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Telemetry System for Measuring Core Body Temperature in Livestock and Poultry

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Abstract. *Core body temperature is an important measure of animal thermal stress and thermoregulation. A short-range telemetry system was evaluated in poultry, beef, and dairy cattle. This system provides good temperature accuracy, excellent temperature resolution, and adequate response time. However, this system would need some improvement before it could be implemented into the livestock industry.*

Keywords. Beef cattle, dairy cattle, poultry, body temperature, telemetry system

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¹Introduction

Measurement of body temperature is an important parameter when studying livestock stress. The most common method has been to make spot measurements with a mercury rectal thermometer, and more recently with electronic dataloggers, continuous measurements are commonly taken either rectally or tympanically. Rectal probes are easy to insert, and are generally non-invasive. The disadvantage to rectal probes in cattle is that they can only be inserted for a short period of time (5 days) without causing tissue irritation. In poultry, an additional disadvantage is that the birds movement is restricted, and the probe tends to fall out. Tympanic probes can be inserted into the cattle's ear canal without anesthetizing the animal by using a headgate or a squeeze chute. Tympanic probes are secured by either prosthetic foam, which fills the ear canal, or the button method, developed at MARC, which secures the probe by using nylon tie straps and a modified ear tag (Brown-Brandl et al., 1999; Paul et al., 1999). The tympanic probes need to be reinstalled every 7 to 10 days; if the probes are left in longer, there is a potential for ear infection. Tympanic probes can be switched between ears, but the process becomes increasingly stressful for the animal. With these time constraints, an improved method of measuring body temperature continuously for an entire study was needed.

Telemetry systems have been used in wildlife, livestock, and medical research for approximately 40 years. Telemetry systems have been used to monitor a variety of measurements including body temperature, blood pressure, movement (of the whole animal or in distinct structures, such as the rumen of cattle, or the jaw), fluid flow, pH, heart rate, respiration rate, and brain activity (Bligh and Heal, 1974; Data Sciences, Intl., 2000). The first telemetry systems had several disadvantages including short transmitter battery life, long-term drift in the temperature sensors (0.2 C in one month; Riley, 1970), and some temperature sensors had the transmitter outside the body and a wire running into the animals body to measure the temperature (Bligh and Heal, 1974; Dorminey and Howes, 1968). Currently, telemetry systems commonly available can be divided into one of two types, one commonly used in the wildlife industry and the other commonly used in the medical research industry. The systems used in the wildlife industry monitor animals over long distances, and are mainly designed to allow for animal tracking, however temperature sensors and heart rate monitors are available. Temperature sensors have an accuracy of 0.1 C, have some known drift associated with their use, and have a non-linear response within the calibration range. The biomedical systems were designed to be used in laboratory environments, therefore have weak signal strength, which travels less than 2 meters, and are very expensive, making them unsuitable (in their current form) for the livestock industry. However, medical industry has a more extensive list of sensors available and while temperature sensors are not more accurate, they are more precise (0.01 C instead of 0.1 C), which allows researchers to study the micro-dynamics of the response. These temperature sensors have little drift associated with them and have a linear response. One critical detail that needs to be addressed is FDA (Food and Drug Administration) approval for use in food animals. Neither system was designed for nor is ideal for monitoring physiological parameters in livestock/poultry research or industry, and few companies are currently addressing the livestock industry needs. However, telemetry systems are continuing to improve, making them a viable alternative that needs to be reevaluated.

¹ Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

Objectives

The objectives of this report are to present an overview of core body temperature measurement using a new telemetry system (HTI Technologies, 9th Street Drive West Palmetto, FL 34221) in poultry, beef cattle and dairy cattle, including installing transmitters, recording data, comparison of data with rectal temperature data, and to overcome difficulties.

Materials and Methods

The telemetry system manufactured by HTI Technologies (Palmetto, FL) was selected based on resolution of temperature transmitters, overall accuracy of the system, and flexibility of taking measurements both on free roaming cattle and on caged poultry. Transmitters were specified based on battery life, size of transmitters, and calibration drift potential.

Descriptions of Data Logging Systems

A CorTempTM miniaturized ambulatory logger was used in the trials with the feedlot steers and dairy cattle. These loggers are small (12 x 6 x 2.5 cm), lightweight (193 g), and record data from only one 262kHz transmitter at a time (Figure 1). A nine-volt battery powers the logger; lithium batteries can be used to extend the data recording period. Battery life is dependent on the sampling frequency; the power usage is 5 mA in the standby mode and 20mA when the logger is taking a reading. At one-minute sampling intervals, a lithium battery will last approximately 10 days. Because the transmitter transmits only a short distance and the logger needs to be setup for each individual transmitter, each animal is required to either be in close proximity to the logger (for example in a tie stall) or have the logger physically secured on the animal (e.g. in a pouch on a harness). This logger can store up to 25,000 data points.



Figure 1. CorTempTM telemetric receiver and logger

A prototype four-channel wireless temperature monitoring system was used for the poultry studies. The system can be directly interfaced with a computer via a RS-232 port. This system is 30.5 x 25.4 x 12.7 cm and has a liquid crystal display and a keypad for entering calibration information about transmitters being used (Figure 2). This system can monitor four separate transmitters at two different frequencies (262kHz and 300kHz) simultaneously using four independent antennas. This system can log up to 10,000 data points independent of the computer and powered by standard AC power (100 – 120 VAC, 50 – 60 Hz).



Figure 2. Four channel telemetric receiver.

Transmitters

Cattle

The transmitters selected for the cattle studies were cylindrically shaped, approximately 10 cm long and 3 cm in diameter. The signal can be transmitted a maximum of 2 m through air, depending on the orientation of the sensors. Battery life of the transmitter was approximately six months. A licensed veterinarian implanted the transmitters in the omental sling (located in the abdominal cavity) using the following procedure. The transmitters were stored in zepharin chloride for a minimum of 2 hr prior to implantation; this provided cold sterilization without jeopardizing the transmitters themselves. The animal was restrained in a squeeze chute. The hair on the flank was clipped and the skin was surgically scrubbed with betadine and alcohol preparation. The steers were given a line block with 60 cc of 2% lidocaine hydrochloride. A celiotomy was performed with a 20 cm vertical incision in the left flank skin and musculature to insert a temperature transmitter. The muscle layers were closed with #3 chromic catgut and the skin was closed with #4 vetafil. Skin sutures were removed after 14 days. Transmitters were retrieved (when necessary) using the same procedure as was used to install them, except using the right flank instead of the left flank, or they were retrieved at slaughter. In the case of dairy cattle, the second installation procedure involved placement of the transmitter in the rumen of a rumen fistulated cow.

Poultry

The transmitters used in the poultry studies were also cylindrically shaped, measuring approximately 2.5-2.8 cm long and 1.2-1.5 cm in diameter. Unlike with the cattle studies, transmitters were not implanted in laying hens, but placed in the digestive tract by the following procedure. The transmitters were first dipped in mineral oil, then placed in the bird's mouth past its tongue so the bird would swallow it. Typically, it took 4-6 hr for the transmitter to move from the crop to the gizzard. If the transmitter remained in the crop, the bird was not used. After each trial, the bird was sacrificed and the transmitter was retrieved and possibly reused (based on the condition of the sensor).

Data handling

Data collected on the CorTemp™ loggers were downloaded using CorTRACK™ software provided with the system. The software allows the user to setup the CorTemp™ loggers, download data, and convert ASCII text data into a time-stamped comma delimited file, which can be imported into any spreadsheet. Collected data were evaluated for stability and the need for further processing.

System Evaluation

The systems were thoroughly tested both before and after the transmitters were placed in the animals by three independent labs: USDA-ARS USMARC in Clay Center, NE—feedlot cattle system; Iowa State University in Ames, IA—poultry system; and University of Florida, Gainesville, FL—dairy cattle system.

Transmitters were factory calibrated using a stable-temperature water bath, a certified RTD, and a frequency counter (Hicks et al., 2001). Each transmitter purchased was supplied with a unique serial number and calibration code, consisting of the slope and offset. The serial number and the calibration code were then entered into the receiver, so the frequency could be

recorded as temperature. A calibration check was performed on the transmitters prior to their use.

Although transmitters were pre-calibrated by the company, a calibration check on transmitters used with the feedlot steers was completed. Each of the transmitter's calibration was checked using a water bath prior to implantation and after removal from the animals, using the procedure described below. Two separate shipments of nine cattle transmitters were checked independently on shipments received in May and October. The calibration of all transmitters was verified between the temperatures of 35 and 45 C, allowing 20 min at each temperature for the sensor to stabilize. The water bath temperature was checked with a mercury thermometer at several temperatures, and then it was used as the standard in these comparisons. The first sensor to undergo this procedure was checked for hysteresis and response time by testing every degree between 35 C and 45 C with increasing the temperature. Temperatures of 40 C and 35 C were rechecked with decreasing the temperature. All other transmitters were checked only at 35 C, 40 C and 45 C with half using increasing temperatures and half using decreasing temperatures.

The two types of cattle transmitters used at MARC were tested for response time. The transmitter was placed in a water bath for 20 min at 40 C, then the water bath temperature was raised to 41 C using a terminated ramp function. The CorTemp™ logger was set to record temperatures at 10 sec intervals during the entire test. Time constants were then calculated for each of two types of transmitters and the water bath. The time constant was defined as the time it takes the sensor to reach $(1-1/e)$ of the total temperature increase—0.63 C increase or 40.63 C absolute value in this case.

Two homogeneity tests were conducted on the CorTemp™ loggers. All loggers were setup identically to record temperatures from a single transmitter with sampling interval of 1 min. Test 1 was conducted for a 24-hr period; the loggers were set in two rows facing a single implant approximately 10 cm apart. Test 2 was conducted for a 90-hr period; loggers were set in a circle with the approximate diameter of 30 cm facing a single transmitter in the center of the circle. Data from all records were averaged and differences between loggers were reported as a difference from that mean.

After the transmitters were installed, concurrent measurements of rectal temperatures were conducted and compared with telemetric temperature readings on each of the three species tested. Rectal temperatures and transmitter temperatures were simultaneously collected and then compared.

Beef Cattle

Seven animals were used in four three-day tests. The four periods had air temperatures of 18 ± 7 C, 18 C constant, 32 ± 7 C, and 32 C constant. These conditions were applied to all animals in the same order and were applied at least 24 hrs prior to the initiation of the measurements. Rectal temperatures were measured using a 0.63 cm diameter by 20 cm stainless steel rectal probe (YSI Incorporated, Yellow Springs, OH) and were electronically logged using a Pace Scientific data logger on a 1-min basis. CorTemp™ data were also logged on a 1-min basis. Data were compared using general linear model procedures (SAS, 1985).

Dairy Cattle

Three dairy cows were used in an eight-day comparison. Daily measurements of rectal (using a mercury thermometer), and core body temperatures (using the CorTemp™ system) were taken

simultaneously for five days. Statistical analysis was performed using a paired t-test (SAS, 1985).

Poultry

Seven tests were conducted measuring body temperatures with both rectal and the telemetric systems. Each test consisted of five 10-point consecutive samples at 10 sec intervals. The rectal temperature was recorded using a Pace pocket logger and a 30 k Ohm thermistor (model PT907, Pace Scientific Inc., Charlotte, NC). Six of the tests had 28.5 min intervals between samples, while the seventh test used 18.5 min between session intervals. Three tests were conducted at 37.8 C, 41% RH, two tests at 32.2 C, 52% RH, one at 32.2 C, 41% RH, and the one test at 26.7 C and 59% RH. All tests had an air velocity of 0.2 m/s. One laying hen was used per test. Mean rectal and core body temperatures for the seven tests were statistically compared using a paired t-test (SAS, 1985).

Results and Discussion

Calibration of Transmitters

There was no significant difference between the calibration checks of the two shipments of sensors ($P < 0.05$). The average slope was 1.00 ± 0.01 which was not significantly different from 1 ($P = 0.588$). The average intercept was -0.27 ± 0.51 which was significantly different from 0 ($P = 0.019$). This offset may have been a result of differences in water baths between the one used for the factory calibration and the one used in this calibration check.

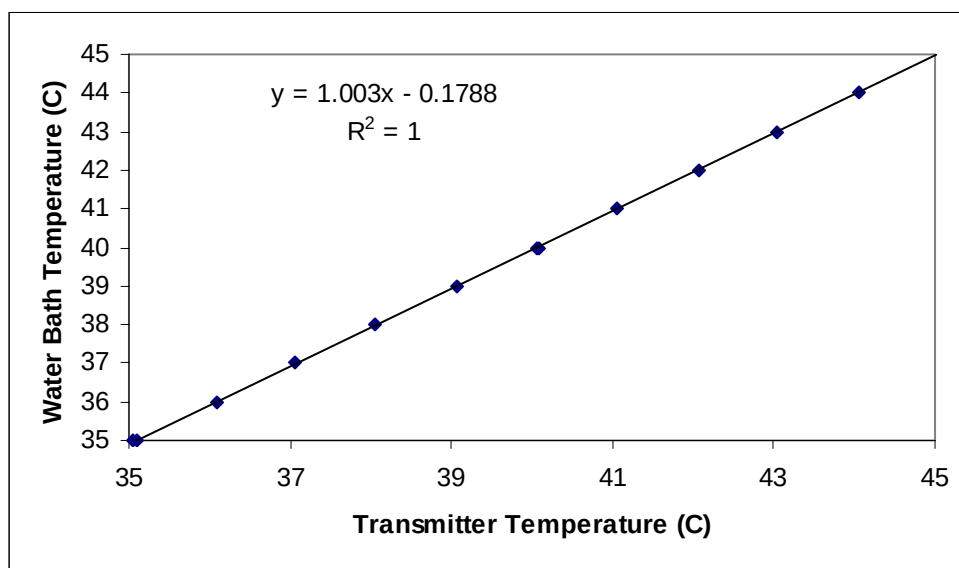


Figure 3. Sample calibration curve demonstrating linearity and non-hysteresis of the transmitter responses.

Transmitters used in the poultry studies were checked at one temperature inside a wind tunnel in an environmentally controlled chamber using a NIST0 certified mercury thermometer as the standard reference. The offset of these transmitters ranged from -0.17 to 0.1 C, averaging 0.01 C.

The original cattle transmitters had a volume of approximately 52 cm³ and the temperature sensor was embedded in the epoxy approximately 2 cm from the end. The second set of cattle transmitters ordered for use at MARC had a larger battery and thus a larger volume of approximately 61 cm³ (Figure 4). However, the temperature sensor was embedded in the epoxy at the end of the transmitter, thus allowing for a faster response time. Because only one waterbath was available a terminated ramp temperature was used instead of a step change in temperature. The time constants estimated by this method are possibly overestimated. The time constant for the water bath was 2.17 minutes, while the original cattle transmitters had a time constant of 5.67 minutes. Moving the sensor to the end of the epoxy in the second set of transmitters resulted in the time constant reduction by more than 2/3 to 3.5 minutes (Figure 5).



Figure 4. Cattle transmitters: a. Original transmitter(1), b. Improved transmitter (2)

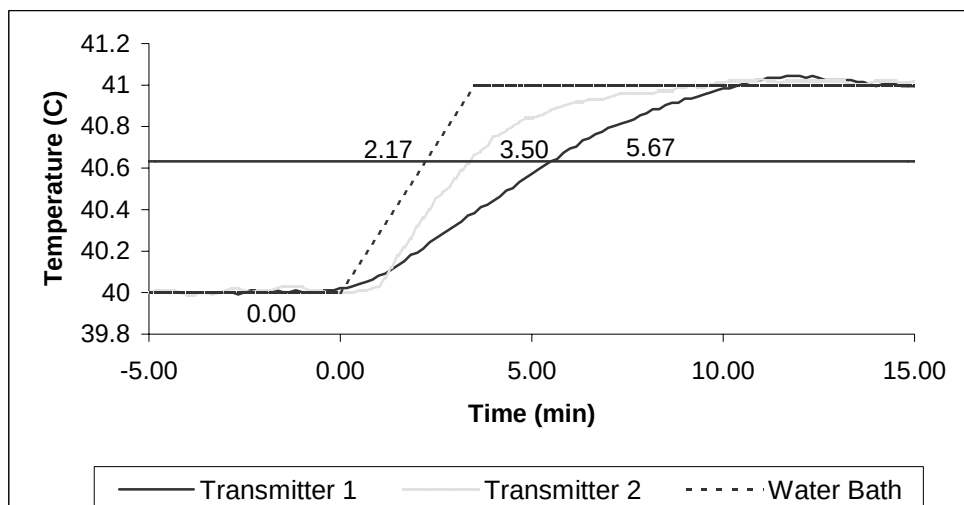


Figure 5. Response times of the two types of the transmitters and the water bath.

Logger performance

When the CT2000 hand-held loggers were compared against one another, logging information from the same transmitter at the same time, small differences were found. Shown in Figure 6, loggers track within their given precision; however, there are small offsets. These offsets are consistent between tests (Table 1). According to the company, these offsets are due to calibration of the logger (completed at the factory), orientation of the sensor signal in relation to the logger, and the presence of feedback from another logger—depending of the logger placement (this usually results in large differences—not seen in these tests). Test 1 used only nine loggers; one of those had only a 3-hr file due to a battery failure in the logger—this logger was left out of the average for the comparisons.

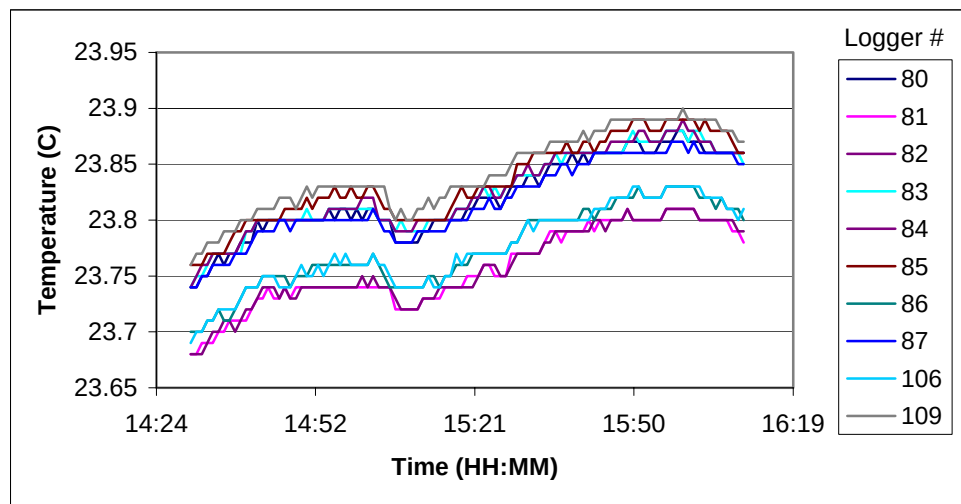


Figure 6. Sample of the logger record from logger comparison test to illustrate the observed offsets.

Table 1. Results of the logger comparison tests, differences between individual loggers, and the average of all loggers.

Logger #	Test 1	Test 2
80	-0.02±0.004 C	-0.02±0.004 C
81	0.05±0.005 C	0.05±0.004 C
82	0.05±0.005 C	0.04±0.004 C
83	-0.02±0.004 C	-0.02±0.004 C
84	-0.02±0.004 C	-0.02±0.004 C
85	-0.03±0.004 C	-0.03±0.004 C
86	0.03±0.004* C	0.03±0.004 C
87	Not tested	-0.01±0.004 C
106	0.03±0.004 C	0.03±0.004 C
109	-0.04±0.004 C	-0.04±0.004 C

* Logger was only tested for a 3-hr period due to a battery failure.

Filtering of Data

The time series data collected appeared to have random noise throughout the record (Figure 7). A clear pattern of core body temperature is obvious, however a number of points can be

identified as “bad” data points. The challenge is to eliminate these points with appropriate filtering that can be implemented in a software program to automate the process.

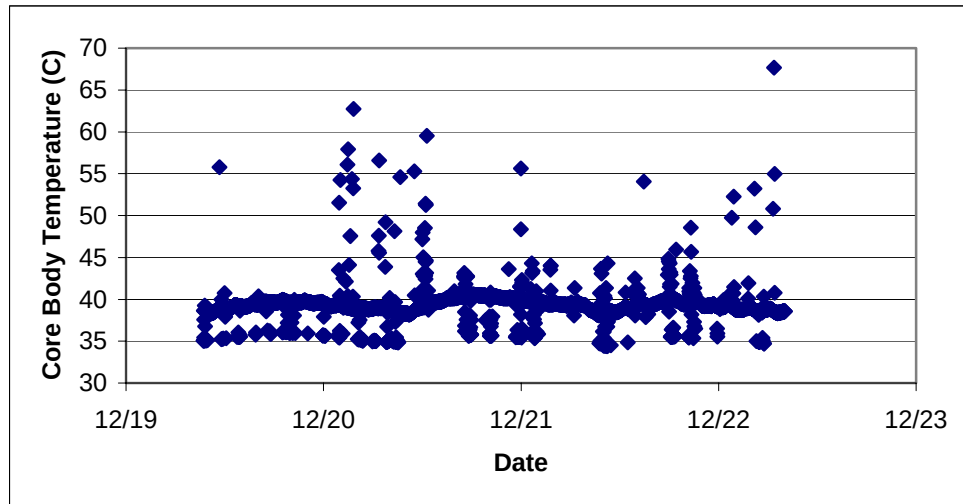


Figure 7. A representative sample of data collected over a three-day period; collected on Steer # 574.

Development of Logic

An Excel spreadsheet was used as the platform to test various filtering logics. Each potential filtering logic was tested on two files: abnormally bad file, and a typical file. Visual observation was used as a subjective on-line test by comparing the filtered results with the corresponding rectal temperatures.

The resultant filter had six steps in the process. The first step eliminated all points in the raw data record that fell outside the physiological range (35 C to 45 C). The second step used the output data from step one and eliminated points based on a dead band range of 0.25 C around a 51-point-running average (25 points before and 25 points after the point in question). These two steps were used to establish a minimum and a maximum value of a second cut on the data. Step three eliminated all points in the raw data that fell outside these bounds determined by the first two steps. Step four eliminated points of output data from step three that fell outside a dead band of 0.25 around a 51-point-running average. Step five eliminated points of output data from step four that were outside the dead band of 0.20 around a 11-point running average. The sixth and final step eliminated points of output data from step five outside a dead band of 0.075 around a 3-point-running average (Figure 8).

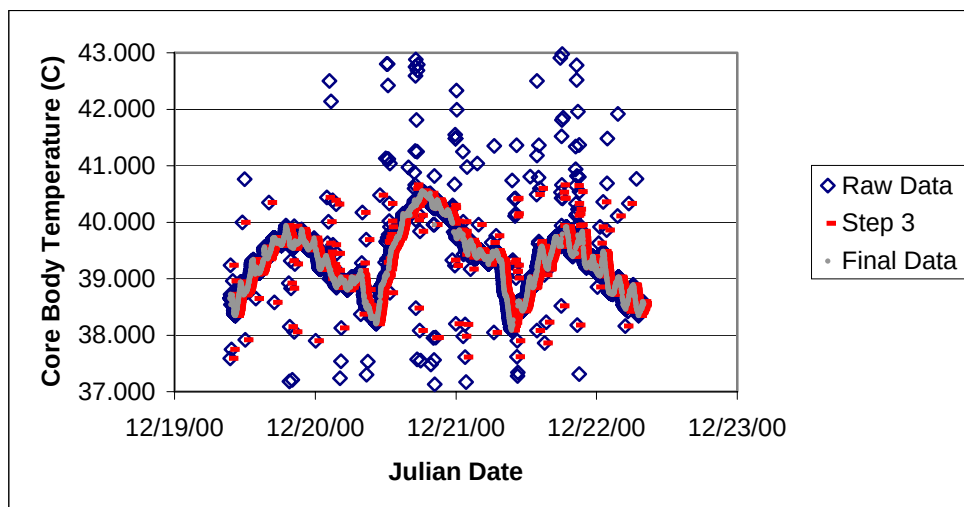


Figure 8. A representative sample of data collected over a three-day period and then post-processed with the filter described above (Data from Steer # 574).

Correlation between methods of measuring body temperature

Beef Cattle

Significant differences were detected between rectal temperature and core body temperature in the beef cattle. These differences had a significant animal effect and ambient temperature effect when tested using the general linear procedure in SAS. While there was a significant ambient temperature effect, it only explained 0.7% of the total variation, whereas the effect of animal explained 93.6% of the total variation. The largest offset, an average of 1.60 C overall condition, was seen in animal #617. The transmitter in this animal was implanted between the muscle layers and the peritoneal membrane. The other extreme was animal # 709 in which core body temperature was higher than rectal temperature. In the human trials conducted using this system, it was noted that as the transmitter passed by the liver the temperature of the implant increased (HTI, 2001; O'Brien et al., 1998). Differences seen in this trial could be related to the location of the transmitter at the time of these tests. Because no method of determining the exact location of the transmitter in the body of a steer has been developed, this hypothesis cannot be tested. However, if this hypothesis is true, then these differences could change over time, since the location of the transmitters are not fixed.

Table 3. Average difference and standard error between body temperature (C) measured by telemetry (T) and by rectal probe(RP), and linear equation for converting between T and RP.

Animal	18 C	18 ± 7 C	32 C	32 ± 7 C	Regression Equation
574	1.12 ± 0.001	1.12 ± 0.002	1.20 ± 0.002	1.14 ± 0.001	RP=1.028*T+0.069
596	0.10 ± 0.004	--	0.28 ± 0.015	0.24 ± 0.004	RP=0.970*T+1.365
617	1.70 ± 0.003	1.55 ± 0.003	1.63 ± 0.003	1.53 ± 0.002	RP=0.875*T+6.231
709	-0.28 ± 0.006	-0.25 ± 0.006	--	-0.19 ± 0.006	RP=0.956*T+1.517
724	1.05 ± 0.003	0.91 ± 0.003	--	1.00 ± 0.003	RP=0.893*T+5.006
753	0.92 ± 0.003	--	--	--	RP=0.762*T+9.892
776	0.49 ± 0.003	0.55 ± 0.002	0.61 ± 0.003	0.56 ± 0.003	RP=1.005*T+0.362

Dairy Cattle

There was no significant difference between rectal, measured using a mercury thermometer, and core body temperature, measured using the CorTemp™ system. Table 4 shows the average temperatures for each cow on each of five days.

Table 4. Daily rectal and core body temperature (CBT)(C) of cows measured once a day for a total of 5 days using the telemetry system and a rectal thermometer.

		Cow 1			Cow 2			Cow 3		
Date	T _{db}	Rectal	CBT	Diff.	Rectal	CBT	Diff.	Rectal	CBT	Diff.
10/20/00	22	38.4	38.3	0.1	38.5	38.4	0.1	--	--	--
10/22/00	29	38.8	39.1	-0.3	38.4	38.1	-0.1	--	--	--
10/24/00	27	38.1	38.8	-0.7	38.4	38.9	-0.5	38.6	38.8	-0.2
10/25/00	28	38.2	38.6	-0.4	38.1	38.7	-0.6	38.4	38.8	-0.4
10/27/00 AM	24	37.9	38.6	-0.7	38.0	38.6	-0.6	37.8	38.8	-1.0
10/27/00 PM	30	38.6	38.9	-0.3	38.3	39.0	-0.7	38.1	39.1	-1.0
Average				-0.4			-0.4			-0.6

Poultry

There were no significant differences noted between rectal and core body temperature in laying hens. Table 2 shows the average temperatures measured using a rectal thermometer and the telemetry system for each trial conducted.

Table 2. Average body temperature (C) of laying hens measured by telemetry and rectal probes during seven trials.

Trial	Environment	Telemetry (T)	Rectal Probe (RP)	Difference (T- RP)
1	26.7 C – 59% RH	41.0	41.1	0.1
2	32.2 C – 52% RH	40.7	40.5	0.2
3	37.8 C – 41% RH	41.2	41.1	0.1
4	32.2 C – 52% RH	41.3	41.3	0.0
5	37.8 C – 41% RH	42.4	42.3	0.1
6	37.8 C – 41% RH	42.2	42.1	0.1
7	32.2 C – 41% RH	42.4	42.4	0.0
Overall				0.06

User Notes

Beef Cattle

During the second MARC beef experiment using this system, several loggers stopped recording data and needed to be sent back for repair. After several logger failures, the problem was identified as a torsion stress caused by the tight fitting pouches on the harness, which held the loggers. This problem was resolved by placing the logger inside a soft neoprene pouch and then inside a hard plastic case with a lid secured by four screws (Figure 9). This prevents twisting of the logger itself by allowing the plastic case to prevent or absorb the stress without transferring it to the logger. Since this protocol was implemented, no such problem has occurred.



Figure 9. CorTemp logger and protective case.

Although great care was taken when implanting the sensors to ensure proper placement, most sensors were found outside the omental sling. It was theorized that the gut motility moved the sensors up and out of the omental sling. This is possible because the omental sling is not completely enclosed, but has an opening on the dorsal side of the rumen. Once outside the omental sling, the implant came to rest ventrally in the abdominal cavity. Consequently, the surgery protocol has been modified by making a smaller incision (8 - 10 cm *versus* 15+ cm long) and placing the transmitter inside the peritoneal cavity, not in the omental sling.

Eleven months after the original implantation surgery, cattle were slaughtered. At slaughter, the tissue surrounding the implant was evaluated. It appears that the implants caused very little or no tissue reaction (Figure 10).



Figure 10. Transmitter in omental tissue.

Laying Hens

Several different antenna designs were evaluated including loop, block, plate type, and omni-directional "L"-shaped antennae. The loop and block antenna did not receive a good signal, so they were eliminated. The plate antenna received an improved signal but was subject to large influence of bird movement. By comparison, the "L"-shaped antenna provided the best signal reception.

The transmitters typically lasted 5 to 7 days; although the batteries were good for approximately 15 days, the harsh environment of the gizzard usually compromised the electronic connections (Figure 11).

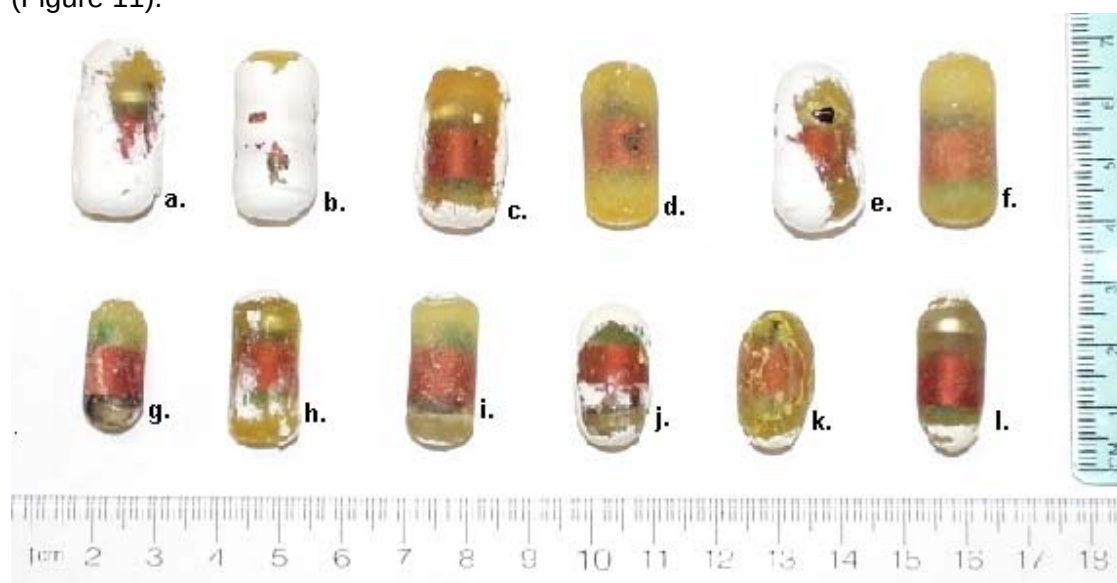


Figure 11. Poultry transmitters after multiple cycles of use, a – f. larger transmitter after 1, 1, 2, 3, 4, 4 cycles, respectively, and g – l. smaller transmitters after 2, 3, 4, 5, 6, 7 cycles, respectively.

Conclusions

A telemetry system was evaluated by three independent laboratories for use in beef cattle, dairy cows, and poultry. Over all, the system was found to be a viable alternative to other methods of monitoring body temperature in a research setting. However, before this system can be used in a commercial livestock setting several changes need to be made. A method of reliably transmitting the signal to a central computer or logging device will need to be developed. Second, there needs to be further investigation of the FDA approval of these transmitters for uses in animal species. The transmitters that were used for these studies have been approved by the FDA for use in the human digestive tract. However, that of cattle and poultry digestive tracts are physiologically different from the human, in that a transmitter in the digestive tract of a cow or a bird will become lodged, whereas in the human system the transmitter will travel through the digestive tract and leave the body in a short period of time. In addition, the digestive tract of a bird is far harsher environment than the human digestive tract. Implantation of the transmitters in these animals is not yet covered in the FDA approval. Lastly, the battery life of the transmitters needs to be extended.

Future Work

Studies are planned to further investigate the use of telemetry in livestock and answer a few more questions about this system in particular. A study is underway looking at the long-term stability of the transmitters used in cattle studies. A study is planned to investigate the uses of

transmitters placed in the rumen, and if rumen temperature is a fair representative of core body temperature. Another study is planned to investigate the use of these implants in growing-finishing pigs.

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