Introduction

Lameness in sheep is one of the most important economic and welfare issues for the UK sheep industry [1]. Estimates of on farm prevalence vary, as lameness will vary throughout the year, but recent studies suggest 4.9% of the UK sheep flock (or 1.75 million sheep) are lame at any one time [2]. Considering labour costs, loss of production, culling and treatment costs, this potentially equates to losses of an estimated £24- 80 million annually [3; 4] to the UK sheep industry. The welfare cost of lameness to the animals is also significant: Lame animals will be in pain, which can be chronic and prolonged, depending on the promptness and efficacy of farm interventions.[5] They are also at risk of concurrent disease such as flystrike (Figure 1), metabolic disease and nutritional deficit, all of which will also affect the welfare of any dependent lambs.

The infectious foot diseases, footrot and contagious ovine digital dermatitis (CODD), are the principle causes of sheep lameness in the UK [6] and therefore should be the first priority for lameness control in flocks. Fortunately, these two diseases have many common features in terms of microbial aetiology, transmission routes and epidemiology, which enable a simple holistic approach to their control on farms by veterinarians and farmers.

Clinical presentation

Footrot and scald had previously been considered as separate disease entities. However, it is now widely recognised that they are part of the same disease spectrum[7]. Scald or interdigital dermatitis (ID) is the earliest stage of footrot where the interdigital skin is inflamed, but without horn separation (Figure 2). As footrot progresses, there is separation of the hoof horn typically commencing at the medial sole and advancing axially and onto the sole (Figure

3). There is usually an accompanying distinctive pungent smell, grey discharge and varying degrees of lameness. Four and five point footrot scoring systems are available to describe different clinical footrot disease presentations [8].

CODD clinical presentation has also been described by a five point scoring system (Figure 4) [9]. This scoring system reflects the progressive nature of the disease from an inflammatory lesion at the coronary band, to progressive separation of the horn capsule extending from the coronary band distally, resulting in complete horn capsule avulsion. CODD is known to cause a more severe lameness in sheep, with foot pathology extending into osteitis of the pedal bone (Figure 5).

Aetiology

Both footrot and CODD have a bacterial aetiology. The primary cause of footrot is invasion of the epidermal tissue by *Dichelobacter nodosus* [10]. There are 10 different serogroups of *Dichelobacter nodosus,* based on the fimbrial antigen, and multiple serogroups can be present on one farm or sheep [11]. The bacteria are classified into benign or virulent strains, depending on proteases present, although most strains on UK sheep farms are classed as virulent. During footrot development the load of *Dichelobacter nodosus* is much higher in the early, ID stage, which is therefore a highly infective stage, whereby bacteria are shed onto the pasture and bedding [7]. *Fusobacterium necrophorum* is also associated with footrot, but is considered a secondary pathogen to *Dichelobacter nodosus* contributing to the severity of the disease [12].

The treponeme bacteria are strongly associated with CODD, specifically three members of the Treponema genus, namely *Treponema medium*-like, *Treponema phagedenis*-like and *Treponema pedis*. Studies of CODD feet and healthy feet also identified *Dichelobacter*

nodosus and *Fusobacterium necrophorum* in many CODD lesions [13] . Currently, the precise aetiology and role of the different consortia of bacteria identified in CODD lesions is unclear, however the treponemes are considered as a necessary cause of disease [13].

Transmission

Understanding pathogen transmission routes informs farm management control strategies aimed to prevent the spread of infectious foot disease both between and within farms. Recent research work on *Dichelobacter nodosus* and the digital dermatitis treponeme bacteria has identified some useful similarities in their transmission pathways. *Dichelobacter nodosus* can be found in healthy sheep's feet, diseased feet (highest at ID stage) [14]; it can also survive on soil for up to 30 days (depending on temperature and soil type) [15]; and be isolated from hoof trimming equipment, workers hands and hoof clippings [16]. The digital dermatitis associated treponemes in CODD have been isolated from foot lesions from diseased sheep, cattle, goats and wild elk; also from fresh faeces, slurry, hoof trimming equipment and gloves [17]. In most of these studies the infective dose of bacteria required to produce foot disease was not established, therefore the precise role of different sources of infection in disease transmission cannot be categorically stated, however the data does provide very useful guidance for appropriate farm management interventions to prevent disease spread.

Epidemiology

Footrot is present in 80-95% of UK flocks. The prevalence of footrot does vary throughout the year. One longitudinal study of 6 farms reported a mean prevalence of 5.0% (95%CI 3.2-6.8%) and a range of 0-20.5%[18]. Risk factors for footrot infection have been clearly described in a

number of recent publications and reviewed by Caetano[12]. Risk factors provide the veterinarian with an evidence base to inform farm management interventions. These will be considered at the end of the article.

Factors that increase the risk of a sheep having footrot are:

- Foot trimming (when bleeding is caused)
- Wet, muddy, under foot conditions
- Poor foot confirmation
- Large flock size
- Increase stocking rates
- Seasonal trend observed (spring and late summer/early autumn)
- Longer sward

Factors that decrease the risk of footrot are:

- Vaccination with Footvax
- Early detection and treatment (within 3 days)
- Separating lame sheep from healthy sheep during treatment
- Breeding replacements from non-lame sheep
- Culling sheep lame ≥2 times within one year
- Quarantine period over 21 days
- Foot bathing to treat/prevent ID

Evidence suggests that CODD occurs on between 35-58% of UK farms. Again, the amount of disease on farms will vary throughout the year. Typically, farmers report disease prevalence to be around 2% but levels of up to 50% of sheep affected are recorded [19]. Epidemiological studies have identified a number of risk factors associated with disease prevalence and which have important implications for CODD control[20].

Factors that increase the risk of a sheep having CODD are:

- Lowland pasture, lush pasture, poached pasture
- Seasonal (spring and late summer/early autumn)
- Large flock size
- Cattle on farm with digital dermatitis
- Biosecurity practices
    - Purchasing replacement ewes
    - Not checking feet on arrival
    - Not isolating sheep on arrival
    - Not foot bathing sheep on arrival
- Footrot
- Foot trimming

Factors that decrease the risk of a sheep having CODD are:

- Vaccination with Footvax
- Following current recommendations for footrot

Treatment

There is a reasonable evidence base for the treatment of footrot. Veterinarians can choose between topical and systemic antibiotics, and non-antibiotic footbaths (Table 1). However, the evidence base is strongly in favour of prompt treatment (within 3 days) with injectable antibiotics and a topical antibiotic foot spray [21], and does not support whole flock treatments[22; 23]. Efficacy of non-antibiotic footbaths is strongly influenced by foot bathing technique, which can be difficult to apply correctly with large numbers of sheep, wet underfoot conditions and inadequate facilities. Current advice is that when correctly undertaken, foot bathing can be beneficial as a general foot hygiene measure, as a

120 preventative measure, and in the early stages of footrot (ID). Foot trimming is not
121 recommended for lame sheep as it delays and reduces the probability of healing, and risks
122 the spread of infection[21].
123

Treatment	Follow Up Period	Proportion of Sheep Recovered
Oxytetracycline LA [24]	3 Weeks	79.3%
Oxytetracycline LA[25]	6 Weeks	89-100%
Amoxicillin LA [26]	9 Weeks	80.4%
Gamithromycin [24]	3 Weeks	93.7%
Zinc Sulphate Footbath[25]	6 Weeks	77%

124
125 **Table 1: Comparison of proportion of sheep recovered from footrot following different**
126 **treatment strategies**
127 Being a relatively new disease, the evidence base for CODD treatment is more limited.
128 However, as with footrot, prompt treatment with systemic antibiotics is also advised in order
129 to improve sheep welfare and reduce the spread of infectious agents. Similarly whole flock
130 antibiotic treatments are not recommended[22; 23]. A summary of the current evidence base
131 for treatment is given in table 2.
132

Treatment	Follow Up Period	Proportion of Sheep Recovered
Amoxicillin LA[26]	9 Weeks	71%
Chlortetracycline Footbath [27]	3 Weeks	52.7%
Tilmicosin (2 doses regime)[22]	7 Weeks	100%

Table 2: Comparison of proportion of sheep recovered from CODD following different treatment strategies

Control of Infectious Lameness

History and Clinical Examination

As with any disease situation, the core principles of taking a detailed farm history and performing a thorough clinical examination of a representative number of animals in the flock together with an inspection of the farm environment are the essential basis of any control plan.

The history should include:

- Estimate of the numbers of animals affected
- Duration of the problem
- Farm risk factors
    - Seasonality
    - Assessment of housing conditions
    - Assessment of field conditions
- Culling policy

- Biosecurity policy
- Current control policy
    - Treatments (dosage, administration technique, drug)
    - Foot trimming
    - Vaccinations (storage, administration technique, dosage used)
    - Foot bathing (facilities, chemical used, technique)

The Five Point Plan for the Control of Infectious Lameness

The Five Point Plan[28] is the sheep industry recognised framework for the control of infectious foot disease and provides a useful basis for the construction of a farm specific control plan. It consists of the following elements that will be considered in turn.

1. Prompt detection and treatment of lame sheep
2. Vaccination with Footvax (MSD)
3. Biosecurity for incoming stock (Quarantine)
4. Farm Hygiene (Avoid)
5. Culling of chronically lame sheep

1. Prompt Detection and Treatment

This should be the corner stone of any infectious foot disease plan, both from a sheep welfare as well as from an infection control perspective. As discussed, systemic antibiotics (plus topical treatment) are the recommended option in clinical cases. In addition, affected animals should be isolated where practically possible to enable monitoring for clinical cure, enable repeat treatments and reduce disease spread. Although whole flock treatments are not advised, group treatments are often necessary.

2. Vaccination

The multivalent vaccine against footrot (Footvax MSD) is a very useful tool in infectious foot disease as it has proven efficacy against both footrot as well as to a lesser extent CODD (about 30%)[26]. Vaccination protocols are tailored to each farm; however, in general, vaccination is usually repeated twice yearly and in advance of risk periods. For this reason, many farmers find post shearing (in advance of a warm wet summer) and post scanning (well in advance of a planned increase in stocking density around lambing time) to be practical and effective times to schedule vaccinations.

3. Farm Hygiene

Based on our current knowledge of transmission routes and the epidemiology for both footrot and CODD, control strategies should include;

- prompt treatment and isolation of affected sheep at the earliest stages of disease
- biosecurity measures for all incoming stock avoidance of hoof trimming, and cleaning and disinfection of equipment and hands
- promotion of good underfoot hygiene by employing measures such as
    - resting fields (current advice is for 14 days for footrot)
    - avoiding poaching of fields by moving field furniture, monitoring stocking rates, improving drainage around gateways and areas of high traffic (Figure 6)
    - ensuring clean, dry, disinfected housing (Figure 7)
    - cleaning and disinfection of handling areas after use (Figure 8)
    - consider risks of co-grazing

4. Biosecurity

- Isolate brought in sheep for a minimum of 3 weeks
- Check feet on arrival as not all sheep with foot lesions are lame (up to 30 %)
- Return clinically affected sheep to vendor or treat the whole group until clinical cure achieved (no guarantee of bacteriological cure)

- Vaccinate incoming animals if this is part of flock policy
- Disinfectant footbath as general hygiene measure

5. Culling policy

Culling repeat cases of infectious foot disease has a number of benefits. It reduces the infection burden in the flock, reduces the welfare impact on chronically lame animals, and if the flock breeds its own replacement animals, then will prevent breeding from footrot susceptible animals.

Conclusion

Infectious foot disease remains a significant welfare and economic issue for many flocks. Thanks to recent research, veterinarians have sound evidence upon which to base their advice to farmers. Control plans should be tailored to individual farms but prompt individual treatment should be the corner stone of any advice, whilst the Five Point Plan provides a very useful framework for a holistic farm approach.

Key Points

- Footrot and CODD are the most important causes of lameness in sheep in the UK
- Footrot and CODD are different, yet strongly associated in terms of microbial aetiology, epidemiology and transmission routes.
- A holistic approach to lameness control is necessary to target footrot and CODD together.
- Prompt individual treatment with systemic antibiotics is an essential step in controlling infectious foot disease.
- The Five Point Plan provides a useful framework to devise holistic control plans

References

1. Phythian CJ, Michalopoulou E, Jones PH, Winter AC, Clarkson MJ, Stubbings LA, Grove-White D, Cripps PJ, Duncan JS. 2011. Validating indicators of sheep welfare through a consensus of expert opinion. Animal : an international journal of animal bioscience. 5(6):943-952.

2. Winter JR, Kaler J, Ferguson E, KilBride AL, Green LE. 2015. Changes in prevalence of, and risk factors for, lameness in random samples of english sheep flocks: 2004–2013. Preventive veterinary medicine. 122(1):121-128.
3. Wassink GJ, King EM, Grogono-Thomas R, Brown JC, Moore LJ, Green LE. 2010. A within farm clinical trial to compare two treatments (parenteral antibacterials and hoof trimming) for sheep lame with footrot. Preventive veterinary medicine. 96(1-2):93-103.
4. Nieuwhof GJ, Bishop SC. 2005. Costs of the major endemic diseases of sheep in great britain and the potential benefits of reduction in disease impact. Animal Science. 81(23-29).
5. Angell JW, Cripps PJ, Grove-White DH, Duncan JS. 2015. A practical tool for locomotion scoring in sheep: Reliability when used by veterinary surgeons and sheep farmers. Veterinary Record. 176(20):521-523.
6. Kaler J, Green LE. 2008. Naming and recognition of six foot lesions of sheep using written and pictorial information: A study of 809 english sheep farmers. Preventive veterinary medicine. 83:52-64.
7. Green L, Clifton R. 2018. Diagnosing and managing footrot in sheep: An update. In Practice. 40(1):17-26.
8. Egerton JR, Roberts DS. 1971. Vaccination against ovine foot-rot. Journal of Comparative Pathology. 81(2):179-185.
9. Angell JW, Blundell R, Grove-White DH, Duncan JS. 2015. Clinical and radiographic features of contagious ovine digital dermatitis and a novel lesion grading system. Veterinary Record. 176(21):544-552.
10. Beveridge WIB. 1941. Foot-rot in sheep: A transmissible disease due to infection with *fusiformis nodosus* (n. Sp.); studies on its cause, epidemiology and control. The Commonwealth Scientific and Industrial Research Organisation, Australian Bulletin. 140(1):1-64.
11. Moore LJ, Wassink GJ, Green LE, Grogono-Thomas R. 2005. The detection and characterisation of *dichelobacter nodosus* from cases of ovine footrot in england and wales. Veterinary microbiology. 108(1-2):57-67.
12. Caetano P BE, Branco S 2018. Reviewing footrot in sheep. Journal of Veterinary Science & Animal Husbandry. 6(4).
13. Sullivan LE, Clegg SR, Angell JW, Newbrook K, Blowey RW, Carter SD, Bell J, Duncan JS, Grove-White DH, Murray RD et al. 2015. High-level association of bovine digital dermatitis treponema spp. With contagious ovine digital dermatitis lesions and presence of fusobacterium necrophorum and dichelobacter nodosus. Journal of clinical microbiology. 53(5):1628-1638.
14. Witcomb LA, Green LE, Kaler J, Ul-Hassan A, Calvo-Bado LA, Medley GF, Grogono-Thomas R, Wellington EMH. 2014. A longitudinal study of the role of *dichelobacter nodosus* and *fusobacterium necrophorum* load in initiation and severity of footrot in sheep. Preventive veterinary medicine. 115(1-2):48-55.
15. Muzafar M, Green LE, Calvo-Bado LA, Tichauer E, King H, James P, Wellington EMH. 2016. Survival of the ovine footrot pathogen dichelobacter nodosus in different soils. Anaerobe. 38:81-87.
16. Locher I, Giger L, Frosth S, Kuhnert P, Steiner A. 2018. Potential transmission routes of dichelobacter nodosus. Veterinary microbiology. 218:20-24.

17. Duncan J, Grove-White D, Angell J. 2018. Understanding contagious ovine digital dermatitis. In Practice. 40(2):60-65.
18. Angell JW, Grove-White DH, Duncan JS. 2018. Sheep and farm level factors associated with footrot: A longitudinal repeated cross-sectional study of sheep on six farms in the uk. Veterinary Record. 182(10):293-293.
19. Angell JW, Duncan JS, Carter SD, Grove-White DH. 2014. Farmer reported prevalence and factors associated with contagious ovine digital dermatitis in wales: A questionnaire of 511 sheep farmers. Preventive veterinary medicine. 113(1):132-138.
20. Angell JW, Grove-White DH, Duncan JS. 2015. Sheep and farm level factors associated with contagious ovine digital dermatitis: A longitudinal repeated cross-sectional study of sheep on six farms. Preventive veterinary medicine. 122(1-2):107-120.
21. Kaler J, Daniels JL, Wright JL, Green LE. 2010. Randomized clinical trial of long-acting oxytetracycline, foot trimming, and flunixine meglumine on time to recovery in sheep with footrot. Journal of Veterinary Internal Medicine. 24(2):420-425.
22. Angell JW, Grove-White DH, Williams HJ, Duncan JS. 2016. Whole-flock, metaphylactic tilmicosin failed to eliminate contagious ovine digital dermatitis and footrot in sheep: A cluster randomised trial. Veterinary Record. 179(12):308.
23. SVS. 2017. Sheep veterinary society policy on responsible use of antimicrobials in sheep flocks
24. Strobel H, Lauseker M, Forbes AB. 2014. Targeted antibiotic treatment of lame sheep with footrot using either oxytetracycline or gamithromycin. Veterinary Record. 174(2):5.
25. Grogono-Thomas R, Wilsmore AJ, Simon AJ, Izzard KA. 1994. The use of long-acting oxytetracycline for the treatment of ovine footrot. British Veterinary Journal. 150(6):561-568.
26. Duncan JS, Grove-White D, Moks E, Carroll D, Oultram JW, Phythian CJ, Williams HW. 2012. Impact of footrot vaccination and antibiotic therapy on footrot and contagious ovine digital dermatitis. Veterinary Record. 170(18):462.
27. Duncan JS, Grove-White D, Oultram JW, Phythian CJ, Dijk JV, Carter SD, Cripps PJ, Williams HJ. 2011. Effects of parenteral amoxicillin on recovery rates and new infection rates for contagious ovine digital dermatitis in sheep. Veterinary Record. 169(23):606.
28. Clements RH, Stoye SC. 2014. The 'five point plan': A successful tool for reducing lameness in sheep. Veterinary Record. 175(9):225.