Infrared thermometry for lesion monitoring in cattle lameness

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Infrared thermometry is a non-invasive tool shown to be useful in detecting claw abnormalities in cattle at an individual and herd level. This study used the technology to monitor foot temperature and investigate the association with lesion presence over time. A 990 cow dairy herd was enrolled and followed for six months, with data collection fortnightly, lesions were identified by examination of any cow with a mobility score >2, using the 0–3 scale. Two level, multilevel analysis of the association between ambient temperature and foot temperature found that the former was a significant predictor of the latter (coefficient estimate (se)=0.277 (0.02)). Actual foot temperatures were calculated by adjusting for this covariate to allow monitoring over time. Presence of a lesion was also found to be a significant predictor of foot temperature (coefficient estimate (se)=0.623 (0.19)), when added to the model, furthermore some lesion types, claw horn and multiple lesions, were found to be associated with differential foot temperatures. When monitoring lesions over time, the mean adjusted foot temperature was highest at the point of lesion identification. A marked drop in temperature then followed after the lesion was trimmed, with the lowest mean temperature recorded six weeks after treatment, significantly different from the point of lesion identification (P=0.003). This temperature was also lower than the six weeks prior to diagnosis of the lesion, suggesting inflammation was present for at least six weeks prior to the behavioural sign of lameness was seen.

Introduction
Lameness in cattle impacts upon production, longevity in the herd and at individual-level welfare. Lameness is the behavioural sign associated with a cause of pain and discomfort, in cattle 90 per cent of lameness is due to claw abnormalities (Murray and others 1996). Many methods of herd level assessment of lameness have been developed and trialled, and are widely used on farms for the detection of animals requiring treatment. However it is lesions on the claws that must be identified to ensure timely treatment, promoting an improved outcome and minimal impact on productivity and welfare (Leach and others 2012). Given the stoical nature of cattle, and their status as prey animals, it is likely that the display of pain associated with claw lesions is suppressed in some animals or until a threshold is reached, and thus detection by stockmen or using lameness scoring systems may be delayed (O’Callaghan and others 2005). Hence lameness behaviours and lameness scoring systems may not accurately reflect foot lesions present in cattle.

Investigation of a foot lesion involves restraint of the cow and lifting of the foot, this is necessary but can be laborious and time-consuming, so accurate selection of cows requiring lesion investigation is paramount.

Infrared thermometry (IRT) is a non-invasive method for evaluating surface temperature. It has been used widely in human and veterinary medicine in the detection of temperature changes associated with inflammation. Tissue injury and release of local inflammatory mediators causes increased blood flow to the affected area. At the extremities surface temperature is closely related to blood flow, hence inflammation is likely associated with an increase in temperature at the affected area. In cattle medicine IRT has been used for the investigation of inflammation associated with mastitis (Berry and others 2003) and lameness (Nikkhah and others 2005, Alsaaod and Büscher 2012, Main and others 2012, Stokes and others 2012). In equine medicine IRT has been evaluated for use in lameness associated with lesions in the limb, such as sole abscesses (Eddy and others 2001).

Correlation between claw lesions in cattle and maximum foot temperature has already shown good results, several studies have set threshold temperatures above which a lesion is likely to be present. To assess the use of this technology as a diagnostic tool, true positive rate (sensitivity) and true negative rate (specificity) have also been calculated (Nikkhah and others 2005, Alsaaod and Büscher 2012, Main and others 2012, Stokes and others 2012). Alsaaod and Büscher (2012) compared feet with lesions to those without a lesion and found that a temperature difference of greater than 0.64°C prior to foot trimming was likely to be associated with a lesion in the foot, given a sensitivity of 85.7 per cent and specificity of 73 per cent. Main and others (2012) found that above 25.25°C a lesion was likely to be present, with a 72 per cent sensitivity and 73 per cent specificity. Stokes and others (2012) set a cut-off temperature for...
identification of a foot with a lesion as 27°C in dirty feet, with a sensitivity of 80 per cent and specificity of 73 per cent. This study found no significant difference in the maximum temperature between lesion types, however, lesions were classified as digital dermatitis or ‘other’ which included sole haemorrhage, sole ulcer, white line lesion and interdigital growth (Stokes and others 2012). Niskahab and others (2005) found a trend towards higher hoof temperatures in feet with sole haemorrhage.

This longitudinal study evaluated the relationship between claw lesions in cattle and maximum temperature in the foot, using a handheld infrared thermometer, and used a large data set to identify the significance of lesion type and the changes that occurred prior to and after lesion treatment.

Materials and methods

Farm details

A 990 cow dairy herd in Somerset was enrolled in the study. Cows were milked three times daily on a rotary parlour. Cows were observed for data collection fortnightly at the midday milking, between February and July 2012.

Infrared thermometry

In the parlour the individual animal ID (freeze brand) was recorded on a recording sheet. The hind feet were then observed while cows were on the parlour, after cluster attachment but prior to high pressure washing, which occurred halfway round the rotation. Stokes and others (2012) concluded that the sensitivity and specificity of lameness detection through IRT was optimal in dirty unwashed feet.

The infrared thermometer used in the study recorded a maximum temperature, with a reported accuracy ±0.1°C (product code NS5FR, Maplin Electronics, Manvrs, Rotherham, UK). The positioning of the thermometer was determined by the crossing of two laser beams at a 15 cm distance, allowing the thermometer to be held at a fixed distance from the foot. The thermometer was moved in a standardised manner, so as to measure from the plantar aspect of the foot between the heel bulbs and the accessory digits. The method used was that developed by Main and others (2012); the perimeter of this area, and then the diagonals of a rectangle approximately 10 cm wide and 5 cm higher being measured. Both hind feet of each cow were assessed. An ‘automatic data holding facility’ allowed data to be saved whilst assessing this area, and a maximum temperature was displayed. All data were then entered into an Excel database. Date (corresponding to time of year) and ambient temperature were also recorded.

Case selection

Foot temperature was recorded from all cows entering the parlour as part of a wider study. Cows were also mobility scored by a trained foot trimmer as they left the parlour, within 24 hours of temperature data recording. The scoring system used was the DairyCo mobility scoring system which is recommended as the standard in the UK (Bell and Huxley 2009); a 0–3 scale, with a score 2 or 3 defined as lame.

Cows with mobility score >2 were presented to the foot trimmer for lesion identification and treatment. Cows due to be dried off were also seen at this time for routine foot trimming. All four feet on every cow were picked up and trimmed as necessary. The lesion type, limb affected and treatment given were recorded in an Excel database by the foot trimmer.

For the first part of the study any cow with a lesion identified at trimming, with a concurrent temperature measurement, was included in the study. For the second, longitudinal part of the study cows with only a single lesion recorded throughout the study period were selected.

Data analysis

A series of general linear models were fitted in which terms for ambient temperature, the presence or absence of a lesion, and the type of lesion were tested as predictors of the temperature of the foot. These models were fitted using the multilevel software MLWiN (Rasbash and others 2009) which allowed the repeated measurement of foot within cow to be accounted for within the models. A χ² test of the change in log likelihood (P≤0.05) was used to determine which variables were retained in the models. To model the pattern of change in foot temperature over time required an overly complex and biologically unlikely model. We simply show a graph (Fig 2) of the mean session temperatures with ±2×se bars. Note that the se is a point estimate and not a constraint on the line showing the overall change over time. A select number of points on the graph is compared using a paired t-test to demonstrate that the pattern of change seen was not likely random variation. These included the point of foot trimming with two weeks prior to and after trimming, and the point of foot trimming with six weeks after foot trimming.

Results

The foot trimmer examined 1386 hind feet from 693 cows between March and July 2012, of these, 325 feet were found to have a lesion. Concurrent foot temperature data were available for 225 of these feet. The feet without a lesion were visually assessed by the foot trimmer as healthy feet ‘requiring only routine foot trimming’.

The lesions found represented the common conditions in dairy cattle and are shown in Table 1. Sample sizes were as follows: bruising (n=56), white line disease (n=48), sole separation (n=32), sole ulcer (n=21), sole puncture (n=15), heel horn erosion (n=15), interdigital growth (n=6), impacted stones (n=5) and digital dermatitis (n=4). Four feet had lesions falling outside these descriptions. Thirty cows had multiple lesions.

The temperature of feet without lesions ranged from 9.3–31.6°C, mean 24.0±3.22°C. Feet with lesions ranged in temperature from 18–29.4°C, mean 24.8±2.3°C. Table 1 shows the mean foot temperature for each lesion type, for all types of lesions the mean temperature of the affected foot was higher than the mean for a foot without a lesion.

For cows with a lesion on only one foot, the difference between the foot with the lesion and the healthy foot was calculated, as presented in Fig 1. The greatest temperature difference was seen for cows with a sole puncture or sole ulcer.

Two general linear models predictive of foot temperature were developed within MLwiN: A model in which foot temperature is predicted from ambient temperature and the presence of a lesion, per se (Table 2), and a model in which it is predicted by ambient temperature and by the type of lesion (Table 3).

Lesion presence was found to be a significant predictor of foot temperature, and associated with an increase in foot

![FIG 1 Temperature difference (°C) to healthy foot by lesion type. Only lesion types with greater than five cases recorded included for analysis. IDG, interdigital growth; WLD, white line disease](http://vetrecord.bmj.com/content/175/24/663.full.pdf)
temperature of 0.623°C (P=0.001). The predictive equation also included a term for ambient temperature (P<0.001), which was based on a variable centred around the general mean ambient temperature for this study (15.6°C). This means that in these models the constant shows what the foot temperature would be in a foot with no lesion, at ambient temperature. Thus from Table 2 it can be seen that for every 1°C above ambient temperature, foot temperature was increased by 0.276°C. Lesions were further categorised by type to determine whether change in temperature related to location of the lesion. These categories were ‘claw horn lesion’ comprising lesions presenting as abnormalities in the wall or sole of the foot, which included bruising, sole ulcer, sole separation, white line disease, sole puncture, impacted stones. Lesions identified in the skin both at the heel and in the interdigital space were categorised as ‘interdigital lesion’, these included heel horn erosion, interdigital growth, digital dermatitis, and cows with both soft tissue and claw horn lesions were classified as ‘multiple lesion’.

Multilevel analysis of the association between lesion type and temperature found that lesion type was a significant predictor of foot temperature (Table 3). Although it did not quite reach statistical significance, feet with claw horn lesions tended to have a higher foot temperature than feet with no lesions, by approximately 0.395°C. Soft tissue lesions did not significantly increase foot temperature, feet with multiple lesions had a significantly higher foot temperature than feet with no lesion present, by approximately 2.005°C.

In the second part of the study, lesions found at claw trimming were monitored over time. Data from 63 cows were available for the longitudinal analysis. Data were adjusted, using parameter estimates from the models developed in the first part of the study, to adjust actual foot temperature to a common ambient temperature (10.0°C).

Session 0 was the time of lesion identification and treatment, the three sessions (6 weeks) prior to and after treatment of the lesion are plotted as Fig 2.

Fig 2 shows the overall pattern of change in foot temperature over time. The relationship between foot temperature at lesion identification and prior to and after lesion treatment was investigated using paired t tests. At the point of lesion identification, the adjusted foot temperature was highest (25.6°C ±0.27). A marked drop in temperature of the foot is evident after the lesion is trimmed, with the lowest temperature being recorded six weeks after treatment (22.3°C ±0.30), this was significantly different to the point of lesion identification (P=0.003). The adjusted foot temperature was also significantly lower than the day the lesion was observed on the session immediately prior to (P=0.04) and after identification of the lesion (P=0.007).

Discussion

This larger-scale study provides additional evidence to support the use of IRT and the impact of foot lesions on foot temperature. In this study IRT involved the use of a practical and cost-effective handheld laser thermometer.

The results found reflect previous work (Nikkhah and others 2005, Alsaad and Büscher 2012, Main and others 2012, Stokes and others 2012) in showing that there is a significant difference in foot temperature in cows with a lesion in the foot. The difference between the average temperature of feet with a lesion and those without is significant (P=0.001) and consistent regardless of lesion type. In addition to foot temperature, this study also evaluated data in temperature difference between a foot with a lesion to the contralateral healthy foot. In this way individual temperature variation is accounted for. However this outcome gave less consistent results in the presence of a lesion, and is therefore unlikely to be of greater use than the actual foot temperature.

The range of foot temperatures recorded in the study was very wide. Some outliers may be accounted for by other causes of pyrexia, these could be assessed by taking other temperature measurements or performing clinical examinations to rule out additional disease. Other factors influencing the temperature of the foot may include whether feet are wet or dirty. Stokes and

**TABLE 2: Parameter estimates and their significance from the multilevel analysis of effect of ambient temperature and presence of a lesion on foot temperature**

<table>
<thead>
<tr>
<th></th>
<th>β</th>
<th>se</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature</td>
<td>0.276</td>
<td>0.023</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Presence of a lesion</td>
<td>0.623</td>
<td>0.190</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Ambient temperature – general mean of ambient temperature*
others (2012) found that cleaning of feet did impact on foot temperature and increased the risk of false positives when using IRT for lesion detection, and thus lesion detection was most reliable in dirty feet. Time of day relating to circadian rhythm, the activity of the cow and period of time spent standing may also alter blood flow to the foot and hence surface temperature.

Adjustment of measurements of foot temperature for the ambient temperature will aid accuracy on farm and allow comparison of herds, and within-herd monitoring over time. The parameter estimates reported can be used to modify data to adjust for ambient temperature. The constant of the equation represents a foot without a lesion, at the average ambient temperature of 13.6°C. For every 1°C change from this temperature the model predicts the actual foot temperature will change ±0.28°C. When a lesion is present the model predicts the foot temperature will increase by 0.62°C. This model can therefore also be used to predict the foot temperature of a cow with or without a lesion at varying ambient temperatures. Although there is an effect of lesion presence on foot temperature, there will be a significant level of individual variability.

Although differences were detected between lesion types based upon a gross classification, differences in mean foot temperature could not be detected between specific lesion types. However further categorisation of lesions highlighted groups of lesions which had a significant impact on foot temperature. Feet with claw horn lesions tended to have a higher mean foot temperature than feet with no lesion. These lesions tend to be considered as more severe causes of lameness, and therefore a higher temperature might have been expected. Soft tissue lesions, however, did not appear significantly different to the other categories, it might be hypothesised that soft tissue lesions would cause a greater amount of inflammation and would be more readily detected by this method, whereby a significant difference in lesion temperature would be expected. However, soft tissue lesions are variable in their presentation, ranging from non-inflammatory heel lesions to acute ulceration, and knowledge of the pathogenesis of lesion progression supports periods of inflammatory reaction and less reactive periods. This study also had a relatively small number of soft tissue lesions, this may be due to the manner of case selection; cows scored as lame or routine trims, it is likely that soft tissue lesions may have been treated separately, without need for a foot trimmer. The farm also had a low prevalence of soft tissue lesions as reported by the veterinary consultant.

Feet with multiple lesions were shown to have a higher mean temperature, these feet could be considered to be more severely affected, so ease of detection of these cases may benefit the welfare of cows suffering more severely.

When lesions were monitored over time a noticeable drop in average foot temperature was evident after treatment, this was significant at the scoring following treatment and dropped to the lowest value six weeks following treatment. Corrective trimming is a recognised treatment for claw horn lesions which made up the majority of lesion types, so this drop in temperature could be associated with reduction of inflammation and correction of the lesion.

The period prior to lesion identification, which in this study was detected by the behavioural sign of lameness evident at mobility scoring, was also of interest. Although the temperature at lesion identification was highest, the six weeks prior to lesion identification showed a temperature higher than temperatures found following lesion treatment. This suggests the period of inflammation extends at least six weeks prior to the behavioural signs are evident. As a temperature change is detectable, prior to inflammatory signs are evident, assessment of foot temperature may be an useful tool in the early detection of foot lesions in cattle.

This study finds that IRT was able to detect the presence of an elevated foot temperature associated with foot lesions, although specific lesions did not seem to affect the temperature differently. Thermometry was also able to detect differences that occurred over time presumably associated with the disease process of the lesions. The significant variation between individuals in foot temperature means reliable identification of individuals with lesions is likely to depend upon frequent monitoring, ideally using automated systems that are able to account for an individual’s normal foot temperature as well as adjustments for ambient temperature.

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Correction notice This article has been corrected since it was published Online First. All instances of ‘thermography’ have been corrected to ‘thermometry’.

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