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Original Article

The use of infrared thermography for detecting digital dermatitis in dairy cattle: What is the best measure of temperature and foot location to use?

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ABSTRACT

Lameness in dairy cattle is a persistent problem, indicating pain caused by underlying disease states and is associated with reduced milk yields. Digital dermatitis is a common cause of lameness. Thermal imaging is a technique that may facilitate early detection of this disease and has the potential for use in automated detection systems. Previous studies with thermal imaging have imaged either the heels or the coronary band of the foot and typically only used the maximum temperature (Max) value as the outcome measure. This study investigated the utility of other statistical descriptors: 90th percentile (90PCT), 95th percentile (95PCT), standard deviation (SD) and coefficient of variation (CoV) and compared the utility of imaging the heel or coronary band. Images were collected from lame and healthy cows using a high-resolution thermal camera. Analyses were done at the cow and foot level. There were significant differences between lame and healthy feet detectable at the heels (95th percentile: $P < 0.05$; SD: $P < 0.05$) and coronary band (SD: $P < 0.05$). Within lame cows, 95PCT values were higher at the heel ($P < 0.05$) and Max values were higher at the coronary band ($P < 0.05$) in the lame foot compared to the healthy foot. ROC analysis showed an AUC value of 0.72 for Max temperature and 0.68 for 95PCT at the heels. It was concluded that maximum temperature is the most accurate measure, but other statistical descriptors of temperature can be used to detect lameness. These may be useful in certain contexts, such as where there is contamination. Differentiation of lame from healthy feet was most apparent when imaging the heels.

Introduction

Lameness is one of the most common production diseases affecting modern dairy cows. It is recognised as causing pain (Whay et al., 1998) and is associated with reduction in milk yield (Green et al., 2002; Archer et al., 2010) and fertility (Hultgren et al., 2004). The incidence of lameness has been reported as varying between 21 and 69% in North America (Cook, 2003; Solano et al., 2015) and from 21% to 37% in the United Kingdom, varying with the grazing and housing system used (Rutherford et al., 2009; Barker et al., 2010). In particular, digital dermatitis (DD) is currently one of the most prevalent infectious diseases associated with lameness, affecting around 70% of all UK dairy herds (Archer et al., 2010). Within-herd prevalence of digital dermatitis has been estimated as between 0 and 74% (Somers et al., 2005; Holzhauer et al., 2006; Solano et al., 2015; Jacobs et al., 2017).

Early detection of infectious conditions such as digital dermatitis facilitates prompt treatment, and is considered the best method of reducing the overall severity of the disease (Stokes et al., 2012; Alsaaod et al., 2014). Such timely detection and treatment of conditions leading to lameness will not only prevent progression of the condition (Leach et al., 2012), but will reduce the level of the infective reservoir within the herd (Stokes et al., 2012). However, this requires that producers have a reliable method of detecting DD available to them, as well as the time and resources to provide appropriate treatment and care. Changes in locomotion or gait characteristics are often the first detectable signs of foot disease. Visual gait scoring methods have been developed to assess lameness (e.g. Manson and Leaver, 1988; Sprecher et al., 1997). However, despite the presence of these systems and other initiatives, prevalence remains high. For instance in the UK, a prevalence of 36.8% was reported in 2010 by Barker et al., which is

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comparable to the prevalence of 31.6% found in a recent study (Griffiths et al., 2018). Automated systems of lameness detection may be useful, so that the farmer does not need to set aside time to observe cows walking. There are automated systems assessing pressure and force of cows' feet when walking or standing (e.g. Rajkondawar et al., 2006; Pastell et al., 2010; Maertens et al., 2011) and more recently, systems have been developed to detect the change in feeding behaviour and activity associated with lameness (e.g. Mazrier et al., 2006; Blackie et al., 2011; Beer et al., 2016). However, the use of more than one type of sensor has been suggested as a way of increasing the accuracy of detection of issues (Borchers et al., 2017). As well as some measure of change in activity, another independent variable such as a measure of infection, would improve detection rates.

In this regards, a non-invasive, accurate and cost-effective method of detecting inflammation or infection would be useful, particularly useful in the case of DD. The use of infrared thermography (IRT) has been suggested as a method of determining whether heat associated with inflammation or infection is present in the feet of cattle (Alsaaod and Büscher, 2012). Thermal imaging is a suitable device for use in animals as it is non-invasive and the camera is remote form the individual being assessed (Stewart et al., 2005). The body surface temperature of animals is influenced by air temperature, convection and radiation and by insulation but is determined also by the blood flow and metabolic rate of the underlying tissues. Thus, measurement of surface or skin temperature using IRT may detect changes in local blood flow due to infection and inflammation (Eddy et al., 2001). Infrared thermography captures the spatial temperature profile of a target area and produces a visual map or thermogram of the surface temperature of this area by utilising false colour scales to represent pre-defined temperatures. Infrared thermographic devices contain an array of sensors and algorithms that measure incoming radiation and convert the values into temperatures. Thus the thermogram contains as many temperature values as there are measurement sensors. Many imaging devices also report the highest temperature within the field of view on a viewing screen, but the presence of this background data in each thermogram opens up the opportunity of using this data in other ways to detect lameness.

Infrared thermography has been used previously to detect foot conditions associated with lameness in horses (Turner, 1998; Eddy et al., 2001) and changes in udder temperature associated with mastitis in dairy cows (Berry et al., 2003). Previous studies have also shown that thermal imaging or thermography can be used in cattle to differentiate between feet affected by lameness-causing lesions and healthy feet (Alsaaod and Büscher, 2012; Stokes et al., 2012; Alsaaod et al., 2014). Non-contact infra-red thermometry has shown similar results (Main et al., 2012; Wood et al., 2014). These studies have involved imaging two major parts of the feet, the coronary band (e.g. Nikkhah et al., 2005; Alsaaod and Büscher, 2012; Alsaaod et al., 2014) and the rear aspect of the hind feet above the heel bulbs (Main et al., 2012; Stokes et al., 2012). The majority of these studies used the maximum temperature detected in the target area as an indicator of the presence of lameness in the foot. However, it is possible that the presence of a lesion or an inflammatory condition might be more accurately detected by using other statistical descriptors of the data obtained from a spatial profile of surface temperatures in the target area.

The aim of this study was to determine whether statistical descriptors that summarise the temperature data other than the maximum temperature were more effective and accurate at distinguishing lame from non-lame cows. The statistical descriptors assessed were the mean, the 90th and 95th percentiles and the maximum temperatures. As the statistical spread of temperatures will also be affected, two measures of variation were assessed: the standard deviation and the coefficient of variation. The relative utility of imaging the heel or the coronary band areas was also investigated.

Materials and methods

Animals, husbandry and management

This study was conducted using an experimental herd of 200 Holstein dairy cattle, based at Crichton Royal Farm, Dumfries, Scotland. The study methods were approved by Scotland's rural College's Animal Experiments Committee (Submission number: ED AC 45-2013) on 26th November, 2013. The herd was managed in two separate feeding and management systems as part of an experiment investigating the effects of genetic line (high genetic merit for milk yield vs. a control line) and management (indoor housing/bought in feeds vs. outdoor housing in summer/feedstuffs grown on the farm) on milk yield and health. Cows were removed from the herd following the fourth lactation and herd turnover was around 25% annually. Historically, digital dermatitis has been the most prevalent infectious condition causing lameness in the herd throughout the year, with a prevalence of 2–3%, and the prevalence of solar ulcers is 1% or less. The overall prevalence of lameness is 8% (Chagunda, 2012).

The indoor housing consisted of a large, well-ventilated barn with standard cubicle beds with at least one bed per cow and two passageways (one behind the feed trough and one between the two rows of cubicles). Passageways were wide enough for 2 cows to pass. All flooring was concrete and an automatic scraper ran down the passageways every hour. Water troughs were located at either end of the barn and were raised to ensure cows were not standing in slurry whilst drinking. All lactating cows were milked three times per day (approximately 6:00, 14:00 and 21:00 h). In the spring (mid-March), the cows in the outdoor management group began to be grazed outdoors, initially in one time 'window' between milkings. By mid-April they were grazing all day, but were housed at night. Whilst indoors, all cows were fed on a total mixed ration which contained 1.8–12.0 MJ/kg DM. Three times a week, all cows were walked through a copper sulphate foot-bath as a preventative measure against infectious foot diseases. Remedial foot trimming was performed as necessary by the vet on cows identified as lame at any stage, but was performed routinely twice a year on the entire herd to maintain good hoof health.

Lameness scoring and foot examination

Cows were locomotion scored on a fortnightly basis by experienced technical staff. Any cows scoring above 3–4 on the lameness scale used (1–4 from sound to very lame (after Manson and Leaver (1988)), were noted, ready for veterinary inspection. Inter-observer reliability for this score is around 70% (e.g. Rutherford et al., 2009). Healthy cows with scores of 1 were also identified at this time. The vet (CM) visited the within 1–3 days of locomotion scoring to inspect and treat these cows.

Foot examination and image collection

Foot examination took place in a claw trimming crush and was carried out by an experienced veterinary surgeon (CM). All cows identified as lame were separated from their management groups and held as a group in a holding pen beside the crush. Control cows, with a locomotion score of 1, were also identified, observed again to confirm this score, and included in this group in the holding pen. One by one, each cow was inspected in the crush. Before any handling of the feet took place, images were taken of the front of the coronary band and the plantar aspect of the pastern joint (image taken from ground level of the area between the heel bulbs and the dew claws) of both rear feet. The feet were not cleaned with water or by any other method. Using only dirty feet not only makes results more applicable for eventual on-farm use (Stokes et al., 2012), as washing feet has shown to increase foot temperature variability (Main et al., 2012) and heat loss to the environment (Stewart et al., 2005).

After imaging, both of the rear feet were lifted in turn. The Dutch 5-step foot-trimming technique was employed. In so doing, the presence and location of DD and/or claw horn lesions were identified. Information on the diagnosis of the foot condition present and its severity were recorded for each foot. Pictorial paper 'foot maps' were also used to mark the precise location of lesions in lame cows. Throughout the entire imaging process, any fresh faeces were quickly cleared away from the imaging area and feet to remove sources of heat artefacts. The feet of control cows were imaged, inspected and lightly trimmed in the same way as lame cows to confirm an absence of pathology. Farm records on disease treatment were also checked to confirm that these cows had no other identified disease.

As the IRT images were taken before the veterinary inspection, images were collected from all 51 cows inspected. Of these, 17 were diagnosed with infectious disease (digital dermatitis or inter-digital dermatitis) and 21 classed as healthy and without disease. Six cows had a claw horn lesion, four had stones lodged in their hooves and the remainder had advanced slurry heel. Because of this prevalence pattern, only images from the healthy cows and those with DD were analysed.