



Development of a self-contained, indwelling vaginal temperature probe for use in cattle research ☆, ☆ ☆

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ABSTRACT

A device was developed to monitor the vaginal temperature of cattle in a research setting. This device decreases labor involved with monitoring body temperature compared with manual temperature readings, allows for continuous monitoring of vaginal temperature at 1 min intervals, and also allows for temperature measurements without the presence of a human handler or without restraint, which can agitate cattle. The device consists of a blank controlled internal drug release (CIDR) device (designed by Pfizer Animal Health as an indwelling vaginal probe) that holds an indwelling vaginal temperature probe logger. The fabrication of the vaginal probe costs approximately US \$325 per unit. Similar rectal and vaginal temperature responses to lipopolysaccharide challenge were observed when vaginal and rectal temperatures were measured simultaneously in the same heifer ($P > 0.05$). Additionally, rectal and vaginal temperatures were highly correlated ($r=0.97$; $P < 0.0001$). Similar to the rectal temperature monitoring device, the vaginal device allows for the measurement of vaginal temperature without the potential biases associated with the stress response produced as a reaction to the handling by and (or) presence of humans. The vaginal temperature recording device will provide researchers with an additional inexpensive tool to study physiological responses in female cattle.

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1. Introduction

The monitoring of core body temperature is utilized to study physiology in many research models, including the study of disease and reproduction in humans as well as animals. Changes in rectal temperature can be used as an indicator of estrus in cattle (Redden et al., 1993). Increases in core body temperature are often the first noticeable signs of illness, including bovine

respiratory disease in cattle (Duff and Galyean, 2007). For livestock producers, rectal temperature is the most reliable diagnostic tool available for identification of sick animals. Many livestock producers classify animals as sick once core body (typically rectal or vaginal) temperature has been elevated above normal thresholds. Therefore, the ability to accurately quantify core body temperature is essential in order to monitor and (or) treat sick animals promptly and efficiently.

Within a research setting, the presence of humans can often disrupt an animal's behavioral and physiological responses, making it difficult to obtain individual temperature readings, and often leading to activation of the stress response in the animal, thus altering physiological, endocrine, and immunological indices. Furthermore, cattle that are more temperamental may have an extreme adverse reaction to humans, thus increasing the risk of injury to humans and cattle, and the risk of damage to working facilities (Voisinet et al., 1997; Burdick et al., 2011). Therefore, methods to continuously measure core body temperature, which decrease/eliminate the need for human presence during measurement, are increasingly important and relevant to researchers.

Many tools used to measure core body temperature, such as temperature monitors placed in the rumen or abdomen, are invasive and not always practical in a research setting. Additionally, in the case of rumen temperature measuring devices, internal

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environmental changes, such as those that result from an animal drinking water, can cause fluctuations in rumenal temperature. Research related to the development of a self-contained indwelling rectal temperature monitoring device, which allows for the measurement of rectal temperature in cattle at 1 min intervals in the absence of human observers, was recently reported by Reuter et al. (2010). While the previously reported rectal temperature device has proven effective in obtaining rectal temperatures during various research settings including transportation and acute immune challenges, limitations with the device led to the development of the indwelling vaginal probe for female cattle. Therefore, the objective of this manuscript is to describe the development of a vaginal temperature recording device for use in female cattle, as well as application of the device in an experimental setting. Additionally, the measurements of rectal and vaginal temperature measured simultaneously in the same animal in response to a lipopolysaccharide (LPS) challenge were compared.

2. Materials and Methods

All procedures involving animals during development of this device were reviewed and approved by the Animal Care and Use Committees of Texas Tech University, Texas A&M University, and the USDA-ARS-Livestock Issues Research Unit.

2.1. Device construction

Probe fabrication and insertion. Blank controlled internal drug release (CIDR) devices were donated by Pfizer (Pfizer Animal Health, Sterling, CO) and the exterior silicon coating was removed. The rectangle opening (Fig. 1, bullet 4), directly below the point where the two arms of the CIDR merge, was lengthened from 22 mm to 27 mm with a motorized drill in order to accommodate the temperature sensor (25.4 mm in length, 8.3 mm in diameter, 3.3 g; Star-Oddi DST micro-T; MeterMall USA, Marysville, OH, USA). The temperature sensor has a sensitivity of ± 0.2 °C according to the manufacturer. The factory-calibrated vaginal temperature recording devices were tested for accuracy upon receipt from the manufacturer. Specifically, the devices were placed in a 35 °C water bath over night. The devices were programmed to measure temperature at 3 min intervals. Any device that did not read the same temperature as the other devices and (or) that did not measure temperature within 1% of the water bath temperature was not used and returned to the manufacturer. After the temperature sensor was secured in the hole, shrink tubing (0.75 in wire range, 1.5 in length, 3:1 shrink ratio; Grainger, Lake Forest, IL, item # 2FFY9) was applied to the CIDR shaft and over the temperature sensor (Fig. 1). Heat was applied to shrink the tubing, sealing the temperature probe within the CIDR (Fig. 1). The CIDR was then coated in a multi-purpose rubber coating (Plasti Dip; Blaine, Minnesota) in order to seal all components of the device, and to cover all edges to prevent abrasion in the vagina (Fig. 1). The vaginal probe was inserted into the vagina with a CIDR applicator. General purpose lubrication was applied to the tip of the applicator prior to insertion.

Design Notes. Restraint of cattle in a stall or squeeze chute was required to install the device. Insertion of the device is rapid, requiring less than 1 min in animals that are restrained in a stall or squeeze chute. Once in place, the device can remain in place for several days (up to 21 days) in transported and stalled, stationary cattle as well as in free-ranging animals in a feedlot or pasture setting. As the risk for irritation and (or) infection increases as the length of time for which the device is inserted increases, it is

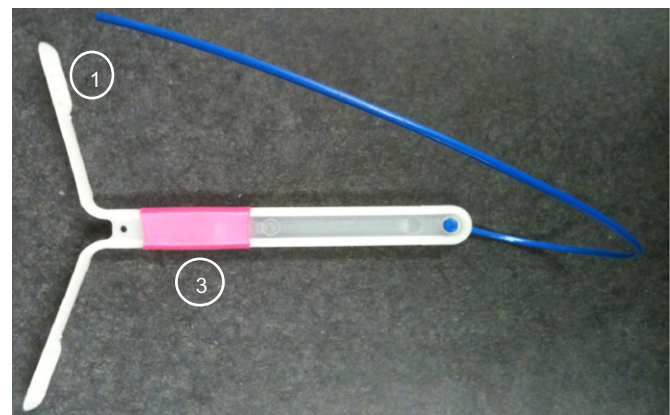
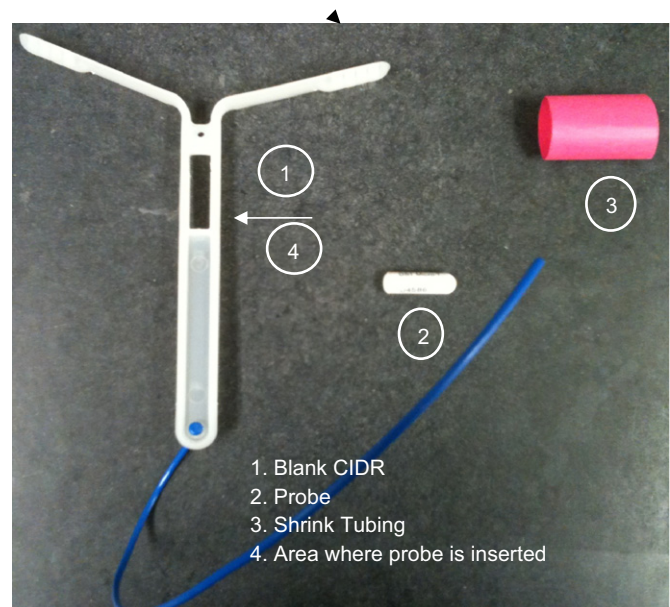


Fig. 1. Device to monitor vaginal temperature automatically in cattle. A blank CIDR is used to house the temperature logger, and the temperature logger is held in place by heat-activated shrink tubing. The entire device is then coated in multi-purpose rubber coating (Plasti Dip) to seal all components.

recommend that the device be visually inspected at least every 3 days during data collection. The device can be used in cattle in a range of sizes from newly weaned heifers (average weight of 200 kg) to mature, multi-parous pregnant cows (average weight of 680 kg). Additionally, the device can be used in smaller heifers

and cows if a smaller CIDR device is used (e.g. blank goat CIDR). If the device is displaced from the animal, the device can be reinserted, with the time frame dependent upon the nature of the study and the time frame in which the device became displaced from the animal. Additionally, the stress involved with handling the animal to reinsert the device may compromise data collection in the study, and therefore it may not be in the best interest of the study and data collection to reinsert the device. No tissue damage has been discovered due to the insertion or reinsertion of the device. This complete device costs approximately US \$325 to construct, and with the exception of the data logger, is not reusable.

2.2. Pilot experiment

An experiment was designed to compare rectal and vaginal temperature data collected on the same animal in response to an immune challenge. In this experiment, five Brahman heifers (194 ± 11 kg body weight) were transported from the Texas AgriLife Research Center in Overton, TX to the Lesaffre Immunology Facility of Excellence cattle facility in New Deal, TX. The following day rectal temperature monitoring devices (Reuter et al., 2010) and vaginal temperature monitoring devices were inserted. Heifers were then moved into a facility that contained individual stalls (2.13 m long \times 0.76 m wide) that housed heifers throughout the remainder of the study (2 days). Heifers were randomly placed into their individual stalls. During the study heifers had *ad libitum* access to feed and water. The following day heifers were administered LPS (*Escherichia coli* O111:B4; Sigma-Aldrich, St. Louis MO, USA) at a dose of 0.25 $\mu\text{g}/\text{kg}$ body weight at 0 min. The dose of LPS was selected in order to elicit an appropriate acute phase response without resulting in mortality. Rectal and vaginal temperature was monitored at 1 min intervals from -1080 to 1440 min (-18 h to 24 h) relative to administration of LPS. Ambient temperature was measured using a HOBO U23 Por v2 Temperature/Relative Humidity Data Logger (Cat. # U23-001; Onset Computer Corp., Pocasset, MA). One ambient temperature HOBO logger was positioned in the center of the barn 2 m above the ground, which measured ambient temperature at 3 min intervals throughout the study.

2.3. Statistical analysis

To facilitate analysis, rectal and vaginal temperatures for each heifer were averaged into 60 or 12 min intervals prior to analysis. Rectal and vaginal temperatures were analyzed using the MIXED procedure of SAS specific for repeated measures. Fixed effects included time, with heifer included as the subject. Specific time comparisons were made using Fisher's Protected Least Significant Difference. A P -value of < 0.05 was considered significant. Data are presented as the least squares means \pm standard error of the mean. Pearson correlation coefficients were also determined using the CORR procedure of SAS.

3. Results and Discussion

The utilization of indwelling temperature measuring devices allowed for the measurement of rectal and vaginal temperature at 1 min intervals in the absence of a human observer. Therefore, the presence of humans, which can cause behavioral and endocrinological reactions in cattle (Curley et al., 2006, 2008; Burdick et al., 2011), were eliminated, allowing for a more precise and constant measurement of rectal and vaginal temperature. Comparisons of rectal and vaginal temperatures 18 h prior to, and the temporal response to an LPS challenge are depicted in Figs. 2 and 3,

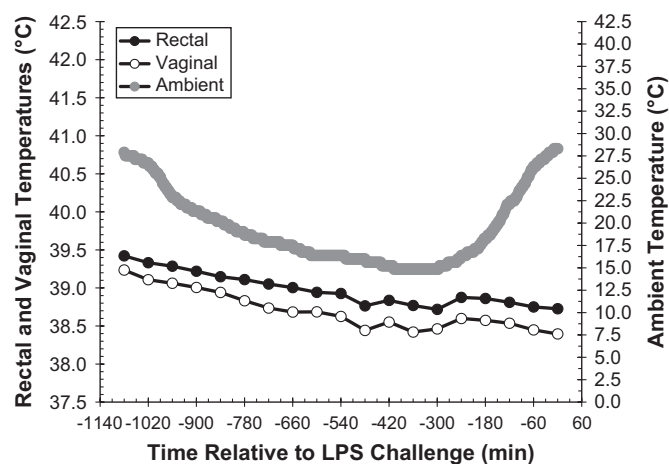


Fig. 2. Rectal, vaginal, and ambient temperatures 18 h prior to intravenous lipopolysaccharide (LPS) challenge. Rectal and vaginal temperature monitoring devices were installed one day prior to challenge, and were measured at 1 min intervals, from -1080 to 0 min relative to LPS challenge at time 0 min. Rectal and vaginal temperatures were averaged into 60 min intervals prior to analysis. Ambient temperature as measured by a HOBO temperature logger was measured at 3 min intervals throughout the study. Both rectal and vaginal temperatures decreased during the 18 h prior to LPS challenge ($P=0.005$ and 0.0004 , respectively). Data for rectal and vaginal temperature are presented as LSM \pm SEM. SEM ± 0.1438 and 0.1481 for rectal and vaginal, respectively.

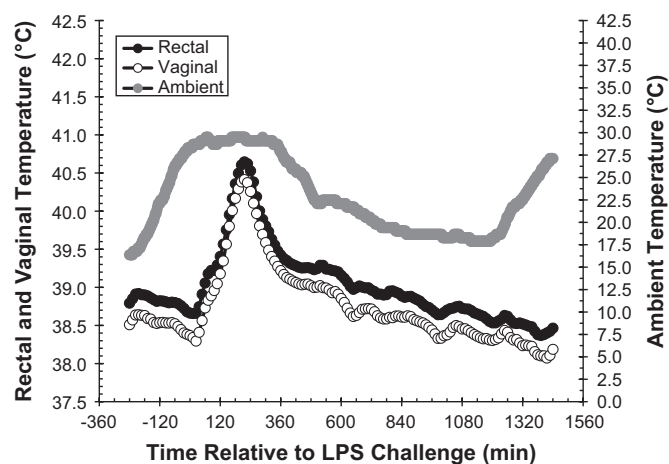


Fig. 3. Rectal and vaginal temperature response to administration of lipopolysaccharide (LPS; $0.25 \mu\text{g}/\text{kg}$ body weight). Rectal and vaginal temperature monitoring devices were installed one day prior to challenge, and were measured at 1 min intervals, from -240 to 1440 min relative to LPS challenge at time 0 min. Rectal and vaginal temperatures were averaged into 12 min intervals prior to analysis. Ambient temperature as measured by a HOBO temperature logger was measured at 3 min intervals throughout the study. Rectal and vaginal temperatures were not affected by time prior to the challenge ($P > 0.05$). Following administration of LPS, rectal and vaginal temperatures increased, with peak temperatures at 216 min for both temperature monitoring devices ($P < 0.0001$). Temperatures then decreased, returning to baseline values within 624 min for both temperature monitoring devices. Data for rectal and vaginal temperatures are presented as LSM \pm SEM. Pre-challenge SEM ± 0.2223 and 0.2046 for rectal and vaginal, respectively. Post-challenge SEM ± 0.1466 and 0.1327 for rectal and vaginal, respectively.

respectively. During the 18 h prior to the LPS challenge, rectal and vaginal temperatures decreased ($P=0.0053$ and 0.0004 , respectively) and were highly correlated ($r=0.92$; $P < 0.0001$). No circadian rhythm was observed during this time period, most likely due to the use of 60 min time intervals rather than smaller time intervals. Additionally, the heifers were confined into individual stalls within a closed building and did not experience extreme variations in ambient temperature. Recent studies in which cattle were housed outdoors in pens or in controlled

environmental chambers with cycling air temperature from 18.5 to 23.5 °C have demonstrated that both the vaginal and rectal temperature devices are capable of measuring the circadian rhythm in vaginal and rectal temperatures during the same time period relative to an LPS challenge and at the same sampling interval as depicted in Fig. 2 (unpublished data). Additionally, masking effects, such as changes in housing environment and constant illumination, have been demonstrated to mask the typical circadian rhythm in core body temperature (Edelstein et al., 1995; Weinert and Waterhouse, 2007). Therefore, the heifers were able to maintain fairly consistent vaginal and rectal temperatures prior to the LPS challenge. Ambient temperature during this time displayed a similar temporal pattern through –300 min at which time the ambient temperature began to increase while rectal and vaginal temperatures continued to decrease. As depicted in Fig. 3, there was no effect of time ($P > 0.05$) on baseline rectal (mean = 38.82 ± 0.07 °C) or vaginal (mean = 38.53 ± 0.02 °C) temperature for 4 h prior to LPS administration. Following administration of LPS, rectal and vaginal temperatures increased ($P < 0.0001$), and the maximum temperature obtained was 40.65 ± 0.15 °C (rectal) and 40.41 ± 0.13 °C (vaginal) at 216 min. Rectal and vaginal temperatures had very similar peaks, demonstrating a greater increase in vaginal temperature from baseline compared to rectal temperature. It is possible that there is greater blood flow in the vagina compared to the rectum, thus resulting in the vagina being more sensitive to changes in core body temperature compared to the rectum. Indeed, studies in humans have demonstrated a greater micro-circulatory flux in the vagina compared to the rectum and skin (Emmanuel et al., 2000). However, similar studies in cattle have not been found. Rectal and vaginal temperatures returned to baseline values at approximately 624 min (10.4 h) after administration of LPS. Both rectal and vaginal temperatures were correlated ($r = 0.97$; $P < 0.0001$) post-LPS administration. Ambient temperature displayed in Fig. 3 demonstrates the environmental temperature changes occurring during the challenge. Ambient temperature fluctuated from 17 to 27 °C during the study (63 to 81 °F), which is typical for the Northwest region of Texas in which the study was completed.

The temporal rectal and vaginal temperature responses to LPS for this study are similar to those, which have been reported by Burdick et al. (2011), in which intact male calves of the same breed were administered an LPS dose of 0.5 µg/kg body weight and rectal temperature was monitored. Changes in body temperature have been reported to be valuable measurements of the febrile response to an LPS challenge in cattle, and are indices routinely used to monitor the severity of the inflammatory response (Elsasser et al., 1996; Bieniek et al., 1998; Jacobsen et al., 2005; Borderas et al., 2008; Reuter et al., 2008; Carroll et al., 2009; Waggoner et al., 2009a, b). The correlations achieved between rectal and vaginal temperature in the current study are higher than those previously reported in Holstein cows postpartum ($r = 0.81$; $P < 0.001$), in postpartum cows with retained placenta ($r = 0.75$; $P < 0.001$), or during peak lactation ($r = 0.46$; $P < 0.001$; Vickers et al., 2010) as well as those reported in pregnant dairy cows ($r = 0.95$; Hillman et al., 2009). However, Vickers et al. (2010) and Hillman et al. (2009) used hand-held thermometers to measure rectal temperature, unlike the current study in which rectal and vaginal temperatures were measured using indwelling temperature measuring devices simultaneously in the same animal. Vickers et al. (2010) concluded that various changes in penetration depth, logger movement and air influx, and thermometer type could contribute to differences found between rectal and vaginal temperature affecting correlations between studies (Burfeind et al., 2010). Rectal and vaginal temperature devices in the current study were inserted at a

minimum depth of 21 and 9 cm, respectively, in the rectum and vagina. It can be suggested that a minimum depth of penetration for temperature measuring devices is necessary in order to lessen the influence of environmental factors. This requires further attention than given in the current study.

As demonstrated by both the vaginal and rectal temperature measuring devices, the information obtained using these two devices provided data to the research team that could not have been collected using conventional hand-held thermometers. Also, as evidenced by the data collected using rectal temperature probes (Burdick et al., 2011), physiological differences due to differences in animal behavior can be elucidated by continuous monitoring of core body temperatures.

Several other methods exist for measuring core body temperature. These include ruminal, udder, and rectal temperature devices. There are several advantages for the vaginal temperature device compared to these other devices. First, the current device is light-weight and very small in size, allowing for it to be fitted inside a CIDR, thus allowing for the device to be maintained in a specific location. This is an advantage over ruminal temperature devices, which have the ability to move throughout the reticulum and rumen if not tethered to the rumen wall (AlZahal et al., 2011). The radiotelemetric rumen temperature device used by AlZahal et al. (2011) produced a similar temperature response to LPS as their vaginal temperature device, yet produced a lower peak rumen temperature value when compared to vaginal temperature. Additionally, a recent study using rumen temperature probes failed to produce a clear response to LPS administration and failed to distinguish breed differences in the ruminal temperature response to LPS, in contrast to rectal and vaginal temperature responses (Chaffin et al., 2011). Studies using vaginal temperature devices similar to those in the current study have been able to elucidate minute differences in core body temperature between various dairy cattle breeds (Dikmen et al., 2009). A disadvantage for ruminal probes is the potential effect of diet on basal rumen temperatures (AlZahal et al., 2011). Another advantage for the vaginal temperature device is that the insertion of the device is simple and quick and does not require surgery as do other implantable temperature loggers (Brown-Brandl et al., 2005). Additionally, with little to no damage posed to tissues in the vagina, the vaginal temperature probe has an advantage over its predecessor, the rectal temperature probe (Reuter et al., 2010), which can cause damage to the tail if not properly secured. Vaginal temperature loggers produce a core temperature response more similar to rectal temperature responses, compared to peripheral radio frequency implants implanted subcutaneously, which have been demonstrated to produce dissimilar temperature responses compared to indwelling core temperature loggers, in response to LPS administration (Reid and Dahl, 2005).

However, the vaginal temperature device does have disadvantages. The device is a data logger, not a radiotelemetry device, and therefore the data is stored and must be downloaded. This is different compared to radiotelemetry devices in which the data is transmitted and therefore can be monitored in 'real time.' Thus, the current vaginal temperature device is best suited for use in a research setting, not in a production setting.

Other researchers have utilized similar devices for measuring vaginal temperature (Suthar et al., 2011; Dikmen et al., 2009; Jousan et al., 2009; Kendall et al., 2009; Vickers et al., 2010; Zimelman et al., 2010; Nabenishi et al., 2011); however all of the aforementioned studies were conducted in dairy cows, not beef heifers as in the current study. Other studies have used larger vaginal temperature devices (Hillman et al., 2009; AlZahal et al., 2011), which may not be appropriate for smaller beef cows and heifers. Additionally, the temperature logger associated with the current vaginal temperature probe can be fitted to a smaller CIDR

to more appropriately fit smaller animals, therefore making the current vaginal temperature probe very versatile. There is a cost benefit to the current device as well. Specifically, blank CIDR devices are low in cost and can be obtained easily, without the need to use a molding system to create the temperature logger anchors, as with the device used by Hillman et al. (2009).

4. Conclusion

The indwelling vaginal temperature monitoring device was developed to aid in the measurement of core body temperature in female cattle in the absence of a human observer. Similar to the rectal temperature monitoring device, it allows for the measurement of temperature without the potential biases associated with stress responses produced in response to handling and (or) the presence of humans. Temperatures measured with the rectal and vaginal monitoring devices simultaneously on the same animal were very highly correlated. The vaginal temperature monitoring device provides researchers with an additional inexpensive tool to study physiology in female cattle.

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