The association between foot temperature and hoof lesions in sheep

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Abstract

Lameness, predominantly caused by footrot and interdigital dermatitis, is a common issue in sheep flocks with negative consequences for animal welfare and productivity. Simple and cheap methods to prevent and monitor lameness are desirable to decrease prevalence within flocks. The aim of this study was to investigate whether a high foot temperature threshold can be used as an early warning for the development of hoof lesions and lameness in sheep. A flock of 47 pregnant ewes and seven non-pregnant ewe lambs were randomly allocated into two equal groups and placed in two different but similar permanent pasture fields for the duration of the study. Foot temperature was measured with a temperature probe placed on the interdigital skin on three dates over approximately 4 weeks. This study showed that increased foot temperature was associated with higher lesion scores (recorded lesions covered a scale of 0 to 3), with healthy feet having a mean temperature of 20°C and feet with severe lesion scores having a mean temperature of 31°C. Also, back feet had a higher foot temperature and lesion score than front feet ($P<0.001$). This study suggests that a threshold of 26.5°C in the back feet

of sheep (mean foot temperature for a lesion score of 1 in back feet) could be used as an indication of when to foot bath or treat feet, and minimise hoof lesions in sheep.

Key words

Sheep, hoof, health, lesions, temperature

1. Introduction

Lameness is one of the most common welfare and productivity issues affecting sheep farming, and is thought to cost the industry in the UK about £24 million per year (Nieuwhof and Bishop, 2005). Footrot and interdigital dermatitis (scald, an early manifestation of footrot) are thought to be responsible for 79% (MSD, 2015) to over 90% (FAWC, 2011) of lameness cases. Footrot is a disease caused by strains of the Gram negative bacterium *Dichelobacter nodosus*, which can manifest as clinically severe to benign cases (Allworth, 2014). The presence of *D. nodosus* in the farm environment is widespread and can be found in soil, pasture, and in both healthy and diseased feet (Clifton et al, 2019), and is the key focus for elimination of foot disease. Another bacterium, *Fusobacterium necrophorum*, found in sheep faeces and diseased feet, plays a secondary role in footrot by enhancing the severity of hoof lesions (Atia et al., 2017; Clifton et al., 2019). Wet conditions provide the ideal environment for both bacterial species to persist (Clifton et al., 2019; Smith et al., 2014), meaning that temperate climates such as the UK provide a challenge to managing the spread of this disease. The Farm Animal Welfare Council set an aim to reduce the incidence of sheep lameness to less than 2% by 2021 in the UK (FAWC, 2011), which is considered achievable by farmers if good control measures are implemented (Clements and Stoye, 2014). Rapid treatment using antibacterial medicines within three days of observed lameness is key to minimising cases within the flock (FAWC, 2011). Therefore, simple early detection methods along with cheap prevention techniques are desirable to enhance sheep welfare and productivity. However, many farmers do not engage with evidence-based practices that involve treating individual sheep and are more receptive to flock management strategies (Prosser et al., 2019). The incidence of lameness in sheep can be controlled through a combination of vaccination, culling, quarantine, treatment and avoidance strategies (Clements and Stoye, 2014).

Detecting footrot normally requires visual examination for hoof lesions, which is subjective, labour intensive, and may not pick up initial stages of the disease. Early diagnostic techniques would be beneficial to both the farmer and the animal. Infrared thermography of the feet has shown potential for detecting lameness in cattle (Lin et al., 2018; Alsaaod et al., 2015) and sheep (Byrne et al., 2018; Talukder et al., 2015). Temperature measurements could be useful for identifying infection before visual signs appear, especially if a temperature threshold could be established.

The objective of this study was to investigate whether a high foot temperature threshold can be used as an early warning for the development of hoof lesions and lameness, in sheep.

2. Material and methods

Approval for this work was obtained from the University of Nottingham animal ethics committee (approval number 222) before commencement of the study. The study was carried out in the autumn/winter months from November to December 2019 at Sutton Bonington University Farm, Leicestershire, UK. A flock of 54 sheep including 47 pregnant ewes and seven non-pregnant ewe lambs were allocated for grazing management to two groups (A or B) of 27 animals to graze two separate but similar adjacent permanent pastures. The ewe lambs were randomly allocated to each group to balance the number of animals. Sheep were either pure Lleyn breed (total of 26) or Lleyn cross-bred animals. The 26 pure Lleyn sheep were randomly allocated to provide 13 in each group, with the remaining 28 cross-bred sheep also randomly allocated to each group. At the beginning of the study, the average bodyweight of group A was 56 (s.d. 13) kg and group B was 59 (s.d. 11) kg. The two fields were adjacent permanent pastures and had similar ground conditions, shelter, and size (each 3 hectares).

Initial foot temperature (FT) and lesion score (LS) measurements were taken on test date 1, which was two days after the sheep were allocated to their groups. The same person throughout the study did both measurements. To measure FT, a temperature probe was placed on the interdigital skin between the claws of each hoof (Figure 1) to record a measurement for all sheep feet in the order of front left (FL), front right (FR), back left (BL) and back right (BR). Lesion scoring was performed manually using the method of Egerton and Roberts (1971) to assign a score between 0 and 4 (Table 1), with each foot assessed in the same order as temperature measurements. After 14 days, FT and LS measurements were repeated (test date 2). Also, all sheep received a foot bath at test date 2 of 2% Progiene as part of routine management. Seven lame sheep (six pure Lleyn with five in the group B) had a single foot (five were front) treated once with an oxytetracycline hydrochloride cutaneous spray (3.92% w/w, Terramycin) during the study. These treated animals displayed gait changes indicative of clinical lameness, and were treated on the next test date and after measurements were obtained, with later test date measurements being excluded from the study. After a further 14 days, the measurements were repeated for the third time (test date 3).

Table 1. Five point lesion scoring (LS) system based on Egerton and Roberts (1971)

LS	Description
0	Normal hoof. No signs of foot lesions, infection or irritation.
1	Mild interdigital dermatitis (scald) with some loss of hair. Slight to moderate inflammation confined to interdigital skin and may involve erosion of epithelium.

2	More extensive interdigital dermatitis and necrotising inflammation of interdigital skin.
3	Severe interdigital dermatitis and under-running of the horn of the heel and sole.
4	Severe interdigital dermatitis and under-running of the horn of the heel and sole and with under-running extending towards the walls of the hoof.

Statistical Analysis

A total of 641 foot records were obtained from 54 sheep. Data were analysed using a mixed model in Genstat software (version 19.1; Lawes Agricultural Trust, 2012) using least significant differences to determine differences between predicted means. A linear mixed model (Equation 1) was used to assess the effects of lesion score, foot position, breed and test date on FT:

$$Y_{ijklm} = \mu + LS_i \times F_j + B_k + D_l + S_m + e_{ijklm} \quad (1)$$

where Y_{ijklm} is the dependent variable of foot temperature or lesion score; μ = overall mean; LS_i = fixed effect of lesion score (i = 0 to 4); F_j = fixed effect of foot position (j = front or back); B_k = fixed effect of breed (k = Lleyn or cross-bred); D_l = fixed effect of test date (l = 1, 2 or 3); S_m = random effect of individual sheep (m = 1 to 54); e_{ijklm} = random error term.

Equation (1) without the fixed effect of LS and as a generalised linear mixed model with a binomial error distribution and a logit link function added was used to assess the fixed effects of foot position, breed and test date on LS. The back-transformed predicted means were calculated and presented on the original LS scale. The effects of field, bodyweight and age on FT and LS were not found to be significant ($P > 0.05$) and therefore were not included in

Equation (1). The most significant explanatory variables were added first in Equation (1). Significance was attributed at $P < 0.05$.

3. Results

The average foot temperature during the study was 21.5 ± 8.3 °C with a range of 8.0 to 36.4 °C across all foot records. Of the 641 feet records, the majority of feet were either healthy (41% and LS 0) or had mild interdigital dermatitis (45% and LS 1) (Table 2). There were no feet with a LS of 4 during the study.

Table 2. Number and percentage of feet categorised from lesion score 0 to 4.

LS	No.	% of total
0	263	41
1	289	45
2	74	12
3	15	2
4	0	0
Total	641	100

Overall, the median FT increased from LS 0 to 3 (Figure 2). While LS 0 to 2 contained sheep with a FT between 10 to 35°C, all sheep classified as a LS 3 and having severe interdigital dermatitis had a FT of greater than 25°C. The percentage of feet with a temperature greater than 25°C for each LS were 20% for 0, 43% for 1, 64% for 2 and 100% for 3.

Differences in FT were associated with foot position (front or back, P<0.001), showing that back feet were warmer than front feet (Table 3). The mean FT was higher on test date 1 compared to other test dates (P<0.01). Pure Lleyn sheep had a higher FT than cross-bred animals (P<0.01). Healthy feet (LS of 0) had a lower FT of 19.9°C and severe interdigital dermatitis (LS 3) a higher FT of 30.7°C compared to other LS categories (P<0.001). There was an interaction between foot position and lesion score (P<0.05), with front feet with a LS of 0 to 2 generally being cooler than back feet with a similar LS (Table 3).

Back feet had a higher average LS than front feet (P<0.001) (Table 4). There was no effect of test date or breed on LS.

Table 3. Effects of test date, breed, foot position and lesion score on foot temperature.

Variable		Mean[1]	df	F statistic	s.e.d.[1]	P value
Test date	1	25.0^{a}	2	5.9	0.6	<0.01
	2	23.7^{b}				
	3	22.9^{b}				
Breed	Lleyn	25.2^{a}	1	8.7	0.9	<0.01
	Cross-bred	22.6^{b}				
Foot position	Front	20.0^{a}	1	473	1.1	<0.001
	Back	27.8^{b}				
Lesion score	0	19.9^{a}	3	13.8	1.4	<0.001
	1	21.6^{b}				
	2	23.3^{b}				
	3	30.7^{c}				
Foot position × lesion score	Front 0	16.3^{a}	3	3.5	1.9	<0.05
	Front 1	16.7^{ab}				
	Front 2	18.0^{abc}				
	Front 3	28.9^{de}				
	Back 0	23.5^{bcd}				
	Back 1	26.5^{cde}				

Back 2	28.7[de]
Back 3	32.5[e]

[1] Means within a column for the variable and with different superscript letters (i.e., a,b,c) differ significantly and attributed at $P < 0.05$. SED means standard errors of differences.

Table 4. Effect of test date, breed and foot position on hoof lesion score (on a scale of 0 to 3).

Variable		Mean[1]	df	F statistic	s.e.d.[1]	P value
Test date	1	0.59	2	2.7	0.1	0.071
	2	0.71				
	3	0.70				
Breed	Lleyn	0.61	1	1.4	0.2	0.244
	Cross-bred	0.73				
Foot position	Front	0.45[a]	1	102	0.1	<0.001
	Back	0.96[b]				

[1] Means within a column for the variable and with different superscript letters (i.e., a,b) differ significantly and attributed at $P < 0.05$. SED means standard errors of differences.

4. Discussion

The fact that higher FT was associated with a higher LS is in agreement with Talukder et al. (2015) and Byrne et al. (2018) that FT can be used to detect hoof lesions. We propose that 26.5°C (mean FT for LS 1 in back feet) could be used as a threshold temperature for treating and foot bathing sheep to minimise hoof lesions. The current study found significant differences in FT and LS between front and back feet, with back feet being hotter and having a higher lesion score on average compared to front feet. Renn et al. (2014) also found a difference in foot temperature between front and back feet and proposed a similar threshold of 27°C when monitoring hind feet.(). Using the temperature of back feet as an indicator of when to foot bath sheep and reduce foot lesions would seem appropriate given the higher mean temperature and LS compared to front feet. In the current study, all sheep with a severe LS of 3 according to the categories defined by Egerton and Roberts (1971) had a FT of greater than 25°C (Figure 2), with an adjusted mean FT of 29°C or more for front and back feet with a LS of 3. As none of the sheep in this study had LS 4, we can only speculate that animals with this score would also be associated with a high FT above 30°C. Sheep that were visibly lame were treated with antibiotics to maintain animal welfare, which could be why we did not see any LS 4; after an animal was treated their subsequent measurements were excluded from the study. Sheep that had LS 3 feet upon examination did not display changes in gait that are typically indicative of lameness. Therefore, temperature measurements could be valuable for identifying sheep that need treatment before the lesions become severe enough to change gait. The proposed threshold of 26.5°C from this study is lower than the 31°C threshold proposed by Byrne et al. (2018) study sheep, but the same as Renn et al. (2014) studying the hind feet of cattle. Based on a threshold of 31°C, Byrne et al. (2018) successfully identified 92% of infected hooves (with LS of 1 to 3) and 91% of healthy hooves (LS of 0), however 94% of hoofs in their study were classified as 'healthy' compared to 41% in the current study and the authors used infrared thermography of the whole hoof to achieve a maximum FT reading. In comparison, a threshold of 26.5^{o}C in the current study would detect 85% of healthy feet (LS of 0 and less than 27^{o}C) and an increasing severity of infected feet from 44% for LS 1 to 93% for LS 3 across all feet. A threshold temperature of 26.5^{o}C or more would cover detect mild interdigital dermatitis in back feet (LS 1 or more) and severe interdigital dermatitis in front feet (LS 3 or more) (Table 3). A threshold of 31°C was comparable to the mean FT of feet with a severe LS 3 across feet in the current study. When Byrne et al. (2018) applied the threshold of 31°C to another flock it was no longer useful, showing that validation experiments within each flock may be necessary to identify a valuable threshold within the cohort. The threshold may alter depending on the foot health of the flock, as shown in the current study with a higher percentage of unhealthy feet compared to the study by Byrne et al. (2018). Furthermore, even within our small data set we found significant differences in FT between the pure Lleyn and cross-bred animals. While ambient temperature may have an effect on FT, Byrne et al. (2018) found no influence on measured maximum FT in sheep. During the current study the mean FT was higher on test date 1, which may have been influenced by the treatment of lame sheep or a change in ambient temperature.

A threshold measure of foot temperature could be used to manage interdigital dermatitis and footrot in sheep, and minimise the occurrence of hoof lesions. The current study suggests a threshold of 26.5°C monitoring back feet could be used to detect the occurrence of hoof lesions and manage hoof health. An on-farm measure of FT in sheep flocks, such as using thermal imaging, and in particular the temperature monitoring of back feet could aid in reducing the severity of hoof lesions in commercial sheep flocks. The average FT of the back feet in the flock could be used to provide more targeted treatment as an indication to the farmer when to use a foot bath as a means of minimising hoof lesions or alternatively identifying individual animals that are more susceptible.

The study was timed to occur after the mating period for sheep, but during early pregnancy, and was limited in duration by the availability of pasture for the sheep in each group. A longer-term study incorporating different environmental conditions such as season, pasture characteristics, temperature changes and soil type would be beneficial. The regular inspection of feet and foot bathing on test date 2 may have helped manage any visible lameness of sheep during the study, along with the treatment of seven visibly lame sheep. Since the mean LS remained under 1 during the study (Table 3), including larger sheep flocks with higher incidence of lameness (i.e. average LS greater than 1) would be valuable and more feet with a severe LS of 3 or 4.

5. Conclusions

This study found that sheep FT increased with hoof lesion score (recorded lesions covered a scale of 0 to 3) and that front and back feet with a lesion score of 3 had a mean temperature of 29°C or more. The current study proposes that the mean FT of 26.5°C in back feet with a LS 1 could be used as a threshold temperature to manage flock hoof treatments before animals display gait changes due to severe lesions. Further studies in different environments and more flocks with higher lesion scores and lameness incidence would be useful.

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Author contributions

Louise Eyre, Kimberley Slinger and Matt Bell collected the data. Zoë Huggett wrote the original draft of the manuscript. Matt Bell analysed the data, edited and reviewed the manuscript, and supervised the project. Louise Eyre and Christina Siettou edited and reviewed the manuscript. All authors read and approved the final manuscript.

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Figure captions

Figure 1. Measurement of foot temperature by placing a temperature probe on the interdigital skin between the claws of the hoof.

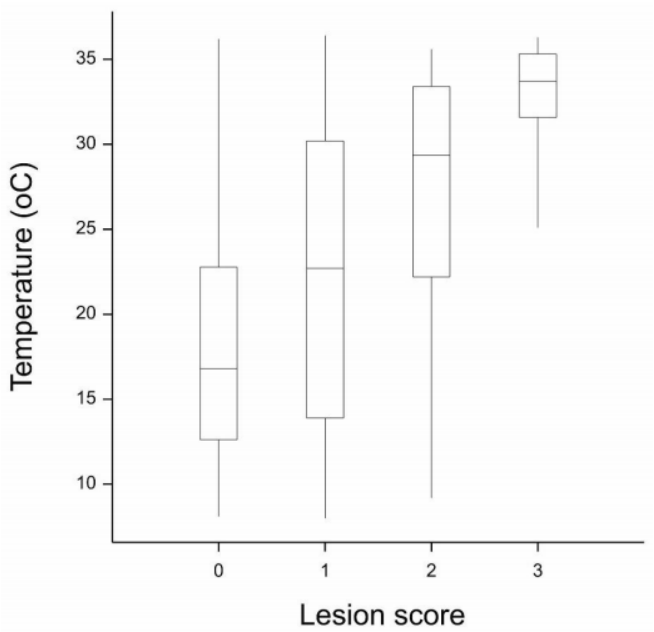

Figure 2. Box and whisker diagram showing the minimum, lower quartile, median, upper quartile and maximum foot temperatures at lesions scores 0 to 3.