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Factors associated with the presence and prevalence of contagious ovine digital dermatitis: a 2013 study of 1136 random English sheep flocks

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Abstract

In 2013, a questionnaire was used to gather data on risks for introduction, and factors associated with prevalence, of contagious ovine digital dermatitis (CODD). There were 1136 (28.4%) usable responses from 4000 randomly selected sheep farmers in England. CODD was present in 58% (662) of flocks, with a reported prevalence of CODD lesions of 2.3%. The geometric mean period prevalence of all lameness was 4.2% and 2.8% in CODD positive and negative flocks respectively. Factors associated with a greater risk of presence of CODD were purchasing replacement ewes, not always checking the feet of sheep before purchase, not isolating purchased sheep, foot bathing returning ewes, foot trimming the flock more than twice in the year all compared with not doing these activities and increasing log10 flock size. Farmers who vaccinated sheep with Footvax™ were less likely to report presence of CODD. Factors associated with increasing prevalence of CODD lesions were not always checking the feet of purchased sheep, flocks that mixed with other flocks and sheep that left the farm for summer grazing and later returned. In addition, flocks where farmers followed the current recommended managements for control of footrot, had a lower prevalence of CODD whilst those who used foot bathing and where feet bled during routine foot trimming had a higher prevalence of CODD. The prevalence of CODD decreased with each log10 increase in flock size. We conclude that CODD is an infectious cause of lameness in sheep of increasing importance in GB. Introduction is linked to poor biosecurity with one likely source of the pathogen being introduction of or mixing with infected sheep. As with footrot, prevalence of CODD was lower in flocks where farmers focused on individual treatment to manage lameness and avoided foot bathing and trimming feet. We conclude that most of the currently recommended biosecurity and treatment approaches to control footrot in GB are also effective for control of CODD.

Introduction

Lameness is estimated to cost the UK sheep industry between £24 and £80 million per annum (Nieuwhof and Bishop, 2005; Wassink et al., 2010). It is regarded by UK sheep farmers as the greatest concern for poor welfare in their flocks (Goddard et al., 2006). Untreated lameness has significant negative effects on bodyweight and wool growth, and reproductive and lactation performance in adults (Stewart et al., 1984; Marshall et al., 1991; Nieuwhof et al., 2008) and reduced growth rates in lambs (Wassink et al., 2010).

Contagious ovine digital dermatitis (CODD) is an infectious cause of lameness in sheep. CODD was first reported in the UK in 1997 (Harwood et al., 1997; Davies et al., 1999) and is currently (2016) not reported outside the UK. Lesions start with hair loss and ulceration at the coronary band, followed by extensive under-running of the hoof wall separating the horn from the underlying sensitive tissue (Angell et al., 2015a). Complete avulsion of the hoof horn from the soft sensitive tissue beneath is common (Naylor et al., 1998; Winter, 2008).

In 2003, 5% of sheep farmers surveyed in England and Wales confirmed the presence of CODD in their flock and a further 8% of farmers suspected that CODD was present in their flock (Wassink et al., 2003b). By 2004, 53% of English sheep farmers reported the presence of CODD in their flocks (Kaler and Green, 2008). In a 2013 survey in Wales, 35% of farmers reported that they had CODD in their flock (Angell et al., 2014).

When CODD is first introduced into a flock all ewes are naïve and an epidemic occurs with up to 50% of ewes and lambs lame (Wassink et al., 2003b). Over time CODD becomes endemic, the within farm mean endemic prevalence is reported to be 1% - 2.4% when many flocks are surveyed (Kaler and Green, 2008; Phythian et al., 2013; Angell et al., 2014). In a recent longitudinal study of six flocks (Angell et al., 2015b) there was an epidemic in one flock where prevalence rose to >20% before falling to <7% and CODD was endemic in other flocks with prevalence 0% - 7%. Although the pattern of disease with an epidemic followed by endemic disease is typical of introduction and persistence of an infectious pathogen, the cause of CODD has not been established. There is recent evidence from PCR of tissue that it is associated with the same treponemes that are associated with bovine digital dermatitis (Sullivan et al., 2015). *Dichelobacter nodosus* (Moore et al., 2005) and footrot (Angell et al., 2015b) are frequently associated with clinical cases, however, Koch's postulates have not been tested.

In the recent survey of Welsh sheep farmers, 43.5% of farmers believed that they had introduced CODD through the purchase of sheep (Angell et al., 2014). From a subset of 11 variables, two factors were associated with increased risk of presence of CODD, these were increasing flock size and presence of bovine digital dermatitis in cattle on the farm (although 1/3 of respondents did not answer the latter question). There have been no other observational studies of risks for introduction or prevalence of CODD.

Recommended control of CODD is isolation of symptomatic cases and tracing contacts so that they can be quarantined (Fraser et al., 2004). Recommended treatments are parenteral antibiotics (Duncan et al., 2011; 2012) or off-license antibiotic foot baths, the former are also recommended for treatment of footrot, both interdigital dermatitis

(ID) and severe footrot (SFR) (Kaler et al., 2010). Foot bathing appears to have been an adopted recommendation from management of digital dermatitis in dairy cattle.

The aim of the current paper was to identify risk factors associated with the presence of CODD in English flocks and risks for high prevalence of CODD in endemically affected flocks.

2: Materials and methods

2.1: Questionnaire design

A 15-page questionnaire on lameness in sheep was designed using questions from a previous study of a random sample of English sheep farmers (Kaler and Green, 2008) and additional questions based on published literature and data from farmer and adviser focus groups (personal communication). Details are presented in Winter et al., (2015). Data on the period prevalence of lameness between May 2012 and April 2013, treatment and management practices were collected. Farmers were also presented with a short description and characteristic photograph of contagious ovine digital dermatitis (Figure 1) and asked what name they used to describe the lesion and the percentage of ewes affected with that lesion in the reporting period.

2.2: Study sample and recruitment of farmers

The target study population was lowland flocks in England and a total of 4000/16000 English sheep farmers with a recorded flock size >200 ewes were randomly selected from lists provided by the Department for Environment, Food and Rural Affairs

(DEFRA) and EBLEX, (now AHDB Beef & Lamb) the levy body for beef and sheep farmers. With an expected response rate of 25% the target sample size was 1000. In May 2013, farmers were sent a letter indicating that they would receive a questionnaire within 14 days and inviting them to participate in the study. They were then sent the questionnaire with a cover letter and a free return envelope. Reminder letters were sent to non-respondents on two occasions, the second reminder contained a second questionnaire.

In 2013, 30 farmers who responded to the survey and reported high prevalence (>5%) lameness were visited as part of a follow up study on control of footrot. The first farm visited had an epidemic of CODD and so the case definition for the subsequent visits was defined to exclude flocks with CODD where possible. A proportion of lame sheep were examined on each farm. In 2014 a further 30 farmers were visited and the prevalence of lameness was assessed.

2.3: Data entry, collation and primary analysis

This is described elsewhere (Winter et al., 2015) but briefly, data were double entered and then cleaned (Winter, 2014) in Python using the Pandas, SciPy and NumPy toolkits (Oliphant, 2007; Perez and Granger, 2007; McKinney, 2010). The dataset prepared by Winter et al., (2015) was used together with further data from the same questionnaire relevant for CODD. These extra data were checked. Responses were excluded from all analyses if data on whether the farm had CODD was missing or if farmers had not provided an estimate of flock size. Questions answered by < 10% of respondents were also excluded from further analyses.

The prevalence of CODD lesions by naming / incorrectly naming CODD was plotted and compared as in Kaler and Green (2008) to investigate whether farmers recognised CODD as a specific foot lesion, whether they named it correctly or not. Then the prevalence of lameness by presence / absence of CODD was plotted.

Two datasets were formed. Dataset A included all usable responses, irrespective of whether the farmer reported CODD in their flock. Dataset B included only those flocks positive for CODD with a reported prevalence (38 farmers did not report a percentage of ewes with CODD) <7% (above the upper 95% confidence interval of the geometric mean and in line with apparent 'epidemic prevalences' in Angell et al., 2015b) to remove flocks with a probable epidemic of CODD.

Latent class analysis was used to group respondents by management of lameness and footrot (O'Kane *et al.,* accepted). Three latent classes of farmers by management type were 'best practice', 'slow to treat' 'traditional' (Supplementary Table 1); this variable was used in the analysis.

2.4: Multivariable modelling of associations between the presence and prevalence of CODD and farmer management practices

Explanatory variables were screened in MLwiN version 2.33 (Rasbash et al., 2014). Binomial logistic regression was used to model Dataset A (N = 1136) to estimate the univariable and multivariable associations between explanatory variables that were associated with the presence of CODD on farms between May 2012 and April 2013. The model took the form:

$$CODD\ present\ on\ farm_j\ in\ 2013 \sim \alpha + \beta X_j + e_j$$

where α is the intercept and ~ is a logit link function. *βXj* represents a series of explanatory variables that vary by farm *j*, and *ej* is the residual random error that follows a binomial distribution.

An over dispersed Poisson model was used to investigate factors associated with the prevalence of CODD using Dataset B (N = 556). It took the form:

$$Number\ of\ cases\ of\ CODD\ on\ farm_j\ in\ 2013 \sim \alpha + offset + \beta X_j + e_j$$

where α is the intercept and ~ is a log link function. The *offset* is the expected number of sheep with CODD in the flock, *βXj* represents a series of explanatory variables that vary by farm *j*, and *ej* is the residual random error. The model used the extra Poisson distributional assumption within MLwiN to account for over dispersion.

For both models, associations between all variables and the outcomes were assessed using Wald's test for significance; variables were considered significant when the upper and lower bounds of the 95% confidence interval did not include unity. Variables significant in the univariable analysis were tested in a multivariable model using manual forward selection (Dohoo et al., 2003). Finally, all variables regardless of their significance in the univariable analysis were retested in the final multivariable model to check for residual confounding and included in the model if significant (Cox and Wermuth, 1996). Where two variables were highly correlated the most biologically relevant was left in the model. The model fit was investigated for both multivariable models.

3: Results

3.1: Response rate and farm attributes

There were 1136 /4000 (28.4%) usable responses. Not all respondents answered all questions. The median flock size was 250 ewes (inter quartile range [IQR] 239-550). Although the target population was lowland farms, 10.2% and 2.4% were upland and hill farms respectively. There were 56 organic farms (4.9%).

3.2: Farmer reported prevalence of lameness and lesions associated with lameness

CODD was reported in 58% (662) of flocks and 637 farmers provided an estimate of the percentage of ewes with CODD lesions. Whilst 336 (50.8%) farmers did not name the lesion correctly, there was no significant difference (P=0.91) in the GM (95% CI of mean) period prevalence of CODD by correct (2.27% (2.03 – 2.54)) or incorrect (2.29% (2.06 – 2.55)) naming of lesion (Figure 2a). The distribution of CODD was highly skewed with 4 farmers reporting extremely high levels of 30 – 35% lameness, indicative of epidemics of CODD.

The geometric mean (GM) period prevalence of all lameness in ewes was 3.6% (95% CI mean: 3.54 – 3.66%). This was significantly (P<0.01) higher in flocks with CODD, 4.2% (95% CI: 4.16% - 4.24%) compared with flocks without CODD, 2.8% (95% CI: 2.75% - 2.85%), Figure 2b.

Among the 30 farmers visited in 2013, the farmer with an epidemic of CODD had >30% lame ewes. The farmer recognised and named CODD correctly. When he was revisited in 2014 the prevalence of CODD had fallen to <2% and footrot was causing 5% lameness. The correlation between the research assistant's estimate of prevalence of lameness and the farmers current estimate of lameness was >0.8 and the 2013 period prevalence of lameness was >0.7.

3.3: Farm management practices

Out of the 636 / 1136 (56%) farmers who practised routine foot trimming, 60.4% trimmed once a year, 28% trimmed twice a year and 6.5% trimmed more than twice a year; 47% reported that feet bled during routine foot trimming. Vaccination with Footvax™ was undertaken by 16.6% of respondents. A total of 60.5% of farmers footbathed ewes and 57.3% footbathed lambs. The majority (78.2%) of farmers purchased sheep and 39% of farmers had sheep that left the farm and later returned for winter grazing (69.3%) or summer grazing (36.8%). Only a few farms (4.4%) had a stocking rate of > 8 ewes per acre, with 43.4% of respondents using a stocking rate of < 4 ewes per acre and 49% using a stocking rate of 4 - 8 ewes per acre.

3.4: Multivariable binomial logistic regression model of management factors associated with the presence of contagious ovine digital dermatitis in 1136 sheep flocks in England in 2013

The frequency distributions of variables and univariable associations between the explanatory variables relating to farm management practices and the outcome (the presence of CODD in the flock) for the risk of introducing CODD into the flock are presented in Supplementary Table 2.

Results from the multivariable model (Table 1) were that farmers who purchased replacement ewes between May 2012 and April 2013 had a higher risk of CODD in their flock than farmers who did not buy in replacement ewes during that period (OR 1.93, 95% CI 1.40-2.66). Farmers who "never" or "usually" checked the feet of sheep before purchase had a greater risk of CODD in their flock compared with farmers who "always" examined the feet of sheep before purchase (OR 1.67, 95% CI 1.10-2.54) and (OR 1.52, 95% CI 1.05-2.20) respectively. Farmers who "never" isolated purchased sheep on arrival had a higher risk of CODD in their flock (OR 1.68, 95% CI 1.11-2.56) compared with flocks where new sheep were "always" isolated. Flocks foot bathed when ewes returned to the farm had a higher OR of CODD being present than flocks where returning ewes were not foot bathed (OR 1.79, 95% CI 1.12-2.86). Farmers who vaccinated sheep with Footvax™ compared with those farmers who did not were less likely to report CODD (OR 0.63, 95% CI 0.45-0.88). Farmers who trimmed their flock "more than twice" had a higher OR of having CODD present in their flocks (OR 2.26, 95% CI 1.26-4.03) in comparison with farmers who "never" routinely trimmed the feet of the sheep in their flocks. The OR of CODD being present in the flock increased with each log10 increase in flock size (OR 1.60, 95% CI 1.33-1.92).

Several variables relating to biosecurity were highly correlated, these were: checked the feet of sheep before purchase, checked the feet of sheep upon arrival at the farm, new sheep isolated on arrival and treated new sheep with ID or SFR upon arrival. Correlations between variables in the multivariable binomial logistic model are presented in Supplementary Table 3. The model fit was good (Supplementary Figure 2).

3.5: Multivariable over dispersed Poisson model of management factors associated with the prevalence of contagious ovine digital dermatitis in 556 English sheep flocks

Out of the 662 flocks with CODD, 637 farmers provided an estimate of the percentage of ewes with CODD. Flocks with a reported prevalence of CODD of > 7%

(i.e. had an epidemic outbreak of CODD) were excluded from the analysis (dotted line on Figure 2a) leaving 556 flocks. The frequency distributions of variables and univariable associations between the explanatory variables relating to farm management practices and the prevalence of CODD are presented in Supplementary Tables 4-12.

From the multivariable model, farmers who “never” or “sometimes” checked the feet of purchased sheep on arrival had a higher prevalence of CODD in their flocks compared with farmers who “always” examined the feet of sheep on arrival (RR 1.43, 95% CI 1.20-1.71) and (RR 1.23, 95% CI 1.03-1.48) respectively. Farmers whose flock mixed with other flocks or where farmers reported that they did not know whether their flock mixed with other sheep (6 flocks) had a higher prevalence of CODD (RR 1.42, 95% CI 1.11-1.82) and (RR 2.08, 95% CI 1.41-3.09) respectively. Flocks where sheep left for summer grazing and later returned had a higher prevalence of CODD (RR 1.20, 95% CI 1.04-1.39) than those flocks where sheep did not leave for summer grazing.

Flocks in the “slower to treat” and “traditional” latent classes had a higher prevalence of CODD than the “best practice” class (RR 1.34, 95% CI 1.10-1.63). Flocks where ewes were foot bathed once a week whilst they were housed had a higher prevalence of CODD than flocks not foot bathed at all (RR 1.68, 95% CI 1.27-2.22). Where sheep bled when they routinely trimmed feet there was a higher prevalence of CODD than in flocks where farmers did not routinely trim feet (RR 1.14, 95% CI 1.01-1.28). Farmers who used a mobile handling facility to catch individual lame sheep for treatment had a higher prevalence of CODD in their flock (RR 1.18, 95% CI 1.03-1.35) than farmers not using such a facility. The prevalence of CODD decreased with each log10 increase in flock size (RR 0.85, 95% CI 0.79-0.93).

Whether farmers checked the feet of sheep before purchase or on arrival at the farm, whether new sheep were isolated on arrival and whether sheep with SFR or ID were treated upon arrival were all correlated. Correlations between variables in the final model are presented in Supplementary Table 13. The model fit for the multivariable over dispersed Poisson model was good (Supplementary Figure 2).

4: Discussion

This is the first study to report factors associated with the presence and prevalence of CODD lesions in a random sample of English sheep flocks. CODD is now contributing significantly to the prevalence of all lameness in sheep in England. Flocks with CODD lesions had a significantly higher period prevalence of all lameness than unaffected flocks with 4.2% versus 2.8%; suggesting that CODD is contributing approximately 33% of all lameness.

A key finding from both models of presence and prevalence of CODD lesions was the importance of biosecurity both to prevent the introduction of CODD and to reduce the prevalence of CODD in positive flocks, for the latter, good biosecurity reduces the risk of reintroductions of CODD. Biosecurity measures linked to lower risks were not purchasing sheep at all, isolating sheep returning to the farm, avoiding use of summer grazing off the farm, preventing ewes from mixing with neighbouring flocks and examining the feet of sheep before purchase/on arrival. These variables were correlated with other variables related to the risk of contact between the flock and new or returning sheep, possibly carrying CODD. All these practices indicate that CODD is an infectious disease, that sheep are highly important for initial introduction and further introductions of CODD and that this risk can be reduced through good biosecurity. These same managements were investigated in association with farmer estimates of prevalence of overall lameness (Winter et al., 2015). In that paper, where footrot was the dominant cause of lameness, isolation of sheep for >21 days was associated with a lower overall prevalence of lameness. Whilst never isolating new stock was associated with an increased risk of CODD in the flock, a specific duration of isolation was not associated with a lower risk of presence of CODD. Anecdotally, farmers have reported CODD emerging many months after the purchase of sheep. The incubation period of CODD is currently not known, the current data and farmer anecdotes indicate that it is probably greater than 21 days.

Foot bathing sheep when they returned to the farm was associated with a higher risk of presence of CODD in the flock. This suggests that foot bathing alone does not reduce the risk of introduction of CODD and that other activities including isolation and inspection of feet are more effective. Foot bathing during housing was associated with a higher prevalence of CODD in positive flocks. This could be because farmers were foot bathing sheep in response to a high prevalence of CODD (some farmers have been advised to use antibiotic in foot baths, although this is not licensed) instead of using more appropriate systemic treatments as reported for CODD and footrot (Duncan et al., 2014; Winter et al., 2015). Foot bathing did not provide as good a control of CODD as parenteral treatment of affected individuals. This is probably for similar reasons to those for footrot; the footbathing agent will not contact bacteria deep in the epidermis and topical treatment only removes superficial bacteria.

In contrast to foot bathing, flocks managed with best practice to treat lameness (Supplementary Table 1) compared with “slower to treat” and “traditional” had a lower prevalence of CODD. This indicates that farmers who practised rapid treatment of lame sheep, recommended for control of footrot (Wassink et al., 2010; Winter et al., 2015) had an effective tool that also lowered the prevalence of CODD. One explanation for this is that CODD is intimately linked to footrot with many sheep with CODD also affected with footrot (Angell et al., 2015b; Winter et al., 2015) but CODD is also most likely bacterial in origin and so systemic antibiotics are an effective treatment.

Using mobile handling facilities is linked to a longer interval between treatments (Winter et al., 2015). This probably explains the association with a higher prevalence of CODD because a longer inter-treatment interval increases the duration of CODD in untreated affected sheep and the incidence of CODD from spread to susceptible sheep.

Many previous studies have reported that flocks which are routinely foot trimmed have a higher prevalence of lameness than flocks which are not routinely foot trimmed and that there is a dose dependent relationship between the frequency of routine trims and the risk of lameness (Grogono-Thomas and Johnston, 1997; Wassink et al., 2003a, 2004; Wassink et al., 2005; Kaler and Green, 2009). Although few, farmers who practised routine foot trimming of their flock more than twice per annum had a greater risk of CODD present in their flocks than farmers who did not routinely trim the feet of their flock between May 2012 and April 2013. This seems an unusual association but one hypothesis is that such trimming increases the risk of successful introduction of CODD by making these sheep more vulnerable through damage to the feet or by using contaminated equipment if an outside contractor trimmed the feet (Sullivan et al., 2014).

Previous studies have highlighted an association between routine foot trimming and a higher flock prevalence of lameness (Wassink et al., 2003a; Kaler and Green, 2009). In the current dataset a higher prevalence of all lameness (the majority being footrot) was associated with farmers trimming feet and causing them to bleed (Winter et al., 2015). The current paper is the first study to report an association between routine foot trimming with bleeding and higher flock prevalence of CODD lesions. This might indicate that trimming sheep feet and causing bleeding with CODD delays healing or increases the spread of CODD between sheep, however, it might be that causing feet to bleed increases the prevalence of lameness overall and that some of this is attributed to CODD in positive flocks. Whatever the cause it is reasonable to conclude that over trimming feet of sheep and causing bleeding negatively impacts on all causes of lameness including CODD. There is increasing evidence that routine foot trimming is a practice best avoided.

Footvax™ (MSD Animal Health) is a licensed vaccine against footrot. It has limited efficacy (Glenn et al., 1985; Hindmarsh et al., 1989; Lewis et al., 1989; Morck et al., 1994; MSDAnimalHealth, 2014) but is recommended as part of the control programme for footrot. For reasons that are unclear, vaccination using Footvax™ has been associated with reduced incidence of CODD within one flock, with a reported efficacy of 32% (Duncan et al., 2012). A reduction in prevalence of CODD was not detected in the current study, however, there was a reduced risk of CODD being present on the farm in flocks that were vaccinated against footrot (50.8% versus 59.8% affected). The reasons for this are unclear but it could be that there is some protection offered from vaccination that reduces susceptibility to CODD, by protecting against footrot, however, it could be a marker for some other management activity.

As with many infectious diseases of livestock (e.g. tuberculosis) the risk of introduction and presence of CODD was higher as flock size increased (also reported by Angell et al. (2014)) but the prevalence of CODD in positive flocks was lower as flock size increased. This indicates that there is some density dependency in the system. Larger flocks are more likely to have more risky events that might lead to introduction of CODD and, because there are more susceptible animals, each event is more likely to be successful for introduction of CODD, so cumulatively larger flocks are at greater risk of introduction of CODD. It is not clear why the prevalence of disease is proportionately lower as flock size increases. One argument is that farmers underestimate percentages when each percentage is a large number of animals, but there are other biological arguments e.g. the flock is more likely to be segregated, there will be a full time shepherd so treatment and biosecurity might be more prompt and standardised.

Angell et al., (2014) reported an association between cattle with digital dermatitis and increased risk of CODD in a flock and a recent study from the same research group reported that the pathogenic treponemes detected in bovine digital dermatitis are present in cases of CODD (Sullivan et al., 2015). The current study did not investigate the role of other livestock species, however, the results from the present study provide evidence that whatever the role of cattle, CODD is a disease of sheep with sheep to sheep transmission; this was also suggested by farmers in Angell et al. (2014).

The accuracy of the estimated period prevalence of CODD within flocks is difficult to validate. The overall distribution of estimates is characteristic of the anecdotal descriptions of CODD as an epidemic falling to a largely endemic situation. The small number of flocks (4) experiencing an epidemic would fit with the fact that the proportion of English sheep flocks positive for CODD has only increased slightly from 53% in 2004 to 58% in 2013. This is interesting given its infectious nature and lack of endemicity compared with footrot (present in >90% flocks (Kaler and Green, 2008). CODD is still being introduced into naïve flocks; the farmers contacted in 2013 were also asked to complete a questionnaire in 2014. Over 880 farmers completed the second questionnaire (personal communication) and CODD was reported for the first time in a small number of naive flocks. It is not clear why the spread of CODD is now so slow but it might be because of heightened awareness among farmers; 51% correctly named CODD in 2013 compared with 36% in 2004 (Kaler and Green, 2008) and therefore more precautions are being taken.

The very high prevalence of CODD in some flocks (Figure 2b) is typical of the epidemic phase; the low endemic prevalence of lesions does suggest a better immune response than that seen in footrot in sheep and different from bovine digital dermatitis where 10 – 15% prevalence is reported (e.g. Holzhauer et al., 2006). A cut off of >7% prevalence of CODD lesions was decided as a flock probably in an epidemic phase of CODD because this was above the upper 95% CI of the mean of flocks and so unlikely to be flocks in an endemic state. These flocks were removed because there were so few and so detection of managements linked to the epidemic phase when whole flock susceptibility would be driving the force of infection was not possible. The multivariable model of prevalence therefore gives an indication of which managements are effective at minimising the prevalence of CODD in an endemic situation. The associations between managements and prevalence of CODD are dependent on farmer recall of the period prevalence of CODD. The graphical representation of prevalence with an overdispersed Poisson distribution is typical of many infectious diseases and adds credibility to the distribution of reported prevalence.

This study relied on farmer recognition of CODD and ability to recall the percentage of ewes affected over one calendar year. The distribution of prevalence of CODD (Figure 2a and 2b) is very similar between correct and incorrect naming. This indicates as in Kaler and Green (2008) and Winter et al., (2015) that farmers recognise CODD but do not necessarily name it correctly. It is, however, possible that farmers are misclassifying CODD. If random misclassification has occurred then the estimated prevalence of affected flocks would be incorrect and the random error of the study would be high; factors significantly related to presence / prevalence of CODD would be incorrectly considered non-significant (a type 2 error). If farmers' responses were biased then the estimated prevalence would be incorrect and error would be non-random and associations between variables could be higher or lower than those estimated in the current analyses. Ideally correct diagnosis and prevalence of CODD lesions would be externally validated by visiting and inspecting a large number of flocks, unfortunately, as with many endemic disease studies, this was not feasible in the current study.

This study is a retrospective questionnaire and so has limitations. The usable response rate (29%) was comparable to both that of Kaler and Green (2009) (27%) and Angell et al. (2014) (25.6%). As a consequence of the study design, cause and effect might be temporally confounded (Bradford Hill, 1965). However, the retrospective observational studies of footrot in GB (Wassink et al., 2003a, 2004) were criticised for temporal confounding (Abbott et al., 2003), but over time the results have been repeated in several other studies and there was no temporal confounding. The weight of evidence has grown for improved management of footrot, most recently reported in Winter et al., (2015) but all based on the first hypothesis generating paper. In addition, the fact that CODD is an infectious cause of lameness means that some information on good management of footrot can be considered as supporting evidence for a role in control of CODD by analogy (Bradford Hill, 1965). The best use of results from the models in this paper is as indications for managements to reduce the risk of introduction of CODD and to aid control of CODD in positive flocks. As such they are useful for veterinarians and farmers and for researchers to identify hypotheses for future research.

Conclusions

Contagious ovine digital dermatitis is an infectious cause of lameness in sheep of increasing importance in GB. CODD is now present in approximately 58% English sheep flocks. It is responsible for approximately 33% of lameness in affected flocks where the geometric mean is 4.2% versus 2.8% in unaffected flocks. Introduction of CODD is linked to poorer biosecurity and the most likely source of the pathogen is exposure to infectious sheep. Prevalence of CODD is lower in flocks where farmers focus on individual treatment of lame sheep rather than foot bathing. As with footrot, foot trimming sheep and causing bleeding is associated with a higher prevalence of CODD and so should be avoided. We conclude that the current recommended biosecurity and treatment approaches to control footrot in GB are also effective for CODD.

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Figure 1: Investigating farmer naming and prevalence of contagious ovine digital dermatitis

What you might notice when you look at the foot	Example picture of the lesion	7. What did you call this lesion? *Circle only one answer in each box below*	8. Did you see this lesion in your flock between May 2012 and April 2013? *Circle one answer and fill in % for each box below*
• Abnormal at coronary band (top of foot) • Loss of hair above coronary band • There may be complete detachment of hoof		**Footrot** **Scald** **CODD** **Shelly hoof** **Other *(please state)***	**Yes** ***If yes,* what percentage of ewes had this lesion?___________%** **No** **Do not know**

Figure 2a: Bar chart of the percentage of ewes with contagious ovine digital dermatitis (CODD) lesions by farmers who correctly named CODD lesions and those who incorrectly named CODD. Differences were not significant

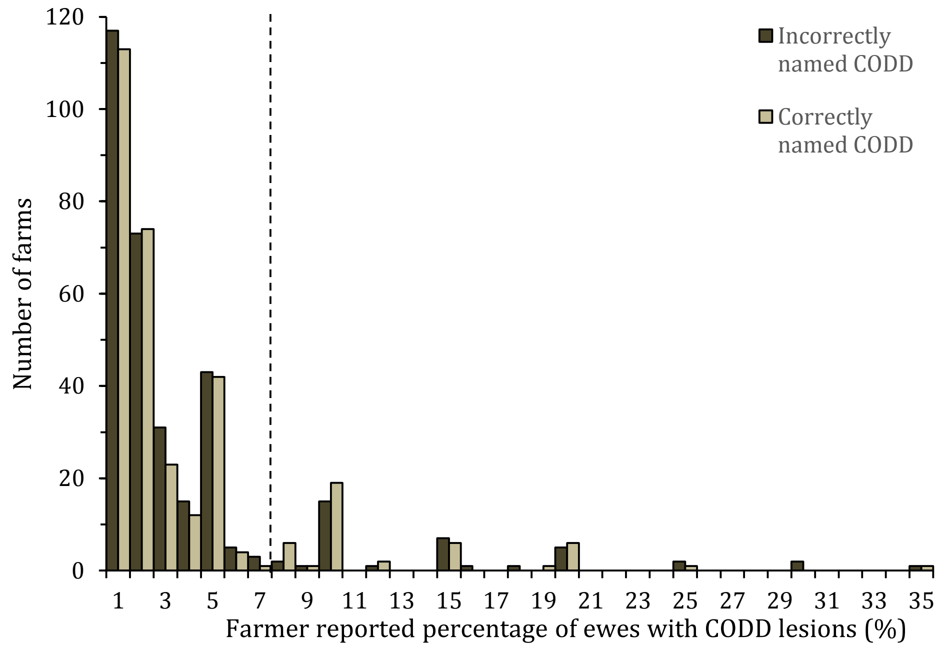

Figure 2b: Bar chart of farmer reported period prevalence of lameness in 1136 flocks by presence and absence of contagious ovine digital dermatitis

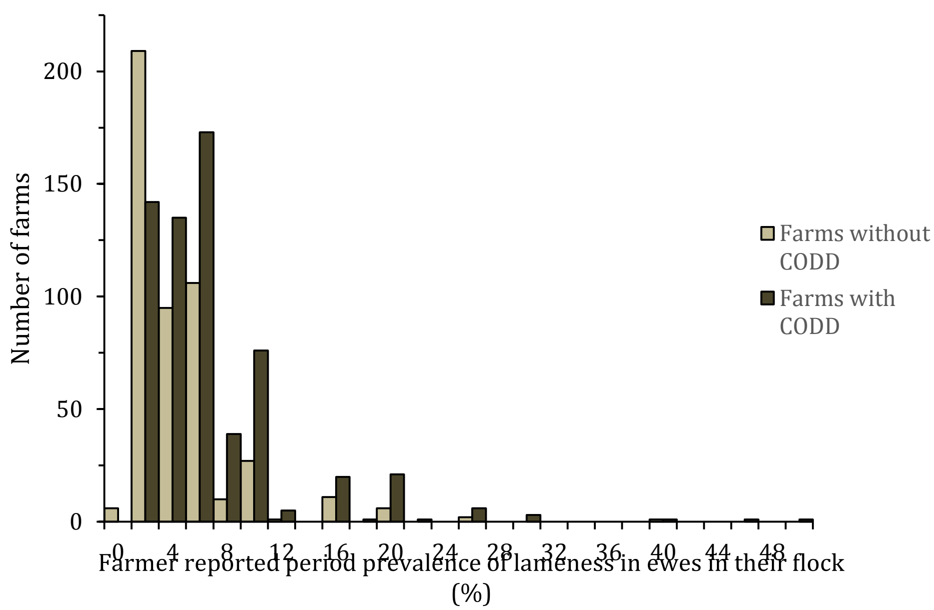

Table 1: Multivariable logistic binomial regression model of factors associated with the presence of contagious ovine digital dermatitis in 1136 sheep flocks in England between May 2012 and April 2013.

Variables		All responses N	All responses %	Flocks with CODD N	Flocks with CODD %	Odds Ratio	95% CI	
Source of replacement ewes								
Homebred		474	41.7	234	49.4	1.00		
Purchased		662	58.3	438	66.2	**1.93**	**1.40**	**2.66**
Check the feet of sheep before purchase								
Always		317	27.9	171	53.9	1.00		
Usually		239	21.0	159	66.5	**1.52**	**1.05**	**2.20**
Sometimes		159	14.0	92	57.9	1.06	0.70	1.59
Never		173	15.2	119	68.8	**1.67**	**1.10**	**2.54**
Did not purchase		235	20.7	114	48.5	0.75	0.35	1.63
Did not answer		13	1.1	7	53.9	0.90	0.28	2.93
Isolation of new sheep on arrival								
Always		499	43.9	285	57.1	1.00		
Usually		162	14.3	101	62.4	1.20	0.82	1.77
Sometimes		92	8.1	59	64.1	1.43	0.87	2.33
Never		142	12.5	96	67.6	**1.68**	**1.11**	**2.56**
No new arrivals		212	18.7	106	50.0	2.03	0.93	4.41
Did not answer		29	2.6	15	51.7	1.71	0.66	4.43
Time at which ewes were foot bathed								
Sheep returning to farm	No	1039	91.5	594	57.2	1.00		
	Yes	97	8.5	68	70.1	**1.79**	**1.12**	**2.86**
Vaccination with Footvax								
All ewes at least once per year	No	945	83.2	565	59.8	1.00		
	Yes	191	16.8	97	50.8	**0.63**	**0.45**	**0.88**
Frequency of routine foot trimmings per year								
Never		476	41.9	274	57.6	1.00		
Once		384	33.8	207	53.9	0.91	0.68	1.22
Twice		178	15.7	110	61.8	1.36	0.93	1.98
More than twice		74	6.5	55	74.3	**2.26**	**1.26**	**4.03**
Did not answer		24	2.1	16	66.7	1.50	0.60	3.75
Flock size								
Log 10 flock size		1136	100.00	662	58.27	**1.60**	**1.33**	**1.92**

N: Number of farms, **%:** Percentage of farms, **95% CI:** 95% Confidence Intervals

Odds Ratios which are significantly different from the baseline (according to Wald's test for significance) at 0.05 are marked in **Bold**

Table 2: Multivariable over-dispersed Poisson model of factors associated with the period prevalence of CODD lesions in 556 English sheep flocks between May 2012 and April 2013

Variables		All responses N	%	Prevalence of CODD (%)	Risk Ratio	95% CI	
Check the feet of new sheep on arrival							
Always		141	25.4	1.73	1.00		
Usually		137	24.6	1.68	1.09	0.93	1.27
Sometimes		74	13.3	1.89	**1.23**	**1.03**	**1.48**
Never		97	17.4	2.15	**1.43**	**1.20**	**1.71**
No new arrivals		101	18.2	1.55	1.06	0.89	1.26
Did not answer		6	1.1	1.46	0.96	0.55	1.65
Sheep mix with neighbouring flocks							
No		509	91.5	1.72	1.00		
Yes		25	4.5	2.35	**1.42**	**1.11**	**1.82**
Do not know		6	1.1	3.38	**2.08**	**1.41**	**3.09**
Did not answer		16	2.9	1.82	0.93	0.68	1.27
Sheep leave the farm and later return							
For summer grazing	No	465	83.6	1.75	1.00		
	Yes	91	16.4	1.87	**1.20**	**1.04**	**1.39**
Latent Class Membership							
Latent Class 1: Best practice		65	11.7	1.34	1.00		
Latent Class 2: Slower to treat		196	35.3	1.82	**1.34**	**1.10**	**1.63**
Latent Class 3: Traditional		295	53.1	1.83	**1.34**	**1.10**	**1.63**
Frequency of routine foot bathing of ewes when housed							
Did not footbath at all		190	34.2	1.60	1.00		
Did not routinely footbath ewes when housed		170	30.6	1.79	1.06	0.91	1.23
Did not house ewes		86	15.5	1.75	1.08	0.90	1.29
Once a week		15	2.7	2.49	**1.68**	**1.27**	**2.22**
Once a fortnight		23	4.1	2.00	1.21	0.93	1.58
Once a month		62	11.2	2.05	*1.19*	*1.00*	*1.43*
Did not answer		10	1.8	1.71	0.94	0.61	1.44
Sheep bleed during routine foot trimming							
Did not trim		233	41.9	1.69	1.00		
Foot trim sheep do not bleed		31	5.6	1.47	0.81	0.62	1.07
Foot trim and sheep bleed		281	50.5	1.86	**1.14**	**1.01**	**1.28**
Did not answer		11	2.0	2.00	1.03	0.69	1.54
Method of catching individual lame sheep							
Mobile handling facility	No	448	80.6	1.75	1.00		
	Yes	108	19.4	1.81	**1.18**	**1.03**	**1.35**
Organic status							
Not organic		526	94.6	1.79	1.00		
Organic		25	4.5	1.31	**0.71**	**0.50**	**1.02**
Did not answer		5	0.9	1.50	0.94	0.50	1.78
Flock size							
Log10 flock size		556	100.0	1.76	**0.85**	**0.79**	**0.93**

N: Number of farms, **%:** Percentage of farms, **95% CI:** 95% Confidence Intervals, **Prevalence of CODD:** Geometric mean percentage of ewes with CODD (%) **Risk Ratios** which are significantly different from the baseline (according to Wald's test for significance) at 0.05 are marked in **Bold**, whilst those in ***Italics*** are significant at 0.1