Disinfectant footbathing agents for the control of bovine digital dermatitis in dairy cattle

The use of biocidal agents in footbaths for dairy cows as an alternative to antibiotics is becoming standard practice in the UK. However, with numerous biocides available for use in footbaths and varying advice on the frequency with which footbaths should be used, practitioners may refer to the published literature for guidance. The evidence would suggest a variety of biocides are effective at improving bovine digital dermatitis (BDD) lesion score in cows with lesions. However, little published data is available on the protective effective of regular (such as daily) foot disinfection protocols for cows without BDD lesions despite the widespread anecdotal evidence for its efficacy. Formalin and copper sulphate are the most commonly used biocides, both of which should be used with significant precautions. Whichever biocide is used, practical considerations with regard to footbath design and care with making solutions to the correct concentration should be addressed.

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Footbathing (FB) has become one of the mainstays for the control of bovine digital dermatitis, foul-in-the-foot, toe necrosis and other related foot lesions in dairy cattle. Reports describing the use of formalin in footbaths for the control of lameness (Davies, 1982; Arkins et al, 1986) pre-date the first occurrence of digital dermatitis in the UK (Blowey and Sharp, 1988) highlighting there may be potential benefits to foot health other than just controlling skin infections.

While there are licensed antimicrobial therapies for the treatment of individual cattle with digital dermatitis, at present there are no licensed treatments available in the UK for herd level treatments in footbaths. Regimens for the use of antimicrobials in footbaths have been proposed (Watson, 1999; Laven and Proven, 2000). However, the importance of reactivating hyperkeratotic ('M4') stages during epidemics is just becoming understood (Döpfer et al, 2012) which indicates more emphasis is needed on footbathing approaches that prevent recrudescence from dormant M4 lesions as well as preventing and treating acute lesions. Furthermore the veterinary profession is likely to face mounting pressure to adopt non-antibiotic alternatives to disease control as the livestock industry adopts more responsible and sustainable

Table 1. Twelve papers describing footbathing intervention studies evaluating biocidal agents for the control of digital dermatitis in dairy cattle

Author (date), country	Study population	Study design	Outcomes	Key results	Study weaknesses
Laven and Hunt (2002), UK	187 Holstein-Friesian cows from a group of 369 cubicle housed lactating cows in a herd of 550 milking cows (8500 litres average milk yield)	Randomised positive-control trial: 2 days of 2.1 g/litre Erythromycin (positive control) comparison with 7 consecutive days of 6% formalin, 2% copper sulphate or 1% peracetic acid	Improvement in lesion score over 21 days for all treatments (no significant difference between treatments over time)	Percentage of hindlimbs with lesions following 21 days: copper sulphate approximately 25%, formalin approximately 35%, peracetic acid approximately 50% and erythromycin approximately 50%	Short (21 day) evaluation of lesions. No preventative outcome measure, i.e. lesion-free cows not acquiring digital dermatitis. Housing and slurry scraping not identical for all groups. Lesion score involved both depth and grade, but current understanding is that grade (M stage as described by Dopfer et al, 1997) is not a chronological scale of lesion progression
Manske et al (2002), Sweden	43 Swedish Red and 15 Swedish Holsteins in one herd	Split-leg footbath design for within cow negative control (water). Five periods of footbathing for a median of 10 days with a gap between bouts of median 5.5 days. Comparison of 0.6% ionised copper (Hoofpro+, SSI, Julesberg, CO) with water as a negative control	Acidified water significantly better at curing digital dermatitis lesions than water but there was no difference in lesion prevention. No difference detected for lesions in front feet	Cure rates: acidified copper 20 out of 24 animals vs 12 out of 24 animals for water	Six point nominal lesion score scale used not consistent with current concepts in lesion transitions. Small herd size and variations in management means replication of this trial would be difficult. For example, refreshing of solutions occurred if the baths were perceived to be dirty. No comments on the limitations of split footbath design in terms of cows placing all feet in one foot well or contamination of chemical from one footwell affecting the other side
Silva et al (2005), Brazil	120 Holsteins from two herds	Randomised field trial with no control and the following four groups: ● Hypochlorite 1% solution in footbath twice daily for 30 days AND intravenous oxytetracycline 10 mg/kg q 48 hours repeated 4 times ● Hypochlorite 1% solution in footbath twice daily for 30 days ● Intravenous oxytetracycline 10 mg/kg q 48 hours repeated 4 times ● Commercial topical ointment	Recovery was best with a combination of systemic antibiotic and footbathing, with footbathing appearing to be most beneficial	Reported recovery rates were as follows: Gp1 86.67% Gp2 73.33% Gp3 56.67% Gp4 50%	All lesions were surgically debrided prior to the trial
Holzhauer et al (2008), The Netherlands	140 lactating dairy cows (95% Holstein-Friesians)	Randomised control trial: Control Gp 5 =1 once per week through 4% formalin Gp 1= twice on one day, every other week, 4% formalin Gp 2 = on days 7, 28 and 90 water sprayed clean and bathed with commercial compound Gp 3 = once per week commercial compound Gp 4 = once per week 3% sodium carbonate solution	The reference group (4% formalin) achieved the lowest and most consistent control of M2 lesions	By the end of the study each group had achieved the following prevalence of M2 lesions: Reference Gp<5% Gp2 5–10% Gp3 ~40% Gp4 outbreak period 12 Gp5 outbreak period 9–13	No cross over and conditions not identical between groups

Thomsen et al (2008), Denmark	Four herds per product;100 randomly selected cows from each farm; Danish breeds	Split-leg footbath design with negative control. Three products tested: • 1.5% Virocid (glutaraldehyde, didecylmethylammoniumchloride, and alkyldimethylammoniumchloride; Cid Lines, Leper, Belgium) • 2% Hoofcare DA(quaternary ammonium compounds; DeLaval, Drongen, Belgium) • 1% Kickstart 2 (hydrogen peroxide, acetic acid, and peracetic acid; Cid Lines) Cows walked through footbathing solutions 2 days per week for 8 weeks	No significance difference compared with the negative control		Split-leg footbath design (disadvantages as outlined above)
Speijers et al (2010), Northern Ireland	118 lactating Holstein-Friesians (95%)	Three biocides tested: • Copper sulphate pentahydrate (2% and 5%) • Sodium hypochlorite (2%) • Sodium chloride (10%) No footbath was used as a control Three footbathing regimens tested: • Four consecutive milkings every week (X4/W1) • Four consecutive milkings every other week (X4/W2) • Alternating weeks of X4 copper and X4 salt	5% copper sulphate 4X/1W was found to be the most effective footbathing agent, significantly more effective than sodium hypochlorite and control. Sodium hypochlorite was no different to the control. There is no benefit to using 10% salt water alternated each week with copper sulphate	Prevalence M1,M2 and M4 lesions for: 5% Cu X4/W1=7% 2% Cu X4/W1=21%	Result potentially confounded by re-allocation of cows to new treatment groups for welfare reasons
Teixeira et al (2010), USA	406 lactating Holsteins in a 2800 herd	A commercial biocide tested using formalin and copper as positive controls in twice weekly footbathing regimens: • Dragonhyde 5% • Formalin 5% • Copper sulphate 5% and 10%	Dragonhyde performed better than formalin but was no different to copper sulphate	Cows had 1.36 greater odds of having a lesion if in the formalin group compared with the Dragonhyde group (30% bovine digital dermatitis (BDD) lesions vs 23%). Copper had 0.88 the odds of having a BDD lesion (26% BDD lesions vs 31%)	Only twice weekly regimens tested. Solutions were replaced every 45 cows
Holzhauer et al (2012), The Netherlands	120 Holsteins	A 4 month, split-leg footbath trial comparing 4% formalin (1 day per week) with acidified, ionised copper sulphate (5 days per week)	Cows were 3 times less likely to develop an ulcerative lesion on the copper based regimen. The was no difference in curative rates between treatments	Prevalence of M2 lesions in the two groups: Formalin=20 new case and 19 cured Copper=7 new cases and 17 cured	Formalin only used 1 day per week (compared with 5 days per week for copper). Split-leg footbath design (disadvantages as outlined above)
Logue et al (2012), Scotland	408 Holstein-Friesians	Split-leg footbath design with 5% copper sulphate as a positive control compared with a commercial heavy metal product. Footbathing twice daily for 3 consecutive days over 103 days in total. Some herds treated with footbaths in serial (4.4 m), some with single baths (2.2 m).	Copper sulphate performed significantly better than the commercial product	4.4 m footbaths (2x2.2 m baths in series) had significantly lower prevalence than the single 2.2 m baths	Opportunity for one or two baths in series was determined by the layout of the exit race. Details about the commercial product not revealed. Split-leg footbath design (disadvantages as outlined above)

Relun et al (2012), France	4677 lactating dairy cows on 52 farms	6 month quasi-randomised trial with negative control (no footbathing and individual treatment of cases) compared with: ● Footbath four consecutive milkings every 4 weeks (FB/4W) ● Four consecutive milkings every 2 weeks (FB/2W) ● Collective spraying for two milkings every 2 weeks (CS/2W) Chelated copper (3.5 g/litre) and zinc (0.5 g/litre) was used in the footbath. A stronger solution was used in the spray (20 g/litre for both chelated copper and zinc)	A walk through footbath every 4 weeks alone is not sufficient to control BDD alone. Rate of healing was influenced by grazing, foot cleanliness, size of initial lesion and addition of topical treatment	Cure rates for each group: Cx=58% FB/4W=55% FB/2W=76% CS/2W=76%	Quasi randomised trial, with a focus on cure rates rather than daily disinfection
Speijers et al (2012), Northern Ireland	Experiment 1: 70 lactating Holstein-Friesian cows with BDD lesions Experiment 2: 64 Holstein-Friesians without BDD lesions	Experiment 1 involved 14 weeks of footbathing using: ● 5% copper sulphate every week, four consecutive milkings ● 5% copper sulphate every 2 weeks, four consecutive milkings Experiment 2 involved 14 weeks of footbathing using: ● 5% copper sulphate every 2 weeks, four consecutive milkings ● 5% copper sulphate every 4 weeks, four consecutive milkings	Increasing the interval between copper sulphate footbaths was not recommended as a means of reducing copper sulphate usage	Experiment 1 — no active (M1, M2) lesions found in either group. Experiment 2 — significantly fewer cows with BDD lesions with fortnightly vs monthly footbathing	The protective effect of 5% copper sulphate footbathing was not evaluated. No M4 lesions were observed (unusual)
Relun et al (2013), France	4678 dairy cows on 52 farms (80% Holsteins, 20% Normande breed)	Farms allocated to treatments by minimisation. Farms allocated to either: ● Footbath vs collective spraying ● 2 days every 2 weeks vs 2 days every 4 weeks Chelated copper and zinc solutions were used in the footbath (5% Hoofit solution, Intracare, The Netherlands) and spray solution (50% Hoofit liquid, Intracare, The Netherlands)	Compared with individual cow treatment alone, collective treatments were better only if used every 2 weeks	88.2% of feet were free of lesions at the start of the study	No reporting of cure rates throughout the study

use of antimicrobials. This article reviews the evidence for the use of non-antibiotic biocides as part of foot disinfection and cleansing protocols.

A systematic review of peer-reviewed literature related to lameness in dairy cattle published between 2000 and 2011 was previously conducted (Potterton et al, 2011). The papers identified as relevant to foot disinfection were supplemented with literature published before and after this period by searching Pubmed, Science Direct, Cab direct and other databases present on Metalib (ExLibris) using the following search terms: 'dairy' AND 'footbath'. Twelve peer-reviewed papers on non-antibiotic biocides that appeared in the English language journals were reviewed, with several other papers on the practicalities of footbathing and best practice. *Table 1* summarises the reported findings from each relevant paper on biocides used in footbaths for the control of digital dermatitis and related foot lesions in dairy cattle.

Very few surveys have been conducted on footbathing practices in the UK. Formalin and copper sulphate are commonly used (Bell, 2004), and it has been estimated on the basis of formalin sales figures that as many as half of UK dairy farmers use formalin on a weekly basis (Stephen Kenyon, personal communication).

Formalin

Formalin (37% formaldehyde by weight) is a tissue fixative used by the embalming industry and for disinfection. It destroys bacteria by alkylating amino and sulphydral groups in bacterial proteins and nucleic acids. Hartshorn et al (2013) found the minimum bacteriocidal concentration (MBC) levels for killing treponemes was about 0.325% with 20% manure contamination. However, under field conditions, concentrations of 3–5% are typically recommended for footbaths which may reflect the benefit of high doses for penetrating the organic matter on epithelium or in hair follicles, or for penetrating exudates on granulation tissue and hyperkeratotic lesions.

Despite its common use in the UK as a foot disinfectant, no long-term longitudinal studies into the efficacy of daily formalin

Figure 1. Long, narrow and high-walled foot bath design has been advocated by some authors as this increases foot immersion time (Cook et al 2013) and reduces kick-out losses of footbath solution.

footbathing for preventing the formation of new bovine digital dermatitis lesions have been published. None-the-less, for many farmers it has proved highly effective, with some lactating cows walking through dilute formalin twice daily, and dry cows and precalving heifers typically walking through dilute formalin once three times weekly (Roger Blowey, personal communication).

Failures with formalin foot disinfection often relate to infrequent or intermittent footbathing regimens. Cows with severe M2 lesions will react adversely to the pain associated with formalin on these lesions. It is likely that organic matter contamination levels will vary considerably according to farm- and regimen-specific conditions, although typical recommendations of replenishment within 2 days or 300 cow passes have been suggested (Holzhauer et al, 2004). Formaldehyde has very limited antibacterial properties below 10°C, but it has been shown that once on the digital skin then temperature rapidly rises above that for antibacterial action provided cows are allowed to stand in a clean and dry environment (Cornelisse et al, 1982). Chemical burns on cows' feet may be encountered if concentrations are misjudged or climatic conditions predispose (sunny, dry, windy conditions) (Dyson et al, 2013). It is a probable carcinogen without a current license under EU biocides directive and so its continued use as a footbathing agent may soon become prohibited in the UK.

Copper sulphate

In the reported trials copper has been used more as a herd treatment rather than a means of preventing new infections, although Speijers et al (2012) demonstrated some protection was offered by fortnightly footbathing with 5% copper sulphate when used on four consecutive milkings. Hartshorn et al (2013) indicated that in conditions of 20% manure contamination copper has an MBC of 0.325% (identical to that of formalin). Consequently the authors suggested there may be scope for using copper solutions at much lower concentrations than the typical levels of 2–5%. Acidification of solutions using commercial products such as sodium bisulphate (pH minus) or other commercially available acidifiers may allow copper to be used at 2% or lower. Chelating copper may be another option although the efficacy of this approach in footbaths remains unclear from the work done by Relun et al (2013).

Given the rising cost of copper and the serious bio-contamination risk with regular footbathing, in some instances leading to reduced lucern yields, further work is necessary to identify optimal concentrations. Brizzi et al (2007) have shown there is an apparent persistency of protection following copper and zinc sulphate footbathing (Kling-on Blue, Forum, UK) which may reflect the on-going presence of copper and zinc on the skin and claw horn many days after footbathing has occurred. While lengthening the interval between footbathing may reduce copper usage, Speijers et al (2012) found this was not effective at maintaining good control of digital dermatitis. Copper used at 5% on four consecutive milkings every 1–2 weeks would appear to work well as a regular treatment option.

Peracetic acid

Laven and Hunt (2002) showed 1% peracetic acid was not significantly different in efficacy after 21 days compared with 6% formalin and 2% copper sulphate (as measured by lesion score) when used on 7 consecutive days. While efficacious in this trial, in practice it has proved more challenging to maintain control using regular peracetic acid footbathing alone, although some commercial products (Hoofsure Endurance, Provita) are recommended at twice daily intervals for optimal results in lactating cows. Early work suggests this twice daily approach may be as effective as some copper sulphate based regimens (Smith et al 2013). The main advantage of peracetic acid as a footbathing agent is that it does not have the adverse environmental impact of copper or the carcinogenic risks of formalin.

Other biocides and foot cleaning agents

Some of the benefit of the daily foot disinfection approach may be derived from the cleaning action of walking through a footbath solution. While parlour washings and hypochlorite solutions may not be effective on their own, they may be useful as part of a rotation with a biocide that has some curative actions (Speijers et

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Figure 2. Wide footbaths (>1.8m) that allow cows to pass are considered optimal for cow flow in positions close to the parlour (Chesterton 2013). Some authors suggest the pre-rinse footbath is unnecessary (Cook et al 2012) although no reports have directly measured levels of contamination with or without the pre-rinse.

al, 2010). Thomsen et al (2008) showed the automatic cleaning of feet with a detergent had a protective effect. Several of the papers in *Table 1* highlighted the potential of some of the commercially available biocides.

Some farmers have reported good control with mixing formalin and copper sulphate although it should be emphasised that mixing of other biocides should be done with great caution to avoid risk of noxious gas release. Glutaraldehyde was evaluated as topical spray by Manske et al (2002) and proved ineffective, but that may reflect the very short shelf life of this biocide. Zinc sulphate appears to have inferior MBCs compared with copper sulphate (Hartshorn et al, 2013), but it could present another option as part of a rotation for footbathing provided the appropriate environmental precautions are taken.

Other practical considerations

Whenever embarking on a regular (daily) footbathing regimen, great consideration should be placed on the practicality of easy filling and cleaning system (the 'easy fill, easy clean' concept). Furthermore, balancing the time cows spend with feet immersed in solution with the need for good cow flow requires careful judgment. Cook et al (2012) proposed dimensions for a foot well (3 m x 0.5 m x 0.28 m) which achieves a steady single file procession of cows immersing 95% of feet at least twice while minimising the solution kick-out rates and the cost of chemical needed (*Figure 1*). However, others have suggested much wider footbaths that allow cows to move through the bath side-by-side as this improves cow flow, as does ensuring the concrete levels are the same inside the bath as outside the bath (*Figure 2*) (Chesterton 2013). The benefit of having a pre-rinse bath is still unclear; further work is needed to demonstrate that long compartmentalised baths do actually ensure the last cows through the footbath leave the last compartment of the footbath with the effective concentrations of biocidal agent. The reality is that priorities will vary between farms and no single design will be optimal for all farms.

One of the biggest variables on farm may be the accuracy with which the bath is filled and chemical added as one study demonstrated large variations in target concentrations (Holzhauer et al, 2004). The correct preparation of solutions deserves review for all management groups, including dry cows and replacement heifers.

Conclusions

Many published papers confirm improvements in lesion prevalence and severity using footbathing regimens based on number of biocides, particularly formalin, copper sulphate and peracetic acid. Despite its widespread popularity in the UK, there are no published reports involving daily formalin footbaths. None-theless, anecdotal reports would suggest this regimen should be investigated further. However, the benefit of cleaning feet between biocidal footbaths should not be overlooked and effectiveness of footbathing may be determined by some of the simple practicalities of footbath design. LS

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KEY POINTS

- Bovine digital dermatitis lesion score and prevalence improves with most biocides with copper sulphate showing the best results in cows with lesions.
- Little is published in the protective effects of biocides used regularly.
- The copper sulphate regimens show relatively little protection.
- There is no consensus on optimal footbath design but issues of cow flow, foot immersion (depth and duration) and solution loss are considered important.
- Correct solution strength and replenishment rates are should not be assumed.

References:

Arkins S, Hannan J, Sherington J (1986) Effects of Formalin Footbathing on Foot Disease and Claw Quality in Dairy-Cows. *Vet Rec* **118**: 580–3

Bell NJ, Whay HR, Main DCJ, Knowles TG, Webster AJF (2004) Assessment of prevalence, treatment and control of lameness-related disease in dairy heifers on 30 farms in Southwest Britain. In proceedings of: 13th International Symposium and 5th International Conference on Lameness in Ruminants, 11-15th February 2004 B. Zemljic, ed. Maribor, Slovenia: 39–40

Blowey RW, Sharp MW (1988) Digital dermatitis in dairy cattle. *Vet Rec* **122**: 505–8

Brizzi A, Cortesi C, Martemucci N, Biacca C, Fornari L, Tagliaferri M (2007) A new product for footbathing: observations of its use in dairy cows. In proceedings of: Buiatria, Journal of the Italian Association for Buiatrics: 3–12

Cook NB, Rieman J, Gomez A, Burgi K (2012) Observations on the design and use of footbaths for the control of infectious hoof disease in dairy cattle. *Vet J* **193**: 669–73

Cornelisse JJ, Peterse DJ, Toussaint Raven E (1982) Formalin footbaths in the prevention of interdigital dermatitis in cattle. *Tijdschr Diergeneeskd* **107**: 835–40

Davies RC (1982) Effects of regular formalin footbaths on the incidence of foot lameness in dairy cattle. *Vet Rec* **111**: 394

Dopfer D, Koopmans A, Meijer FA et al (1997) Histological and bacteriological evaluation of digital dermatitis in cattle, with special reference to spirochaetes and Campylobacter faecalis. *Vet Rec* **140**: 620–3

Döpfer D, Holzhauer M, Boven M (2012) The dynamics of digital dermatitis in populations of dairy cattle: Model-based estimates of transition rates and implications for control. *Vet J* **193**: 648–53

Dyson S, Armstrong T, Allen T, Allen N, Davies A, Bell NJ (2013) Suspected chemical burn on the digital skin of dairy cows following foot bathing with 5% formalin solution. In proceedings of: 17th International Symposium and 9th International Conference on Lameness in Ruminants, 11th – 14th August 2013 Bristol Marriott City Centre Hotel, Bristol, UK: 211

Hartshorn RE, Thomas EC, Anklam K et al (2013) Short communication: Minimum bactericidal concentration of disinfectants evaluated for bovine digital dermatitis-associated Treponema phagedenis-like spirochetes. *J Dairy Sci* **96**: 3034–8

Holzhauer, M., Bartels, C. J., Bergsten, C., van Riet, M. M. J., Frankena, K. and Lam, T. J. G. M., 2012. The effect of an acidified, ionized copper sulphate solution on digital dermatitis in dairy cows. The Veterinary Journal 193, 659-663.

Holzhauer, M., Bartels, C. J. M., Döpfer, D. and van Schaik, G., 2008. Clinical course of digital dermatitis lesions in an endemically infected herd without preventive herd strategies. The Veterinary Journal 177, 222-230.

Holzhauer M, Sampimon OC, Counotte GHM (2004) Concentration of formalin in walkthrough footbaths used by dairy herds. *Vet Rec* **154**: 755–6

Laven RA, Hunt H (2002) Evaluation of copper sulphate, formalin and peracetic acid in footbaths for the treatment of digital dermatitis in cattle. *Vet Rec* **151**: 144–6

Laven RA, Proven MJ (2000) Use of an antibiotic footbath in the treatment of bovine digital dermatitis. *Vet Rec* **147**: 503–6

Logue DN, Gibert T, Parkin T, Thomson S, Taylor DJ (2012) A field evaluation of a footbathing solution for the control of digital dermatitis in cattle. *Vet J* **193**: 664–8

Manske T, Hultgren J, Bergsten C (2002) Topical treatment of digital dermatitis associated with severe heel-horn erosion in a Swedish dairy herd. *Prev Vet Med* **53**: 215–31

Potterton S, Bell NJ, Whay HR, Main DCJ, Huxley JN (2011) A Review of the Peer Reviewed Literature on the Treatment and Prevention of Foot Lameness in Cattle Published Between 2000 and 2011 [Online]. DairyCo. http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CDMQFjAA&url=http%3A%2F%2Fwww.dairyco.org.uk%2Fnon_umbraco%2Fdownload.aspx%3Fmedia%3D10391&ei=riCeUZTvGqTl4QTiiID4Bg&usg=AFQjCNF3lmTzwo6xqJxuXg3X648aDEOB-w&sig2=ecIkAKiZ5b8AoiMMAvXsKA&bvm=bv.46865395,d.bGE (accessed 23th May 2013)

Relun A, Lehebel A, Bareille N, Guatteo R (2012) Effectiveness of different regimens of a collective topical treatment using a solution of copper and zinc chelates in the cure of digital dermatitis in dairy farms under field conditions. *J Dairy Sci* **95**: 3722–35

Relun A, Lehebel A, Chesnin A, Guatteo R, Bareille N (2013) Association between digital dermatitis lesions and test-day milk yield of Holstein cows from 41 French dairy farms. *J Dairy Sci* **96**: 2190–200

Silva LAF, Silva CA, Borges JRJ, Floravanti MCS, Borges GT, Atayde IB (2005) A clinical trial to assess the use of sodium hypochlorite and oxytetracycline on the healing of digital dermatitis lesions in cattle. *Can Vet J* **46**: 345–8

Speijers MHM, Baird LG, Finney GA et al (2010) Effectiveness of different footbath solutions in the treatment of digital dermatitis in dairy cows. *J Dairy Sci* **93**: 5782–91

Speijers MHM, Finney GA, McBride J, Watson S, Logue DN, O'Connell NE (2012) Effectiveness of different footbathing frequencies using copper sulfate in the control of digital dermatitis in dairy cows. *J Dairy Sci* **95**: 2955–64

Smith, A. C., Wood, C. L., McQuerry, K. J. and Bewley, J. M. 2013. Effect of a tea tree oil and organic acid footbath solution on digital dermatitis in dairy cattle. In proceedings of: 17th International Symposium and 9th International Conference on Lameness in Ruminants, 11th – 14th August 2013 Bristol Marriott City Centre Hotel, Bristol, UK

Teixeira AGV, Machado VS, Caixeta LS, Pereira RV, Bicalho RC (2010) Efficacy of formalin, copper sulfate, and a commercial footbath product in the control of digital dermatitis. *J Dairy Sci* **93**: 3628–34

Thomsen PT, Sorensen JT, Ersboll AK (2008) Evaluation of three commercial hoof-care products used in footbaths in Danish dairy herds. *J Dairy Sci* **91**: 1361–5

Watson CL (1999) Digital dermatitis - current clinical problems and lesions involved. *Cattle Practice* **7**: 341–4