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Why are sheep lame? Temporal associations between severity of foot lesions and severity of lameness in 60 sheep

J Kaler*†‡, TRN George‡ and LE Green‡

† The School of Veterinary Medicine and Science, The University of Nottingham, Sutton Bonington Campus, Leicestershire LE12 5RD, UK
‡ School of Life Sciences, University of Warwick, Coventry CV4 7AL, UK
* Contact for correspondence and requests for reprints: Jasmeet.Kaler@nottingham.ac.uk

Abstract

We investigated the temporal associations between the severity of foot lesions caused by footrot (FR) and the severity of lameness in sheep. Sixty sheep from one farm were monitored for five weeks. The locomotion of each sheep was scored once each week using a validated numerical rating scale of 0–6. All feet were then examined, FR was the only foot lesion observed; the severity of FR lesions was recorded on a scale from 0 to 4. Sheep had a locomotion score > 0 on 144/298 observations. FR lesions were present on at least one foot on 83% of observations of lame sheep but also present on 27% of observations where sheep were not lame; 95% of these sheep with a lesion but not lame had FR score 1. The results from a linear mixed model with locomotion score as the outcome were that the mean (95% CI) locomotion score of 0.28 (0.02, 0.53) in sheep with no lesions increased by 0.35 (0.05, 0.65) in sheep with FR score 1 or 2 and by 1.55 (1.13, 1.96) in sheep with FR score > 2 at the time of the observation; indicating that as the severity of the lesion increased, the severity of lameness increased. One week before an FR score > 2 was clinically apparent, sheep had a locomotion score 0.81 (0.37, 1.24) higher than sheep that did not have an FR score > 2 in the subsequent week. One week after treatment with intramuscular antibacterials the locomotion score of lame sheep reduced by 1.00 (0.50, 1.49). Our results indicate a positive association between severity of FR lesions and locomotion score and indicate that some non-lame and mildly lame sheep have footrot lesions. Treatment of even those mildly lame will facilitate healing and probably reduce the spread of infection to other sheep in the same group.

Keywords: *animal welfare, footrot, lameness, locomotion, multilevel model, sheep*

Introduction

Lameness has a considerable impact on the welfare of sheep by causing pain and discomfort (Fitzpatrick *et al* 2006). It also leads to significant production losses (Marshall *et al* 1991), eg poor body condition in ewes, which leads to production of fewer lambs and increased ewe and lamb mortality. In contrast, no lameness or lameness of a short duration and low severity, because of prompt treatment, has been associated with few ewe and lamb deaths, good body condition in ewes and fast growth rates in lambs (Wassink *et al* 2010).

Sheep farmers in the UK attribute > 90% of lameness in their sheep to footrot (FR) (Kaler & Green 2008a), with 60% presenting as interdigital dermatitis with no separation of the hoof horn (FR scores 1 or 2 [Egerton & Roberts 1971]) and 40% with interdigital dermatitis and separation of the hoof horn (FR scores 3 or 4). The strain of *Dichelobacter nodosus* and the environment play an important role in the spread and severity of FR. Warm, moist conditions soften the interdigital space and predispose sheep to interdigital damage. Skin damage facilitates invasion of *D. nodosus*, the causal agent of FR, (Beveridge 1941) leading to development of FR with a range of severities. Warm, moist conditions also facilitate survival of *D. nodosus* on pasture for 7–14 days, where it can spread from sheep-to-sheep (Beveridge 1941).

In a recent study (Kaler & Green 2008b), when farmers were shown video footage of sheep with a range of locomotion scores (Table 1; Kaler *et al* 2009), farmers could identify lame sheep of locomotion score 2 or higher with ease. However, only 50% of these farmers said that they would catch a sheep with a locomotion score of 2 with the intention of treating it when it was the only lame sheep in a group. The remaining 50% said that they would not inspect a sheep until it was lame with a locomotion score of > 2. These latter farmers considered that mildly lame sheep were not 'lame enough' to treat.

Remarkably, there has been no study to-date to investigate the relationship between lameness and FR lesions in sheep. If even mildly lame sheep have FR lesions then delaying treatment affects a sheep's welfare and productivity and might lead to progression of disease, in addition, if these sheep are infectious, delayed treatment will facilitate trans-

Table 1 Numerical rating scale for locomotion score (source: Kaler *et al* 2009) and foot footrot score (source: Egerton & Roberts 1971).

	Locomotion score						
Definitions	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Bears weight evenly on all four feet	↑						
Uneven posture, but no clear shortening of stride		↑	↑	↑	↑	↑	
Short stride on one leg compared with others		↑	↑	↑	↑	↑	
Visible nodding of head in time with short stride			↑				
Excessive flicking of head, more than nodding, in time with short stride				↑	↑	↑	
Not weight bearing on affected limb when standing				↑	↑	↑	
Discomfort when moving				↑	↑	↑	
Not weight bearing on affected limb when moving					↑	↑	
Extreme difficulty rising						↑	
Reluctant to move once standing						↑	
More than one limb affected						↑	
Will not stand or move							↑
	Footrot score						
	0	**1**	**2**	**3**	**4**		
No abnormality	↑						
Limited mild interdigital dermatitis		↑					
More extensive interdigital dermatitis			↑				
Severe interdigital dermatitis with under-running of horn, heel and sole				↑			
Severe interdigital dermatitis with under-running of horn, heel and sole and extending to wall					↑		

mission of *D. nodosus* to susceptible sheep. The aim of this paper was to test the hypotheses that: i) sheep are lame because they have temporally linked damage to the foot; ii) the severity of lameness is positively correlated with severity of lesions; and iii) a reduction in the severity of lesions is associated with a reduction in severity of lameness.

Materials and methods

Sixty, individually identified, mule, Suffolk and Roussin sheep were selected for the study. Thirty (group A) were from a group of 144 sheep where the farmer treated individual sheep when he considered them sufficiently lame using foot trimming and topical antibacterial spray; he footbathed the group with zinc sulphate (Sheep Fair, UK) once. The other thirty (group B) were from a group of 131 sheep: in this group when a sheep became lame with FR with locomotion score > 1 it was treated with long-acting oxytetracycline (Terramycin LA 200 mg ml^{-1}; Pfizer Ltd, UK) @ 1 ml 10 kg^{-1} intramuscular injection and topical oxytetracycline (Terramycin Aerosol Spray 150 ml pack, 4 g Oxytetracycline Hydrochloride 3.92% w/w; Pfizer Ltd, UK) spray within 1–3 days. These protocols were ethically approved by the Home Office as a comparison of currently used methods to treat FR and these sheep were part of a larger trial (Wassink *et al* 2010).

There was a similar distribution of sheep with respect to breed and age in both groups. Approximately 50% (29/60) of the sheep had a locomotion score > 0 at the start of the study; 16 and 13 from groups A and B, respectively. Data were collected from these 60 sheep for five weeks. Each week, the locomotion of all 60 sheep was scored by one researcher using a numerical rating scale (Table 1; Kaler *et al* 2009). Sheep were then turned and all four feet examined. All lesions on the feet were recorded. The severity of FR lesions was classified using the scoring system of Egerton and Roberts (1971); (Table 1).

All observations and scoring were carried out by one observer (JK) and recorded by another observer (TG). The data were stored in Microsoft Access® and checked for errors.

Model building and analysis

A sheep was defined as having FR if it had at least one foot with an FR lesion score > 0. The severity of FR for a sheep was defined as the highest severity score from all four feet.

The outcome variable was locomotion score at the current week. A general linear mixed model with two hierarchical levels (Goldstein 1995) with the repeated measure of week at level 1 nested within sheep at level 2 was built using MLwiN version 2.01 (Rasbash *et al* 2000) and analysed using an iterative generalised least squares procedure.

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The explanatory variables were: (i) treatment group (A or B); at each observation; (ii) a categorical variable with FR score 0, 1 or 2 or > 2; (iii) a 4-level categorical variable with category 1, FR score 0; category 2, existing case of FR (no change in footrot score between the previous and current week, and > 0); category 3, a resolved case of FR score 1 or 2 (ie sheep with FR score 1 or 2 at the previous week moving to score 0 at the current week) and category 4, a resolved case of FR score > 2 (ie sheep with FR score > 2 at the previous week and FR score ≤ 2 at the current week; (iv) a 4-level categorical variable with category 1, FR score 0; category 2, existing case of FR (no change in footrot score between the current and following week, and > 0); category 3, an incident case of FR score 1 or 2 (ie sheep with score 0 in the current week that had score 1 or 2 the following week) and category 4, an incident case of FR score > 2 (ie sheep with FR score ≤ 2 in the current week that had FR score > 2 the following week); and (v) three binary variables for treatment the previous week (no treatment versus intramuscular antibacterials, no treatment versus footbathing, no treatment versus foot trimming).

The model took the form:

$$y_{ij} = \beta_0 + \sum \beta X_{ij} + \sum \beta X_j + \nu_j + e_{ij}$$

where y_{ij} = locomotion score of sheep (j) at week (i), β_0 = constant, and βX is a vector of fixed effects varying at level 1 (i) or level 2 (j), i = 1 … 5, j = 1 …. 60 and ν_j = level 2 residual variance, e_{ij} = level 1 residual variance.

As a result of the inclusion of data from the previous week and following week, outcomes from only weeks 2, 3 and 4 were used in the model.

The model fit was checked by analysis of residuals at level 1 and level 2.

Results

It took approximately 2 h to score the locomotion of 60 ewes and 15 min to catch, turn and inspect each sheep. The sixty sheep were examined over two days each week. Complete data were available for all sheep in both groups, with the exception of two sheep that were missed on two separate occasions.

Locomotion scores and lesions

The only foot lesions on the 60 sheep over the five-week study were caused by FR.

There were 46% (136/298) of observations where there were no foot lesions on all four feet. The locomotion scores of sheep with no foot lesions were scores 0, 1 and 2 on 82, 16 and 2% of occasions, respectively.

There were FR lesions in sheep on 54% of occasions. A maximum FR severity score of 1, 2, 3 and 4 was observed on 55, 7, 27 and 12%, respectively, of these 162 occasions. Sheep had a locomotion score < 1 on 46, 0, 5 and 0% of occasions for these severities, respectively; on 14 occasions, ewes with FR lesion severity > 2 were not lame.

Number of feet affected

There were 301 feet affected with FR during the study, 46% were front feet and 54% were hind feet. On approximately 38, 24, 12 and 26% of the 89 occasions when sheep had FR score 1; there were 1, 2, 3 and 4 feet affected, respectively. Similarly, of the 11 occasions when sheep had FR score 2 there were 3, 1, 1 and 6 sheep with 1, 2, 3 and 4 feet affected, respectively. On 95% (41/43) of occasions when sheep had FR score 3 and 79% (15/19) of occasions when sheep had FR score 4, only one foot was affected; there were two feet affected on the other occasions. There was no significant association (χ^2; $P > 0.05$) between locomotion score and the number of feet affected with FR scores 1 or 2. A statistical test between locomotion and number of feet affected with FR scores > 2 could not be performed because very few sheep had more than one foot affected with FR scores > 2.

Multi-level model of factors associated with locomotion in sheep

The baseline locomotion score for a sheep with no lesions was 0.28. The mean locomotion score of sheep with an FR severity score of 1 or 2 and > 2 at the examination was significantly higher by 0.35 (0.05, 0.65) and 1.55 (1.13, 1.96), respectively, suggesting a dose effect, compared with sheep with no foot lesions, (Table 2). Sheep that had an incident case of FR score > 2 in the following week had a further raised locomotion score of 0.81 (0.37, 1.24) in the current week compared with sheep that did not have new foot lesions the following week. The locomotion score of sheep with an incident case of FR score 1 or 2 the following week was also higher at the current week but not significantly so. Prevalent cases of FR did not influence locomotion score significantly (Table 2).

The treatment of eight sheep with intramuscular antibacterials led to a significant reduction in mean locomotion score of 1.00 (0.50,1.49) the following week, compared with lame sheep that did not receive such treatment. There was no significant change in locomotion in the four sheep treated with foot trimming or those footbathed (Table 2). Having accounted for the variables above there was no significant association between groups and locomotion score.

There was a significant reduction in random variation at level 2 compared to the null model (sheep) (Table 2). In the final model, both levels (sheep and week) had significant unexplained random variation.

Discussion

This study is the first investigation of the relationship between FR lesions and locomotion in sheep and suggests that even mildly lame and some non-lame sheep have FR lesions. Considering this, not catching (and treating) mildly lame sheep could lead to poorer locomotion and an increase in the severity of FR lesions in sheep that are not treated as indicated in the current study and thus to poorer welfare. Delaying treatment could also result in a higher incidence of FR through transmission of *D. nodosus* (Beveridge 1941) to susceptible sheep.

Table 2 Two-level hierarchical linear mixed model of factors associated with the continuous outcome variable locomotion score in 60 sheep.

Variable	N	Coefficient[a]	95% CI	*P*-value
Intercept		0.28	0.02, 0.53	
Prevalence				
FR score 0	80	reference		
FR score 1 or 2	100	0.35	0.05, 0.65	0.02
FR score > 2	62	1.55	1.13, 1.96	< 0.01
Incidence				
FR score 0	73	reference		
Existing case of FR current and following week	62	–0.06	–0.21, 0.33	0.64
Incident case of FR scores 1 or 2 following week	31	0.08	–0.17, 0.33	0.53
Incident case of FR scores > 2 following week	11	0.81	0.37, 1.24	< 0.01
Resolution				
FR score 0	103	reference		
Existing case of FR previous and current week	50	0.25	–0.04, 0.54	0.10
Resolved case of FR scores 1 or 2 current week	19	0.12	–0.19, 0.43	0.48
Resolved case of FR scores > 2 current week	5	0.07	–0.52, 0.66	0.32
Treatments				
Not treated with intramuscular antibacterials	169	reference		
Treated with intramuscular antibacterials	8	–1.00	–1.49, –0.50	< 0.01
Not treated foot trimming	173	reference		
Treated foot trimming	4	–0.40	–1.02, 0.21	0.20
Not treated with footbathing	149	reference		
Treated with footbathing	28	–0.20	–0.43, 0.04	0.09
Treatment group				
Group B	90	reference		
Group A	87	–0.15	–0.40, 0.10	0.24

[a] Variance level 2 (sheep): null model 0.48 (SEM 0.10), multilevel final model 0.08 (SEM 0.04).
Variance level 1 (week): null model 0.39 (SEM 0.04), multilevel final model 0.29 (SEM 0.05).

The major contribution to a raised locomotion score was the lesion present at the time that the scoring was done. The presence of lesions one week before or after the observation did not have an additional effect on locomotion. However, sheep were more lame one week before a new case of FR score > 2 was clinically apparent. This might indicate the time delay between invasion of the inflamed interdigital skin by *D. nodosus* and clinical expression of an under-run footrot lesion (Egerton *et al* 1969). Only sheep with locomotion score > 1 in group B were treated with intramuscular antibacterials. The response to this treatment was a reduction in locomotion score within one week because of partial or complete resolution of FR. Previous studies have also demonstrated that intramuscular antibacterials are an effective treatment for FR (Kaler *et al* 2010; Wassink *et al* 2010). In contrast, there was no significant decrease in locomotion score one week after treatment with foot trimming; this might be because only four sheep were treated with this treatment and thus there was not enough power to detect a significant difference, or that foot trimming delays healing (Kaler *et al* 2010). Similarly, there was no significant association between footbathing and reduced locomotion score, which indicates the probable ineffectiveness of footbathing in resolving FR within one week. Since the current study was only five weeks in duration, it was not possible to investigate whether any of these treatments were effective after more than one week. However, a treatment such as injectable antibiotics, that is effective within a week of administration, is excellent for the welfare of these diseased sheep.

There was no significant association between cases of FR that had resolved and locomotion score; suggesting that resolved lesions probably do not contribute to residual raised locomotion score. It is possible that there was insufficient power in the current study to detect a delay in resolution of lameness after lesions have resolved, however, the coefficients were very small (0.07 and 0.12) suggesting any delay in recovery would raise locomotion scores only slightly. This highlights the rapid resolution of lameness once lesions resolve.

The locomotion scoring system did not identify all sheep with footrot lesions in the current study. Over 95% of lesions that were in sheep that had a locomotion score < 2 were FR score 1 or 2, and most were FR score 1, that is mild interdigital dermatitis. It would be ideal to have a locomotion scoring system that detected all sheep with any lesion so that treatment was given to 100% of affected sheep; however, we think it would be difficult to develop a sufficiently sensitive and specific scoring system. With the current definition of lameness as locomotion score > 1 only 3/54 inspections would have led to sheep that did not have a foot lesion being caught, if we reduced the definition to locomotion score > 0 then 22/90 (25%) sheep inspections would have been on sheep with no lesion. In addition, FR score 1 might be a temporary interdigital inflammation caused solely by *Fusobacterium necrophorum* that is indistinguishable from FR score 1 (Parsonson *et al* 1967) that is not infectious. To protect sheep welfare, locomotion score 2 and above seems a good cut-off point to determine when a sheep should be caught and examined because farmers can identify sheep lame at this score and the vast majority of sheep will have a lesion. This approach keeps sheep in good body condition (Wassink *et al* 2010) indicating that their health is not compromised.

Since sheep have to be turned to inspect the feet and the welfare impact of this is considerable, it is probably best to inspect all feet only when a flock is going to be separated by foot lesions, eg at housing or turnout or in an elimination programme.

The sample size of 60 sheep was chosen taking into account the time to catch, score and record the data and because all scoring was done by one observer, this number was practically possible. This sample size was sufficient to give statistically significant results and indicates the reliable nature of the observations and the impacts of FR and treatment. The locomotion scoring scale used in this study was validated for reliability (Kaler *et al* 2009) and the reliability of the lesion-scoring scale has recently been done; this scale is reliable when used by one observer as done in the current study (unpublished data). This approach avoided between-observer bias.

The purpose of studies such as the one presented here is to elucidate biology. A longitudinal study design was used to investigate the temporal relationship between FR and locomotion. We selected lame and non-lame sheep to study transition between the two states. This study design not only gives more causal evidence because of the correct temporal sequence of association but also allows investigation of the pattern of association over time (Twisk 2003). Although the data come from only one flock observed over time, the results are biologically plausible and they were sufficiently significant, indicating that the number of sheep and time of observation was sufficient. The treatments provide some insight into this since intramuscular antibacterials were apparently more effective than foot trimming or foot-bathing. When data have to be gathered by observation it is unlikely that sufficient resource will ever be available to collect truly generalisable results and there has to be good reason to increase the study size and duration, including the ethical concerns of using animals.

A multi-level linear mixed model where the outcome variable, locomotion score, was continuous is a reasonable choice of model when the dependent variable has a number of categories (Torra *et al* 2006) and the residuals indicate a good model fit (results not shown). These data could have been analysed by fitting an ordinal model using a proportional odds or continuation odds approach. Multinomial models allow the impact of a lesion on each locomotion score to be studied separately to test, eg whether the relationship between locomotion score 3 and an FR lesion is different from the relationship with locomotion score 1; the model fit in the current dataset suggests that this is not the case. These models also have strong assumptions, such as the proportional odds assumption (Ananth & Kleinbaum 1997) and multi-level approaches for ordinal models are less developed than linear models (O'Connell & McCoach 2008). Multinomial models generally require more data, and therefore more experimental animals, than linear models. Using this analytical approach for the current dataset gives very large odds ratios (OR) that are difficult to interpret and, not surprisingly, significant but very wide confidence intervals, however, the pattern of results remains the same; the more severe the lesions the stronger the association (larger OR) with locomotion score. There was some correlation between the presence of FR in more than one week, but these variables were not co-linear. Including explanatory variables with time lags reduced the unexplained variation in locomotion scores between sheep and ensured that the baseline group was observations with no foot lesions.

The fact that the mean locomotion score of unaffected sheep was > 0 could be as a result of injuries to the limbs or other diseases (eg mastitis) etc which were not recorded. There was also some unexplained variation between weeks of observation, and this might be a result of variation in the environment between the weeks or observer error in the measurement of the outcome or explanatory variables.

Various approaches have been used to provide a single score for a footrot lesion, these include adding scores from all four feet to give a total foot score (TFS) (Egerton & Roberts 1971), using an average foot score which is TFS/4 (Woolaston 1993), a maximum foot score (Stewart *et al* 1982) and a total weighted foot score (Whittington & Nicholls 1995). All have their advantages and disadvantages. We chose a score that reflected the most severe lesion on any foot in the current study so that we could compare maximum foot lesion severity with sheep locomotion score. There was no significant association between the number of feet affected with FR scores 1 or 2 and locomotion score, which implies that it was probably the severity of the lesion rather than the number of feet affected that had greatest influence on locomotion in the current study. However, because the majority of FR lesions scores > 2 were recorded on one foot, it was not possible to fully elucidate the relationship between the number of feet affected with FR score > 2 and locomotion score.

Animal welfare implications and conclusion

This longitudinal study on one farm provides evidence for a positive association between severity of FR lesions and severity of lameness in sheep; with a few mildly lame and some non-lame sheep having FR lesions. This suggests that locomotion scoring is a good but not perfectly sensitive indicator for the presence of lesions in sheep feet. Rather than inspecting sheep when they are markedly lame (as some farmers and veterinarians currently do [Kaler & Green 2008b]) catching and treating all lame sheep, including those mildly lame, would lead to earlier detection of milder lesions. Early and effective treatment, ie the correct dose of intramuscular antibacterials would then significantly improve the welfare of ewes and increase their health and productivity. Inspection of the feet of all sheep is required to detect all foot lesions.

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