Development of an Early Detection Method for Mastitis Using Infrared Thermography

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Background and Objectives:

Mastitis is a common and costly infectious disease in dairy cattle. Recent figures place its incidence between 20 and 25 per 100 cows per year. Early detection of this disease would prevent its ultimate progression and likely reduce the need for repeated treatment and associated costs. With mastitis, inflammation of the udder typically results in an increase in temperature of the affected area within 24 hours of infection. This rise in temperature could be used in an early detection system for mastitis. A reliable method is needed to frequently measure udder temperature throughout lactation and to determine whether the udder temperature has risen above an acceptable threshold.

One possible method may include use of infrared thermography (IRT), which measures the heat radiated off of any object and calculates its surface temperature. An IRT camera (Figure 1) produces detailed pictures of surface temperature, with regions of differing temperature being portrayed in various shades of grey or in various colours (Figure 2). IRT has the potential to be a non-invasive tool for the detection of health disorders in the livestock sector. In the case of infections, the inflammatory response usually leads to a localised increase in surface temperature, and may also result in elevated core body temperature or fever. Previous work by members of the research team showed that IRT could be used to identify and locate problem areas resulting from infection and disease in cattle. It...
can produce rapid results and be used on large numbers of animals quickly in sequence.

Previous research with dairy cows conducted by members of the research team showed that infusing a toxic compound produced by bacteria (endotoxin) into the teats in a controlled research setting induced an inflammatory response in the udder similar to mastitis. IRT images taken of the udder after the infusion revealed a measurable rise (+2.7°C) in udder skin temperature (US$_{\text{temp}}$) over 9 hours.

In order to use IRT to detect a rise in udder temperature due to mastitis, it is first necessary to establish the normal day-to-day variation in udder temperature that occurs due to a number of factors such as the animal’s metabolism, the days in milk, the environment, and the season. Once the normal level of variation is known, it will be possible to determine whether a certain change in udder temperature falls inside or outside of normally-expected variation. Numerous studies have shown that the core body temperature of dairy cattle fluctuates on a daily cycle. Theoretically, daily fluctuations in udder surface temperature may also occur. A method of mastitis detection that relies on the measure of changes in udder surface temperature would need to account for daily variation under various environmental conditions, thus a reference baseline would need to be established.

In a recent study conducted by the group, baseline information on the magnitude and pattern of daily and within-day variation in udder temperature was gathered using IRT. The influence of exercise and environmental temperature was also examined. Data from this study were used to develop a mathematical model which allowed udder temperature on a given day to be predicted with a high degree of accuracy using the previous day’s udder temperatures together with environmental temperature parameters. The difference between udder temperature predicted from the statistical model and actual udder temperature measured using IRT ranged from 0.22°C to 0.46°C. These values are well below the rise in udder skin temperature of 1.0 to 3.0°C that would be expected with a mastitis infection. The results of this study suggested that a test for mastitis relying on IRT-measured rises in udder temperature may be feasible if coupled with environmental temperature monitoring. This initial study was conducted under moderate summer thermal conditions using only ten cows. In order to assess the potential of IRT as a diagnostic tool for mastitis detection, it is important to demonstrate that the method has good predictive value under a variety of environmental and management conditions.

The objective of this study therefore was to determine the variability in US$_{\text{temp}}$ under two different management systems (tie-stall and free-stall) on two dairy farms during both summer and winter. These contrasting management and environmental conditions were used to highlight the potential of IRT for early detection of mastitis as well as any possible drawbacks.

**Procedure and Project Activities:**

**General Approach**

Overall, the approach taken to meet the objective of the project was to explore the effect of different factors on the day-to-day variation in udder temperature. Infrared thermography was used to take images of the rear surface of the udder from just before calving to 120 days in milk. In order to determine the effect of season, measurements were taken both in summer and in winter. The team also wanted to determine the effects of management system on udder surface temperature, so infrared thermographic images of cows housed in a tie-stall barn as well as a free-stall barn were obtained. Once data were collected, the results were used to create an equation to predict udder temperature under various environmental conditions. In order to determine normal variations in udder temperature, only healthy cows were studied.

**Animals and Housing**

Farm 1 was the University of Manitoba Glenlea Research Farm. Cows were housed in a 60-cow tie-stall barn. The diet consisted of a stepped total mixed ration fed at 11:00 h daily. Cows were milked twice daily in their stalls at 04:30 h at 16:00 h. Cows were released daily into an outdoor enclosure between 9:00 h to 11:00 h for exercise. Two groups of 10 cattle comprised of both heifers and older cows were used. One group was studied during the summer (May-September, 2001) and the other during the winter (December 2001-May 2002).
Farm 2 was a 150-cow commercial dairy. Cows were housed in free-stalls. The diet was a total mixed ration. Cows were milked three times a day and they remained indoors throughout lactation. A group of 15 cows was studied during the summer (May-September, 2001) and a group of 10 cows was studied during the winter (December 2001-May 2002).

**Milk Sampling**

Milk yield was recorded daily. Milk samples were taken from each quarter on a weekly basis and analysed for somatic cell count (SCC) at the provincial dairy lab using a Coulter Counter. Assessment of milk fat and protein was performed by the same lab. Assessment of clinical and subclinical mastitis was based on two criteria:

1. Stockman's definition: daily check of foremilk for discoloration, flakes, etc. Additional indicators were employed, e.g., depressed yield and appetite, high temperature.
2. Pre-study SCC below 200,000.

Weekly milk samples for each quarter were also analysed for the concentration of bovine serum albumin (BSA). BSA is a protein normally found in the blood serum. With mastitis, BSA can “leak” into the milk, therefore it can also be used as an indicator of the presence of mastitis.

**Thermographic Imaging**

On Farm 1, infrared images were taken approximately one hour before afternoon milking. Measurements were taken every other day starting five days before calving until 120 days in milk. Prior to capturing the infrared image, the cows were in a standing position and the udders were clean and dry. On Farm 2, infrared images were captured immediately prior to midday milking as the cows stood in the parlour stall. Measurements were taken every other day starting from 5-7 d after calving until 120 days in milk. Due to the constraints of the parlour design, only the bottom third of the udder was within view for the IRT imaging. Images of the surface of the left and right rear quarters of the udder were taken directly behind the standing animal. The back surface was chosen primarily for ease of measurement and the fact that the majority of mastitis cases occur in the two hind quarters. Images were taken using a thermal scanner and output from the IRT camera was saved onto digital video. Subsequently, a single image captured from the digital video was saved for temperature analysis. The udder area was defined by tracing the outline of the back surface of the udder, excluding teats, using image analysis software. The mean udder surface temperature ($US_{\text{temp}}$) in the traced udder surface area was calculated using the image analysis software.

**Other Measurements**

On Farm 1, rectal temperatures were taken using a digital probe at the time of IRT imaging, while on Farm 2, they were measured in the crowding pen immediately following the mid-day milking on every IRT sampling day during the summer trial and once weekly during the winter trial. Environmental temperature ($E_{\text{temp}}$) and humidity were recorded every 10 minutes at 2 sites in each barn over the entire study period using dataloggers with probes placed at cow height.

**Data Analysis and Development of Prediction Model**

Mathematical models were developed to predict current udder surface temperature from udder surface temperature on previous days and from environmental temperature. Models were initially simple, including only udder surface temperature on previous days, and then were increased in complexity by adding environmental temperature parameters from previous days, SCC and BSA. Two models were applied to both the summer and winter data from each farm.

**Results and Discussion:**

**Farm 1 (Tie-Stall) Results**

Measures of SCC were generally below 200,000. In the summer, barn temperature ranged between 9.91°C and 31.7°C, with a mean of 20.0°C. In the winter, barn temperature ranged between 1.11°C and 25.5°C, with a mean of 9.83°C. The most simple mathematical model was not able to predict current udder surface temperature with accuracy. Use of the more complex model, which included environmental temperature parameters, increased model accuracy considerably in the winter and somewhat in the summer. The difference between the predicted udder surface temperature and the actual udder surface temperature, called the residual, ranged from 0.34 to 1.25 for both the summer and winter trials.

**Farm 2 (Free-Stall) Results**
Measures of somatic cell count were generally below 200,000. In the summer, barn temperature ranged between 4.02°C and 31.9°C, with a mean of 18.6°C. In the winter, barn temperature ranged between –3.13°C and 20.4°C, with a mean of 4.30°C. Using the most simple mathematical model, it was apparent that udder surface temperature in the previous days was an excellent determinant of the current udder surface temperature. Using a model that included environmental temperature parameters had little additional effect. With the more complex model, residuals were very low in the summer (0.17-0.35) and approximately double this in the winter (0.18-1.1).

Discussion

As in the previous experiment, udder surface temperature was variable among days. Relatively simple modeling could consistently predict udder surface temperature with a high degree of accuracy on Farm 2 (free-stall) but not on Farm 1 (tie-stall). The more complex model did not perform well during either the summer or winter on Farm 1, but did in both the summer and winter on Farm 2. Thus, under some circumstances, the model need only contain the previous day’s udder surface temperature. Relatively poor performance of both the simple and complex models on Farm 1 is difficult to understand. It is possible that sampling every second day in the current study was inadequate in the tie-stall management system of Farm 1. Environmental conditions at Farm 1 were more variable than those of Farm 2, thus under such variable conditions, daily sampling may be required.

Results of this experiment with free-stall housed cows are extremely promising. In 23 out of 25 cows, the mathematical models developed could predict udder surface temperature with a great deal of accuracy. Due to this accuracy, the residual values (difference between predicted and actual udder surface temperatures) were below 0.50°C for the majority of cows. The significance of the residual value is that in order for a mastitis-induced increase in udder surface temperature to be detected with infrared thermography, it would have to be greater than the residual value. The researchers previously found that udder surface temperature measured with infrared thermography increased about 2.7°C during the first 9 hours of an experimentally-induced mastitis. This value of 2.7°C is well above their residual values of 0.50°C. Thus, the more complex mathematical model that includes udder surface temperatures and environmental temperatures shows high potential for detecting a rise in udder surface temperature associated with mastitis.

Future work may generate models specific to individual cows, increasing prediction accuracy. The variables tested in the model were those that could realistically be collected under commercial conditions. For instance, it would be unrealistic for a producer to measure rectal temperature for his entire herd on a daily basis. At present, the equipment used in this study is laborious to use. Future commercial development would be needed to produce hardware that could be efficiently used by a producer or attending veterinarian. Such technology may employ an automated scanning mechanism, simply alerting the producer to potential problem animals. In summary, IRT shows promise as an early detection method for mastitis.

Conclusion:

The results of this study show that a test for mastitis relying on IRT-measured increases in udder temperature may be feasible. Results were promising for both tie-stall and free-stall housed cows. In future, sampling every day may be necessary, and infrared equipment will need to be adapted for use on commercial dairy barns. Implementation of an early detection system for mastitis based on infrared thermography could allow producers to treat affected cows more rapidly, which in turn could reduce production losses associated with the disease.

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