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ORIGINAL ARTICLE

Digital Infrared Thermal Imaging and manual lameness scoring as a means for lameness detection in cattle

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Abstract

Lameness is a serious issue in the dairy industry, both economically and from an animal welfare perspective. The incidence of lameness in UK herds has been estimated to be around 20-25%. The study looked at the use of Digital Infrared Thermal Imaging (DITI) and manual lameness scoring as a means for lameness detection in cattle. This was carried out at dairy unit in Northamptonshire in the United Kingdom. 150 cattle were used in the study and foot temperatures were recorded using a handheld Forward Looking Infrared (FLIR) thermal imaging camera. All subjects were lameness scored directly after images were taken, as the animals exited the milking parlour. Data collections were repeated twice weekly for the following 3 weeks. The Kruskal-Wallis test found no significant difference between the mean values on temperatures collected for each lameness score in weeks 1-3 (p=0.823) and weeks 4-6 (p=0.935). Chi-Squared tests for association found an association between individual foot temperatures for weeks 1-3 (X^2= 8, df= 82.25, p<0.001), and 4-6 (X^2=8, df=133.3, p<0.001) and that there was a high level of lameness in hind limbs (n=139) when using a threshold of 27°C for disease. Results indicated that such a high level of lameness recorded using thermal imaging techniques and not by the method of mobility scoring meant that lameness scoring may be subjective when compared to objective techniques. Therefore the prospect of using DITI as a diagnostic tool for lameness should be considered.

Keywords: Dairy cow health, lameness, digital infrared thermal imaging, diagnosis.

Introduction

The term lameness is used to describe a clinical presentation of impaired locomotion and mobility, regardless of its cause (Archer *et al.*, 2010). Many cases of reported lameness are caused by lesions of the hind limb (Gonzalez-Sagues, 2002). The most common lesions seen in the UK dairy herd frequently include; digital dermatitis characterised by erosive infection usually affecting the skin on the bulbs of the heels, digits or coronary band (Blowey, 2006). Other lessons include sole ulcers and white line disease (Blowey, 2006; Archer *et al.*, 2010).

Lameness is a serious issue in the dairy industry, both economically and from an animal welfare perspective (Bichalo *et al.*, 2008). Lameness issues are estimated to cost around £20-30 per cow (Enting *et al.*, 1997; Blowey, 2006; Archer *et al.*, 2010) each year in the UK dairy industry alone. This includes costs from loss of milk, treatments and also the labour incurred. The incidence of lameness in UK cattle herds is difficult to determine due to various influencing factors although studies have estimated levels to be around 20-25% of a herd of 100 cows (Whay *et al.*, 2003; Burnall and Reader, 2010). This has increased from around 17% of cows being reported as lame in 1996 (Clarkson *et al.*, 1996).

Lameness is a prevalent issue throughout the world, not just on UK dairy farms. This is apparent in the existing studies on lameness throughout a variety of countries. Manske *et al.* (2002a) assessed the level of lameness in Swedish dairy herds as 5.1%, while Espejo *et al.* (2006) assessed a small percentage of American dairy farms in the state of Minnesota as 24.6%. This was not a true reflection of prevalence in America as a whole but just an inference into the overall prevalence, using 50 farms. Katsoulos and Christodoulopoulos (2009) looked at the prevalence of lameness and claw disorders in Greek dairy farms and found a prevalence

of 18.7%. Interestingly, Smits *et al.* (1992) found a lameness prevalence of 1.2% in 34 Dutch dairy farms.

A number of methods have been employed in diagnosing cases of lameness in dairy cattle for example, mobility scoring which refers to a structured subjective assessment of a cow's gait (Archer *et al.*, 2010). The ideal scoring system is designed to reduce variation between scores observed. The DairyCo mobility score (DairyCo, 2009) has four points that broadly reflect the typical actions that farmers take when assessing cows for lameness treatment. The advantages of using lameness scoring in order to assess the prevalence of lameness within a herd include the fact that lameness scoring is carried out immediately and may be used as verification of incidence records (Whay *et al.*, 2003). Also the opportunity is provided for the observer to look at all individuals in the herd in one instance (Whay, 2002). Subsequently, decisions to do with management of lameness are not based on records of unknown reliability (Main *et al.*, 2010). The fact that it requires no specific equipment and therefore is inexpensive should also not be overlooked in terms of its importance to industry.

Alternative lameness detection methods have been documented for example Kujala *et al.* (2008), Mokaram *et al.* (2012) and Rajkondawar *et al.* (2006) have all looked at the use of force plates and sensors as an assessment of lameness and gait. These force plates measured the weight distribution and the pattern of gait in the animals. However, these methods did not necessarily pick up on infectious causes of lameness and also required the animal to stand still for a long period of time which is not always possible, even during milking. A more recent technique referred to as Digital Infrared Thermal Imaging, also known as infrared thermography involves, a non-invasive quantitative assessment of temperature (Kunc *et al.*, 2007; Stokes *et al.*, 2012) which produces a pictorial representation of the surface temperature of the object being scanned. The colour gradient on the scale used on the camera reflects the differences in the emitted heat from the object. An infrared scanning device is used to convert infrared radiation emitted from the skin surface into electrical impulses that are visualised in colour on a monitor (Alsaaod and Buscher, 2011). This visual image graphically maps the body temperature and is referred to as a thermogram. Alsaaod and Buscher (2011) used digital infrared thermography as a non-invasive, early diagnostic tool for foot pathologies in dairy cattle. Their method involved measuring coronary band temperature in the foot before and after hoof trimming, as a response to visual detection of abnormalities in the hoof. They concluded that an increase in temperature of the surface area of the hoof occurs in the lame limb when the hoof has a lesion.

There are limited studies on lameness scoring systems compared with digital infrared thermal imaging as a diagnostic tool for lameness thus it was the aim of this study to investigate on the benefits of using digital infrared thermal imaging as an early diagnostic tool on a small scale dairy enterprise in order to provide early treatment and control, and to determine issues that may arise from the use of lameness scoring systems when compared with digital infrared thermal imaging.

Materials and Methods

The study was carried out in April 2013 at a 142 cow milking herd in Northamptonshire, UK. The unit consists of a rapid exit milking parlour set up with cows milked twice daily. The animals used were lactating primiparous and multiparous Holstein-Friesian cows at differing stages of lactation with an average of just over 10000 litres of milk per lactation period (305 days). Cows were housed in free stall barns with individual cubicles. Foot temperatures were recorded using a handheld FLIR (Forward Looking Infrared) e40bx thermal imaging camera (FLIR systems Inc.) during afternoon milking around 3pm, twice a week for 3 consecutive weeks. The emissivity value for the subjects was 0.93 and a sensitivity value of 0.12 degrees centigrade was used as previously demonstrated by Pezeshki *et al.* (2011). All images were taken from the same distance of 2 metres. Images were captured in an area where there was less chance of environmental factors influencing the resulting images. Wherever possible only cattle with 'dry' limbs were recorded in order to create the most accurate measurement of limb temperature.

Thermograms of both front and hind limbs were collected concurrently at a distance of 2 metres (Pezeshki *et al.*, 2011) in order to reduce the chance of environmental factors affecting the temperature recordings. The image number and cow identification number were recorded for analysis purposes. All images were analysed using FLIR software after each data collection to determine maximum temperatures of each limb.

All subjects were lameness scored directly after thermal images were taken, as the animals exited the milking parlour. All subjects were identified by symbols that were sprayed on to the right hind leg, using spray marker, to ensure that the correct animals were being scored for lameness. The animals were all required to exit the parlour using a race which allowed for single file walking, this meant that animals were all observed individually within a well-lit area. The DairyCo 4 point (0-3) lameness scoring system was used to subjectively identify animals that were showing signs of lameness as they walked at a normal pace from

the parlour (DairyCo,2011). A lameness scoring of 0 was given to an animal that showed no evident signs of lameness within posture and gait, whereas a lameness score of 3 was given to an animal that had severely impaired mobility that was obvious whilst assessing posture and gait. The observed lameness score was then recorded alongside the subjects' identification number and image details.

Statistical analysis

The data were analysed using statistical software Minitab version 1.5. Kruskal-Wallis test was used to test for differences in the mean of the values collected. A critical significance value of 0.05 was used.

In order to determine whether there was an association between the temperatures of individual feet, the Chi-Squared test for association was used. All temperature values were categorised into either normal or abnormal using 27°C as the minimum parameter for feet with lesions as determined by Stokes *et al.* (2012).

Results

Incidence of lameness

From the 142 cows used in the study 139 (97%) were considered 'lame' on at least one foot when the 'normal (N), 'abnormal (A)' parameter (27°C) was used on all feet. There was more lameness seen in the hind feet (N=4 A=138, N=3 A=139) than in the front feet (N=46 A=96, N=41 A=101) in weeks 1-3 and equally in weeks 4-6 (N=4 A=138, N=3 A=139) (N=64 A=78, N=58 A=84).

A significant level of lameness was seen within the herd in both weeks1-3 (X^2 = 82.25, P<0.001) and weeks 4-6 (X^2 =133.3, P<0.001).

Frequencies of abnormal to normal temperatures in each individual foot are represented for both weeks 1-3 and weeks 4-6 in Fig 1 and 2. It can be seen that the frequencies of abnormal temperatures were significantly higher than those for normal temperatures in both time intervals. Frequencies and results for Chi-square tests for association for both weeks 1-3 and 4-6 are shown in Table 1.

Mean temperature

Results from the Kruskal-Wallis test showed that there was no significant difference between the mean temperatures collected for each lameness score in weeks 1-3 (Kruskal Wallis- H= 0.39, p-value=0.823) and weeks 4-6 (Kruskal-Wallis-H= 0.13, p-value=0.935). This suggests that the samples were collected from populations with the same median. The descriptive statistics of lameness scores and results of Kruskal-Wallis test can be found in Table 2. Mean temperatures for each lameness score for 0, 1, 2 within weeks 1-3 were 30.22^{O}C, 30.24^{O}C and 30.10^{O}C respectively, and those within weeks 4-6 were 29.17^{O}C, 29.18^{O}C and 29.2^{O}C. The mean temperature for each lameness score is represented in Fig 9 and 10 and from this it can be seen that there is little variation in each mean temperature collected for lameness scores 0-2 during the study. There were no cows scored as a lameness score of 3 (severely impaired mobility) during the study.

Discussion

The incidence of lameness recorded was high according to the thermal imaging technique when used in conjunction with the 27°C parameter set out by Stokes *et al.* (2012). This parameter was used to determine those animals with lesions; however, one of the aims of the study was to provide an alternative technique for the diagnosis of early lameness within cattle. Use of the 27°C parameter resulted in a high number of lame animals when considering each individual hoof temperature measurement. During the study, 139 out of 142 animals were recorded as having a temperature of over 27° C on at least one foot.

Animals with lesions are expected to have a significantly higher temperature recording (Gloster *et al.,* 2011) than those animals that are suffering from general laminitis and overgrowth problems in the foot (Lischer and Ossent, 2002). For this reason it is important to consider that nearly all animals used in the study were over the 27°C parameter in at least one of their feet.

Overall a significant level of lameness was seen within the herd in both weeks1-3 (X^2 = 82.25, P<0.001) and weeks 4-6 (X^2 =133.3, P<0.001).There were significantlymore animals that were considered to have 'abnormal' temperatures within the hind feet than in the front, in both time intervals of the study. In total, 97% (n=139) of animals during weeks 1-3 and 4-6 were considered lame on at least one of their hind feet. Studies have found that the majority of lameness is found within the hind limbs (Lawrence *et al.,* 2011), more specifically the lateral claw. This is due to the hind foot being unstable as a result of the concavity of the medial sole. Murray *et al.* (1996) found that when analysing different foot lesions in cattle from 37 different dairy farms 92% of all lesions that were assessed were found within the hind limb of the animal, of which 65% were in the outer (lateral) claw. Alternatively, McLennan (1988) found that 65% of lesions that were surveyed were in the hind limb and therefore 35% of lesions were present in the front limb, whilst surveying lesions existing in lame cattle in Queensland, Australia.

Other studies have found that heifers seem to suffer an increased incidence of front foot lameness when compared to older cows. Eddy and Scott (1980) found that there was an increased risk of hind foot lameness in older (increasing parity) cows than heifers, who suffered significantly more from front foot lameness. This could be due to the change in hoof formation that occurs during calving.

Lameness scores (0-3) were compared with the temperature recorded for the same animal in order to assess the mean temperature for each lameness score. The mean temperatures for each lameness score were not significantly different in weeks 1-3 suggesting that the lameness scoring technique is unreliable when compared with objective measurements such as temperature.

The variation between mean temperatures during weeks 1-3 and weeks 4-6 could be due to changes in the ambient temperatures within the environment at the time of measurement.The latter part of the study (weeks 4-6) was carried out during early to mid-December 2012, and so there was a significant decrease in temperature during this time compared to the beginning of the study (weeks 1-3), which took place during late October- early November 2012. The ambient temperature was not measured during the study; due to this future studies should consider recording such things as the ambient temperature in order to assess its effect on temperature measurements. This can be demonstrated in Gloster *et al.* (2011) where it was found that a change in ambient temperature would change the temperature measurement of the hoof respectively.

The mean temperatures for all lameness scores were approximately 30°C for weeks 1-3 and 29°C for weeks 4-6. Stokes *et al.* (2012) found that animals with dirty feet with no lesions had a mean plantar temperature of 22.2^{o}C. Those with dirty feet with digital dermatitis and other lesions had a mean temperature of 30.1^{o}C. Alsaaod and Buscher (2012) found mean skin temperatures for healthy hooves ranged from 29.9-32.1^{o}C when assessed within an ambient temperature of 20.3 ^{o}C. This is more reflective of the results found during this study. However, Alsaaod and Buscher (2012) also assessed the mean temperature of the animals depending on the stage of lactation they were currently at. Cattle that were in early/mid lactation were seen to have as much as a 2°C increase in skin temperature within the hoof compared to those cattle that were in late lactation (31.8 vs. 29.8^{o}C).

Table 1: Frequencies and results- Chi-square test for association for both weeks 1-3 and 4-6

Feet	Normal	Abnormal	Total	X^2	Df	P-value
Weeks 1-3						
Front left	46	96	142			
Front right	41	101	142			
Hind left	4	138	142	82.25	8	<0.001
Hind right	3	139	142			
Weeks 4-6						
Front left	64	78	142			
Front right	58	84	142			
Hind left	4	138	142	133.3	8	<0.001
Hind right	3	139	142			

Table 2: Descriptive statistics for individual lameness score values and results for Kruskal-Wallis test.

Lameness Score	Mean Temperature(^{o}C)	Standard Deviation	Frequency	Percentage	H-value	P Value
	Weeks 1-3					
0	30.22	2.31	80	56.3		
1	30.24	2.23	53	37.3	0.39	0.823
2	30.10	1.36	9	6.4		
	Weeks 4-6					
0	29.17	1.93	85	59.9		
1	29.18	2.18	50	35.2	0.13	0.935
2	29.2	1.73	7	4.9		

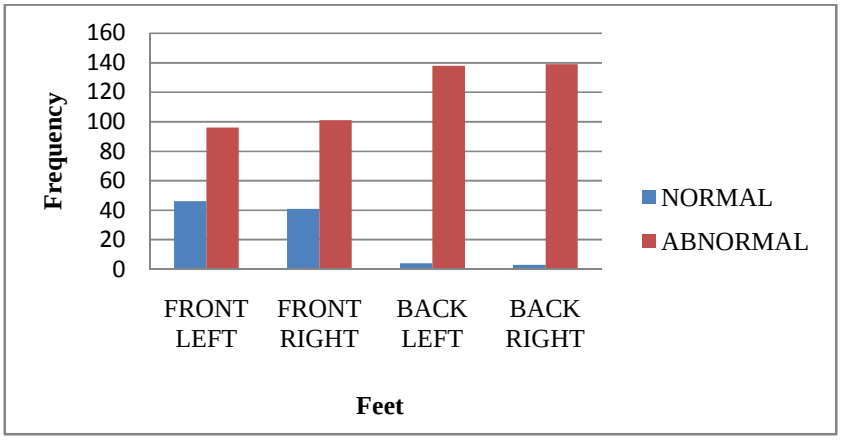

Fig 1: Frequencies for 'Normal' and 'Abnormal' temperatures in each foot for week 1-3

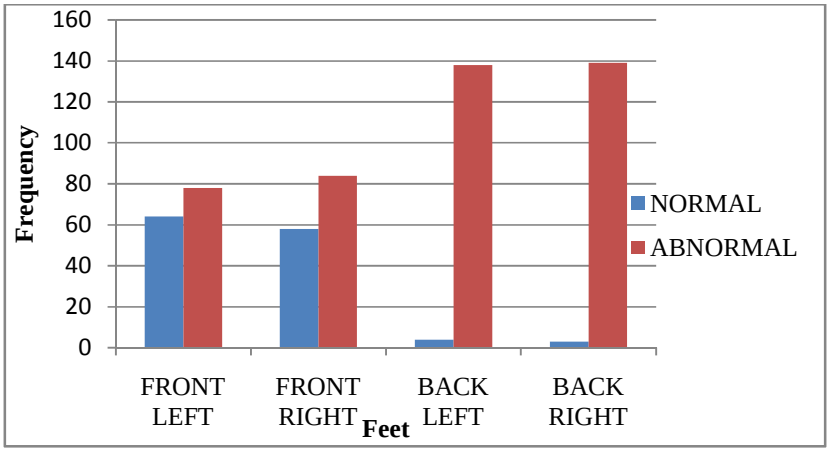

Fig 2: Frequencies for 'Normal' and 'Abnormal' temperatures in each foot for week 4-6

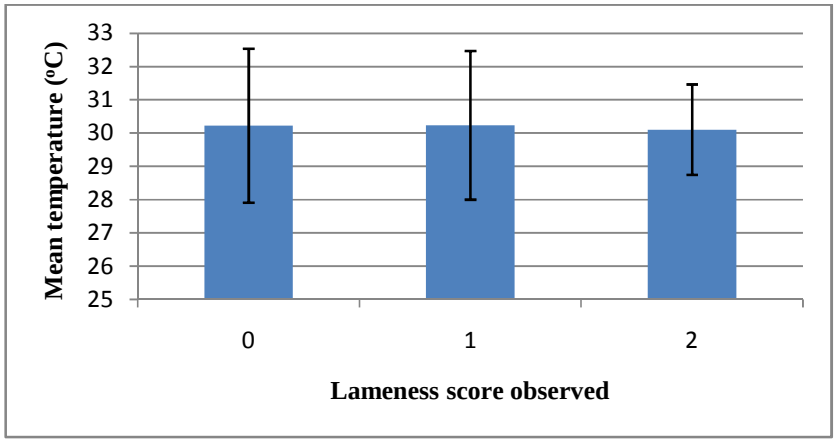

Fig 3: Mean temperatures in °C (±1SE) for lameness scores observed during weeks 1-3

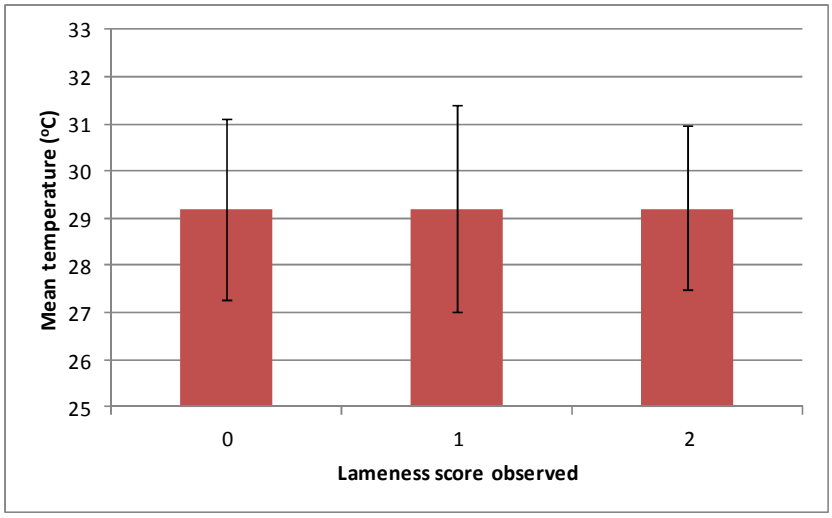

Fig 4: Mean temperatures in ^{o}C (±1SE) for lameness scores observed during weeks 4-6

Differences between walking patterns of each cow do exist (Viazzi *et al.,* 2013) and so the effect of lameness on the measured variables cannot be considered identical for each individual cow. Lameness scoring does not take into account variability between animals whilst walking, such as udder size, age and environment (Viazzi *et al.,* 2013). Due to this, studies need to take place which are representative of these different factors to allow conclusions to be drawn about the individual differences and thus the reliability of lameness scoring. Also, body posture whilst walking could be dependent on the area of the lesion that may or may not be present, and so this means that the animal may appear to have a normal gait, therefore lameness would not be highlighted by the lameness scoring system until the situation had worsened (Flower and Weary, 2006).

Temperature measurements may also be brought into question, in that inflammation processes may cause a fluctuation of temperatures depending on the level of infection and duration of the problem (Stokes *et al.,* 2012). Animals that have been suffering from a lame limb for a substantial amount of time may emit highest temperatures during periods of activity within the affected area. An untreated injury will be aggravated when in use at the site of the trauma (Whay, 2002). Inflammatory processes within the limb during this period of activity would be the body's way of attempting to reduce the amount of damage caused to the area (Lischer and Ossent, 2002).

During inflammatory reactions there is impairment in the vascular system of the corium. Vasodilation in the blood vessels within this area means that blood stagnates (Lischer and Ossent, 2002) and does not move freely from the affected area. Valves within the vessels remain open causing the blood destined for the corium to short circuit, and so it does not reach the claws as easily as it should (Lischer and Ossent, 2002). These affected blood vessels leak plasma fluid into the tissues and can cause swelling, redness, haemorrhages and clots in the area and eventually necrosis of the surrounding tissue can occur (Van Amstel and Shearer, 2006).

Conclusions

Lameness scoring is a subjective method and therefore there are risks involved with relying on it as a tool for diagnosing early lameness in dairy cattle. The dairy industry would benefit from being able to use an objective method of diagnostics such as DITI.Although this would incur costs to the farm, it would prevent costs incurred from loss of yield, fertility and veterinary and culling expenses that come from not being able to resolve a lameness issue in the early stages. Preventative measures for lameness can also be incorporated to make early lameness detection more reliable on the whole with the use of this labour extensive method. A larger study involving many cattle farms could provide better results.

Conflict of interest statement

The authors have no conflict of interest to declare.

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