livestock (Lacetera, 2019; Collier and Gebremedhin, 2015).

The differences found among the measurement techniques tested and rectal temperature in previous studies were mostly small and stable due to the control of environmental conditions (Cilia et al., 1998; Goodwin, 1998). Therefore, the variation between methods to assess body temperature is reduced as the environmental control increases, which includes the theoretical isolation of elements such as ambient temperature, the incidence of radiation, and wind. This concept, although hypothetically correct, does not become applicable outside the scope of research nor has real relation with management practices of livestock. It may underestimate possible additional fluctuations dependent not only on the animal factor but also on the environment to which it is submitted at the time of thermal measurement. Therefore, it is of paramount importance to evaluate the methods applied in field conditions (Lee et al., 2016; Lees et al., 2018). Thus, the present study included, in an unprecedented way, the monitoring of the internal body temperature of beef cattle raised in field condition using a transponder type electronic device. In the present study, the mean RT value was significantly higher than the values measured by the subcutaneous transponder and by infrared thermography, information corroborated by previous research (Reid et al., 2012; Hoffmann et al., 2013). These findings were theoretically expected since each technique is applied at different anatomical points and different methods of analysis are used to determine body temperature (Schmidt et al., 2013). Even, the rectal temperature profile was ever higher than the subcutaneous or surface temperatures since it is the most traditional and representative thermal measurement of core body temperature of endothermic animals. However, it often requires relocating the animal to appropriately designed handling facilities (Lees et al., 2019).

Throughout the experiment, animals were naturally submitted to a specific thermal challenge in some periods of data collection, mainly in D4 and D6, in which THI values indicated mild caloric stress (Armstrong, 1994), and BGHI as an emergency for cattle (Baêta and Souza, 2010). However, even in hotter periods, RT remained within the maximum physiological limit for the species, 39.3 °C (Silva, 2000). After challenging cattle for a certain period in a controlled environment with high temperature, Reid et al. (2012) reported elevation in RT of about 1.1 °C, when compared to the average of animals in thermoneutral condition. Probably, the collection interval in the present study did not challenge the animals to the point of elevation of their internal body temperature by caloric addition coming from the environment. Heat dissipation may also have occurred by adaptive physiological responses, with peripheral vasodilation and increased sweating, which are the primary mechanisms activated in response to thermal stress and, subsequently, respiratory rate elevation (Cunningham, 2013). In spite of that, all tested techniques showed a similar profile of detection, differing only in the amplitude of oscillation, which was notably higher to ear surface thermography technique.

The subcutaneous route is covered by the skin, which in bovines has a relatively thin thickness (3–5 mm), has variable hair coverage and limited blood circulation when compared to the rectal mucosa. Therefore, subcutaneous tissue is more susceptible to environmental influences, especially at low temperatures (Lee et al., 2016). However, the region adopted for implantation of transponders in the present study, that is, under the scutiform cartilage, presents small deposition of subcutaneous fat and greater ease of access during animal management (Hasker et al., 1992), in addition to low commercial value and the possibility to recover the devices from the final carcass just after slaughter. As an alternative, the transponders would be implanted in regions not destined to human consumption, such as the nuchal ligament, similarly to the technique used in horses and donkeys (Stein et al., 2013). However, in this situation, a single extrapolation of subcutaneous temperature from other anatomical regions is not possible, that implies specific studies to identified values of reference for each body part accurately. In the present study, it was not observed local inflammatory changes after transponder implantation, break of devices or considerable migration of the transponders, as previously seen in equine (Gerber et al., 2012; Wulf et al., 2013). For these reasons and for presenting consistent results in previous literature, the use of subcutaneous transponders has been recommended (Reid et al., 2012).

The overall mean ST temperature recorded was 2.72 °C lower than RT. This difference was higher than that found by Lee et al. (2016), of about 1.39–1.65 °C, using thermologger device surgically implanted in different anatomical points in cattle. Although ST reading has presented values lower than RT, it may still represent a viable alternative for quick, but less precise identification of body temperature. Thus, ST measurement would require a correction algorithm to increase its accuracy in the identification of body temperature. This algorithm would adjust the temperature measured in the subcutaneous tissue, removing outliers caused by environmental influence (Lee et al., 2016). This adjustment procedure would increase the technique sensitivity and precision, as the best result described by Adams et al. (2013), when evaluating an intra-ruminal bolus-type sensor to determine the internal temperature of cattle.

Some studies have already proved the efficiency in the estimation of rectal temperature by alternative use of implanted subcutaneous devices in different animals, such as mice (Kort et al., 1998), swine (Lohse et al., 2010; Jara et al., 2016), primates (Pereira and Barros, 2016) and ferret (Maxwell et al., 2016). However, other studies have denied the effectiveness of this use (Brunell, 2012; Greer et al., 2007; Nguyen et al., 2010), and there are few reports of this use in cattle (Reid et al., 2012), especially in field conditions (Lee et al., 2016). Technologies that optimize management for the identification of internal body temperature are of great importance for breeders because they favor control over the livestock and reduce production losses due to possible environmental and sanitary corrections that can be adopted. Although the values observed in the correlations between ST and RT, the use of devices with RFID technology to record body temperature seems to be a promising tool for the future of livestock. Their use could be applied, for example, along with other information recording devices, such as in pass-through scales or automated behavior control devices (Garcia et al., 2018), which would allow the collection of data remotely and with animals free in the pasture environment. This would allow not only increasing the database of each animal and monitor them in real time but also to be the fundamental component of an automation system, composed of integrated operation between transponders, pass-through antenna, data transmitter, and data management program, increasing control and the technification to the level of smart farms.

Previous work has reported that the ocular globe surface temperature tends to be highly correlated with rectal temperature (Hoffmann et al., 2013). In the present study, OGT measurements showed the lowest standard error values, is the technique most accurately evaluated for RT determination. For practical considerations, the head, and especially the eye and the back of the ear, have been considered promising body regions to an assessment of the health of bovine (Hoffmann et al., 2013). The observed OGT value was higher than that described by Schaefer et al. (2012), of 34.90 ± 0.22 °C, and by Hoffmann et al. (2013), of 36.09 ± 0.90 °C, the latter evaluated in adult bovines and calves.

The measurement of surface ear temperature by thermography showed the lowest mean values and the highest standard deviation (1.89 °C), compared to the other techniques. Schmidt et al. (2013) reported that this technique has less precision when compared to the ocular globe surface temperature measurement. In turn, Hoffmann et al. (2013) obtained a more adjusted average of 35.60 ± 1.13 °C but using for analysis the technique of considering the maximum temperature of the region (hot spot). The mean ET temperature presented the highest correlations with THI, BGHI, and RHL when compared to the other techniques. It is known that meteorological conditions directly influence body surface temperature and that cattle dissipate sensible heat through the skin by radiation and conduction (Cunningham, 2013). The activation of the autonomic system in a condition of thermal stress is initiated by the skin thermal receptors, activating latent heat loss by sweating and increasing the respiratory rate. Therefore, there is a greater direct relationship of this process with skin temperature than with body temperature (Collier and Gebremedhin, 2015). This may have resulted in the higher amplitude of ET during evaluations, in which the surface temperature presented oscillatory behavior similar to the meteorological elements of the respective days and, therefore, being less stable than body temperature over time, as previously demonstrated in dairy cattle (Martello et al., 2010).

Also, density, color, the thickness of the hair fibers, and hair length interfere with the caloric elimination capacity. These variables depend, among other factors, on the origin and breed of the animal. In the present study, cattle were of Canchim breed, that presented a white coat color, and had lower hair density compared to Zebu breeds, which is an advantage for thermal exchange (Collier and Gebremedhin, 2015). Although ET and ST were measured at the same anatomical site, i.e., at the ear base, the correlation of highest magnitude was between ET and OGT. Thus, there was a higher correlation between two surface temperatures, than between surface and subcutaneous temperature, even when evaluated at the same body region.

By using only one daily temperature measurement, it is not possible to cover all oscillations of internal temperature inherent in the natural circadian rhythm, which is responsible for changes in the animal's body temperature throughout the day (Reid et al., 2012). Likewise, a single calibration does not allow to accurately assessing changes attributed to meteorological variables, even those that can cause the discomfort condition or thermal stress, which can be subject to oscillations in field evaluations (Gaughan et al., 2010; Scharf et al., 2011). Thus, the use of this variable for clinical diagnosis requires the previous formation of a database for the correct interpretation of the fluctuations of animal temperature. The correlation coefficients values found to infer RT using OGT directly, ET or ST showed a relatively low predictive power. There was, therefore, no strong linear relationship between the observed values of temperatures recorded by the techniques studied with the adopted reference temperature (RT). It is possible that a data filtering analysis, which disregarded the outliers values measured by each method, could increase the predictive values of the techniques studied (Hoffmann et al., 2013; Lee et al., 2016). Moreover, shortly it is possible that the enlargement of databases containing thermal information of complete circadian cycle of beef cattle raised in pasture increases the internal temperature prediction based on most complex mathematical models.

5. Conclusion

The use of the microchip for subcutaneous temperature measurement represents a practical method, but still with limited capacity to determine body temperature. Infrared thermography has shown to be the safest and non-invasive method, and the measurement of the ocular globe surface temperature was more accurate for inference of internal body temperature. Measurement in the posterior ear region was more susceptible and influenced by oscillations of meteorological conditions, which reduces its efficiency for use in fluctuating field conditions as a measurement of the thermal status of animals and changes in their health status.

Conflicts of interest

The authors declare no potential conflicts of interest concerning the research, authorship, and publication of this article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jtherbio.2019.06.009.

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