Efficacy of formalin, copper sulfate, and a commercial footbath product in the control of digital dermatitis

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ABSTRACT

The objective was to evaluate the relative efficacy of a novel, commercially available disinfectant agent (T-Hexx Dragonhyde HBC, Hydromer, Branchburg, NJ) compared with formalin and copper sulfate. The hypothesis was 2 sided; therefore, the hypothesis was that the new agent would be better or worse compared with the industry gold standard footbath agents, formalin and copper sulfate. The study was conducted in a large commercial dairy farm located near Ithaca, New York, from June 18, 2009 to October 26, 2009. Two identical studies were conducted, the first comparing Dragonhyde (5% solution, twice weekly) and formalin (5% solution, twice weekly) and the second comparing Dragonhyde (5% solution, twice weekly) and copper sulfate (10% solution, twice weekly). The study design was identical for both studies with 4 pens (physically identical), 2 treatments (Dragonhyde vs. formalin and Dragonhyde vs. copper sulfate), 2 periods (crossing over the treatment within pen), and 3 repeated measures (3 observations per cow: enrollment, wk 2, and wk 4). For study 1, 406 cows were enrolled ($n = 201$ formalin and 205 Dragonhyde). For study 2, 356 cows were enrolled ($n = 189$ copper sulfate and 167 Dragonhyde). The adjusted odds of digital dermatitis lesion (DDL) throughout the study period were analyzed by mixed logistic regression model. In study 1, the odds of DDL were 1.36 times higher for the formalin group compared with the Dragonhyde group. In study 2, the data were analyzed by a similar statistical model and the variable treatment did not significantly affect the overall prevalence of DDL. In conclusion, the performance of 3 hoof care products was evaluated and it was concluded that Dragonhyde performed better than formalin and that there was no difference between copper sulfate and Dragonhyde.

Key words: dairy cow, lameness, footbath

INTRODUCTION

Lameness, a highly prevalent disorder observed in dairy cows, is widespread throughout the world and has serious economic and welfare implications (Clarkson et al., 1996; Green et al., 2002). The economic losses associated with lameness are a consequence of lower milk production (Bicalho et al., 2008), high death and culling rates (Warnick et al., 2001; Bicalho et al., 2007), and lower reproductive performance (Lucey et al., 1986; Melendez et al., 2003). Diseases affecting the digit are the cause of more than 90% of all lameness observed in dairy cattle (Murray et al., 1996). The digital diseases of dairy cattle can be categorized into 2 groups: infectious and noninfectious (Divers and Peek, 2008). Additionally, 3 major infectious digital diseases are prevalent on North American dairy farms: digital dermatitis (DD), interdigital dermatitis, and foot rot (infectious pododermatitis).

One of the 4 most frequent diagnoses of lameness is DD (Green et al., 2002). Digital dermatitis is a multifactorial disease defined as a circumscribed, erosive to papillomatous, intensely painful lesion that is often surrounded by a ridge of hyperkeratotic skin bearing hypertrophied hairs and is associated with lameness (Read and Walker, 1998). The complex etiology of DD is not completely understood, but the spirochete *Treponema* spp. is thought to be associated with the disease (Collighan and Woodward, 1997).

Interdigital dermatitis, an acute chronic inflammation of the skin between the digits, is believed to be caused by *Dichelobacter nodosus* (Peterse, 1985). Often, the interdigital dermatitis infection extends to the heel horn, resulting in heel horn erosion; the infection produces a mild irritation, resulting in a hypertrophy of the skin. Lameness is not typically directly associated with interdigital dermatitis; however, heel erosions can cause imbalanced weight distribution on the sole, which can lead to sole ulcers and other claw horn diseases (Cornelisse et al., 1981; Peterse, 1985).

The third relevant infectious disease is foot rot, which causes an acute necrotic infection that occurs after primary injury of the interdigital skin. *Fusobacte-*

Received March 9, 2010.

Accepted April 30, 2010.

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rium necrophorum is the major etiologic agent, but it is believed that other bacterial pathogens are also relevant in the disease process (Divers and Peek, 2008). The prevention of infectious digital diseases is accomplished by good hygiene and husbandry and arguably by the practice of foot bathing using disinfectant or antibiotic solutions. The literature that regards the efficacy of footbath solution is scarce and controversial. Laven and Hunt (2002) reported that 5% formalin and 10% copper sulfate (CuSO_4) were effective in the control of DD. However, Thomsen et al. (2008) reported no effect of 3 different commercially available footbath agents on percentage cured and percentage new DD infections; formalin and copper sulfate were not evaluated in that study.

Therefore, the objective was to evaluate the efficacy of the novel, commercially available disinfectant agent T-Hexx Dragonhyde HBC (Basic Green #1 and phenoxyethanol; Hydromer, Branchburg, NJ) relative to formalin and CuSO_4 . The hypothesis was 2 sided; therefore, the hypothesis was that the new agent would be better or worse compared with the industry gold standard footbath agents formalin and copper sulfate.

MATERIALS AND METHODS

Farm and Management

The study was conducted on a large commercial dairy farm located near Ithaca, New York from June 18, 2009 to October 26, 2009. This farm was selected because of its long history of a working relationship with the Ambulatory and Production Medicine Clinic at Cornell University (Ithaca, NY). The farm milked 2,800 Holstein cows 3 times daily in a double-52 parallel milking parlor. Cows were housed in free stall barns that were bedded with waste paper-pulp and cleaned by automatic scrapers. The cows were fed a TMR consisting of about 55% forage (corn silage, haylage, and wheat straw) and 45% concentrate (corn meal, soybean meal, canola, cotton seed, and citrus pulp). The diet was formulated to meet or exceed the NRC (2001) nutrient requirements for lactating Holstein cows weighing 650 kg and producing 45 kg of 3.5% FCM. The study population used was the far-off (from dry-off to -25 d relative to expected parturition) dry cows that were housed in free stalls bedded with sand and cleaned by skid steer scrapers 2 to 3 times daily. Maternity pens were adjacent to the free stall area of the barn and pack bedded with shredded paper and cleaned once weekly. The far-off dry cows were chosen because of historical high prevalence of DD, easier management that avoided disturbing the lactating herd, and the availability of 4 physically identical free stall pens.

Study Design

Two identical studies were conducted, the first comparing Dragonhyde and formalin and the second comparing Dragonhyde and CuSO_4 . The study designs were identical with 4 pens (physically identical), 2 treatments (Dragonhyde versus formalin and Dragonhyde versus CuSO_4), 2 periods (crossing over the treatment within pen), and 3 repeated measures (3 observations per cow: enrollment, wk 2, and wk 4).

For study 1, cows were randomly allocated to 1 of 4 pens; 2 pens were treated with formalin 5% and the 2 other pens were treated with Dragonhyde 5%. Footbath treatment was applied twice weekly for a total period of 4 wk. After 4 wk of treatment, new cows entered the study and the treatment applied in each pen was switched in order to mitigate pen effect. The same strategy was adopted for study 2, in which the treatments were 10% CuSO_4 and 5% Dragonhyde.

Case Definition

For both studies all cows had hooves trimmed and examined at enrollment, wk 2, and wk 4 after enrollment and the following data were recorded: presence or absence of active DD lesions (**DDL**), visual locomotion score (**VLS**), and BCS. The VLS system was a 5-point scale: 1 = normal, 2 = presence of a slightly asymmetric gait, 3 = the cow clearly favored 1 or more limbs (moderately lame), 4 = severely lame, and 5 = extremely lame (non-weight-bearing lame). Body condition score was evaluated using the scoring system of Edmonson et al. (1989).

Digital dermatitis evaluation was performed using a standing hoof trimming chute (HSeries, Comfort Hoof Care, Baraboo, WI). The cows were restrained in the chute and each foot was restrained individually, cleaned, and visually inspected for the presence of DDL. Whenever a lesion resembling a DDL was detected, the lesion was evaluated for the presence of pain by applying gentle pressure by pressing the index finger into the lesion. Whenever an obviously painful lesion was detected, the cow was spared from applying pressure into the lesion. The DD score was considered 1 when an active DDL (painful lesion) was present and 0 if not present (Figure 1). All data were collected by 1 of 2 trained and experienced veterinarians.

To compare the relative effect of Dragonhyde versus formalin and Dragonhyde versus CuSO_4 on the prevention, cure, and prevalence of DD, the following outcome variables were evaluated: cured DDL (**CDDL**), new DDL (**NDDL**), DDL, and visual lameness (**VL**). The dichotomous outcome variable CDDL was considered 1 when a cow was diagnosed with an active DDL at

Figure 1. Illustration of the digital dermatitis lesion (DDL) scoring system used. Cows were dichotomized into having or not having an active DDL. From the left to the right, the first picture illustrates a foot completely free of digital dermatitis (DDL = 0), the second illustrates a healed or inactive DDL (DDL = 0), the third illustrates an active DDL (DDL = 1), and the fourth illustrates a severe DDL (DDL = 1). Color version available in online PDF.

enrollment and diagnosed as free of DDL at the end of the study and was considered 0 when a cow was diagnosed with an active DDL at enrollment and also at the end of the study; cows free of DDL at enrollment were excluded from this analysis. The variable NDDL was considered 1 when a cow was free of DDL at enrollment and diagnosed with an active DDL at the end of the study and was considered 0 when a cow did not have a DDL at enrollment or at the end of the study; cows diagnosed with DDL at enrollment were excluded from this analysis. The variable DDL was 1 when active DDL was present and 0 when active DDL was absent, and the variable VL was considered 1 when $VLS \geq 3$ and 0 when $VLS < 3$.

Management of Footbath Treatments

The use of a split footbath was attempted in the beginning of the study and had to be discontinued because of complications that included cows getting injured when passing through the footbath and the contamination of 1 side of the footbath with solution contained on the opposite side by cows splashing footbath solution. Therefore, a conventional walk-through footbath (1.00 m $\times$ 1.50 m $\times$ 0.10 m, 150 L capacity) was used. The use of a “pre-footbath” was adopted to clean the feet before the cows walked through the footbath prepared solution; the dimensions of the pre-footbath were the same as those described above for the footbath. All study cows were forced to walk through the footbath. The footbath solution was discarded after each pen (45 cows) was treated because the pens were physically separated and transportation of used footbath solution from one pen to the next was not feasible.

Statistical Analyses

To assess the effect of footbath treatment on the odds of CDDL and NDDL, mixed logistic regressions were

fitted to the data using the Glimmix procedure of SAS (SAS Institute Inc., Cary, NC). The models included the fixed effects of treatment (Dragonhyde vs. formalin and Dragonhyde vs. CuSO_4), parity (primiparous = 1 and multiparous = 2), and BCS (BCS < 3 , BCS = 3, and BCS > 3). Additionally, study pen number (1, 2, 3, or 4) was included in the model as a random effect to control for potential pen effect.

To assess the effect of footbath treatment on the odds of DDL at enrollment, at wk 2 and 4 mixed logistic regressions were fitted to the data using the Glimmix procedure in SAS. In this model, the following dependent variables were used: treatment (Dragonhyde vs. formalin and Dragonhyde vs. CuSO_4), parity, study week, and BCS. To control for the repeated measure nature of the study (3 measurements per cow) and for pen effect, the variable cow identification number nested within pen number was included in the model as a random variable. Additionally, the variable DD at enrollment was added to the model as a fixed effect to adjust for a potential initial DD prevalence imbalance between the different treatment groups. A model similar to the one described above was used to assess the effect of footbath treatment (Dragonhyde vs. formalin and Dragonhyde vs. CuSO_4) on the odds of VL; in this model the outcome variable was VL. For all models described above, 2-way interactions between the variable treatment and all other independent variables were tested; there were no significant ($P < 0.05$) interactions. Variables were considered significant when their respective P -values were < 0.05 ; the variables parity and BCS were kept in all models because of their known association with lameness.

RESULTS

Descriptive Statistics

For study 1, a total of a 406 cows were enrolled, of which 201 were in the formalin group and 205 were

Table 1. Logistic regression model evaluating the effect of treatment, parity, and BCS on the odds of curing digital dermatitis lesions (CDDL) and the odds of new digital dermatitis lesions (NDDL)

Variable	CDDL ¹			NDDL ²		
	% (n)	Odds ratio	P-value	% (n)	Odds ratio	P-value
Study 1						
Formalin	17 (41)	0.49	0.24	15 (130)	1.10	0.75
Dragonhyde ³	31 (29)	Baseline	0.24	15 (151)	Baseline	0.75
Multiparous	21 (38)	0.68	0.52	16 (128)	0.84	0.62
Primiparous	26 (31)	Baseline	0.52	14 (139)	Baseline	0.62
BCS <3	21 (38)	1.51	0.90	18 (120)	3.47	0.09
BCS = 3	28 (21)	1.33	0.90	15 (98)	2.9	0.09
BCS >3	18 (11)	Baseline	0.90	6 (63)	Baseline	0.09
Study 2						
Copper sulfate	24 (41)	0.98	0.98	18 (119)	0.92	0.83
Dragonhyde ³	18 (38)	Baseline	0.98	20 (111)	Baseline	0.83
Multiparous	18 (45)	0.89	0.86	19 (107)	0.81	0.58
Primiparous	26 (34)	Baseline	0.86	19 (123)	Baseline	0.58
BCS <3	18 (27)	0.23	0.2	6 (82)	0.17	<0.001
BCS = 3	10 (31)	0.10	0.2	26 (96)	0.86	<0.001
BCS >3	43 (21)	Baseline	0.2	25 (52)	Baseline	<0.001

¹CDDL = Cured digital dermatitis lesion. CDDL was considered 1 when a cow was diagnosed with an active digital dermatitis (DD) lesion at enrollment and diagnosed as free of DD lesion at the end of the study and was considered 0 when a cow was diagnosed with an active DD lesion at enrollment and also at the end of the study. Cows free of DD lesions at enrollment were excluded.

²NDDL = New digital dermatitis lesion. NDDL was considered 1 when a cow was free of DD lesion at enrollment and diagnosed with an active DD lesion at the end of the study and was considered 0 when a cow did not have a DD lesion at enrollment or at the end of the study. Cows diagnosed with DD lesions at enrollment were excluded.

³T-Hexx Dragonhyde HBC (Hydromer, Branchburg, NJ).

in the Dragonhyde group. In the formalin group, 112 cows were primiparous and 80 cows were multiparous, whereas in the Dragonhyde group, 108 cows were primiparous and 93 cows were multiparous. Additionally, 45 cows in the formalin group were detected with DD at enrollment and 36 cows from the Dragonhyde group were detected with DD at enrollment.

For study 2, a total of 356 cows were enrolled, of which 189 were in the CuSO₄ group and 167 were in the Dragonhyde group. There were 74 and 89 primiparous cows for the CuSO₄ and Dragonhyde groups, respectively. Additionally, 45 and 41 cows were diagnosed with DD at enrollment for the CuSO₄ and Dragonhyde groups, respectively.

Effect of Footbath Solution on the Odds of CDDL and NDDL

In study 1, Dragonhyde was compared with formalin. In the formalin group 41 cows were diagnosed with active DD at enrollment, of which 17% were cured by the end of the study. In the Dragonhyde group 29 cows were with active DD at enrollment, of which 31% were cured by the end of the study (Table 1). The variables parity and BCS did not significantly affect the odds of CDDL but were forced into the logistic regression model because of their biological relevance. Also, in study 1, 130 and 151 cows were free of DDL at enroll-

ment in Dragonhyde and formalin groups, respectively. The incidence of NDDL was 15% for both Dragonhyde and formalin groups (adjusted odds ratio = 1.1; $P = 0.75$; Table 1).

A similar mixed logistic regression model was performed for study 2; there were no differences in the odds of CDDL and NDDL between the Dragonhyde and CuSO₄ groups (Table 1). Additionally, there was a significant effect of BCS on NDDL (Table 1)

Effect of Footbath Solution on the Prevalence of DD. The adjusted odds of DDL throughout the study period were analyzed by mixed logistic regression model. In study 1, the odds of DDL were 1.36 times higher for the formalin group compared with the Dragonhyde group ($P = 0.04$; Table 2). The numerical difference in the prevalence of DDL at enrollment was adjusted for by adding the variable DDL at enrollment to the model as a fixed effect. In study 1, the variable parity did not significantly affect DDL, but BCS did significantly affect the overall odds of DDL (Table 2). In study 2, the data were analyzed by a similar statistical model and the variable treatment did not significantly affect the overall prevalence of DDL, but there were significant effects of parity and BCS.

Effect of Footbath Solution on the Prevalence of Lameness ($VLS \geq 3$). A third set of mixed logistic regression models was completed to analyze the effect of footbath treatment on the prevalence of VL. In study

Table 2. Mixed logistic regression models evaluating the effect of treatment, parity, and BCS on the prevalence of digital dermatitis (DD) throughout the study period

	% DD (n)					
Variable	Enrollment	Wk 2	Wk 4	Total	Odds ratio	P-value
Study 1						
Formalin	25 (175)	29 (167)	34 (155)	30 (497)	1.36	0.04
Dragonhyde ¹	19 (187)	23 (186)	30 (142)	23 (515)	Baseline	0.04
Multiparous	13 (159)	24 (157)	33 (135)	25 (451)	1.08	0.60
Primiparous	25 (201)	26 (188)	31 (159)	27 (548)	Baseline	0.60
BCS <3	26 (163)	32 (174)	38 (141)	32 (478)	1.45	<0.001
BCS = 3	21 (124)	22 (110)	31 (89)	24 (323)	1.01	<0.001
BCS >3	16 (75)	17 (69)	19 (67)	17 (211)	Baseline	<0.001
Study 2						
CuSO ₄	26 (170)	22 (175)	31 (162)	26 (507)	0.88	0.41
Dragonhyde ¹	26 (155)	34 (154)	33 (145)	31 (454)	Baseline	0.41
Multiparous	21 (155)	23 (158)	29 (147)	24 (460)	1.55	0.01
Primiparous	31 (167)	32 (167)	36 (157)	33 (491)	Baseline	0.01
BCS <3	26 (113)	21 (130)	27 (113)	24 (356)	0.65	0.04
BCS = 3	26 (137)	34 (128)	37 (122)	32 (387)	0.94	0.04
BCS >3	29 (75)	31 (71)	32 (72)	31 (218)	Baseline	0.04

¹T-Hexx Dragonhyde HBC (Hydromer, Branchburg, NJ).

1, the odds of VL were 1.55 times higher for the formalin group when compared with the Dragonhyde group ($P = 0.01$). In study 2, there was no significant effect of treatment, parity, or BCS on the prevalence of VL (Table 3).

DISCUSSION

Dragonhyde significantly outperformed formalin in 2 of the 4 evaluated outcomes: prevalence of DD and prevalence of VL. However, the odds of CDDL and NDDL did not differ significantly between the Dragonhyde and formalin groups. It is reasonable to assume

that the prevalence of DDL in a certain population is a factor of the duration of the disease, the incidence of new cases, and the probability of curing existing lesions (Alho, 1992).

The literature regarding footbath efficacy is remarkably scarce and few studies have evaluated the efficacy of formalin and copper sulfate. Kyllar et al. (1985) used a once-weekly 12.5% formalin footbath solution and reported a cure rate of 91%. However, in that study the cows had to stand with the feet inside the formalin solution for 1 h, which would be considered an infeasible footbath routine for most commercial dairy farms. Laven and Hunt (2002) compared the efficacy of

Table 3. Mixed logistic regression models evaluating the effect of treatment, parity, and BCS on the prevalence of visual lameness (VL)¹

	% VL (n)					
Variable	Enrollment	Wk 2	Wk 4	Total	Odds ratio	P-value
Study 1						
Formalin	19 (201)	24 (201)	29 (201)	24 (603)	1.55	0.01
Dragonhyde ²	16 (205)	21 (205)	18 (205)	18 (615)	Baseline	0.01
Multiparous	21 (189)	23 (189)	26 (189)	23 (567)	1.03	0.88
Primiparous	14 (204)	22 (204)	22 (204)	19 (612)	Baseline	0.88
BCS <3	19 (207)	27 (207)	26 (207)	24 (621)	1.50	0.15
BCS = 3	18 (124)	21 (124)	20 (124)	20 (372)	1.10	0.15
BCS >3	13 (75)	13 (75)	23 (75)	16 (225)	Baseline	0.15
Study 2						
CuSO ₄	21 (189)	21 (189)	22 (189)	21 (567)	0.87	0.37
Dragonhyde ²	21 (167)	26 (167)	24 (167)	24 (501)	Baseline	0.37
Multiparous	23 (170)	24 (170)	23 (170)	23 (510)	1.00	0.99
Primiparous	20 (176)	24 (176)	25 (176)	23 (528)	Baseline	0.99
BCS <3	22 (144)	16 (144)	23 (144)	20 (432)	0.82	0.59
BCS = 3	20 (137)	28 (137)	22 (137)	23 (411)	0.90	0.59
BCS >3	23 (75)	27 (75)	27 (75)	25 (225)	Baseline	0.59

¹Cows were considered lame if visual locomotion score was ≥ 3 .

²T-Hexx Dragonhyde HBC (Hydromer, Branchburg, NJ).

4 different footbath products (erythromycin 210 g/100 L, 6% formalin, 2% CuSO₄, and 1% peracetic acid) in the control of DD; there was no statistical difference between the products.

Formalin is a 37 to 39% solution of formaldehyde (methyl aldehyde) and its use as a footbath agent is widespread in the North American dairy industry. Formalin is a noncorrosive, biodegradable chemical that is rapidly degraded when in contact with manure (Sullivan, 2005).

There was no statistical difference between Dragonhyde and CuSO₄. The bacteriostatic effect of CuSO₄ is a consequence of the reaction of Cu⁺⁺ with protein thiol groups in target organisms (Epperson and Midla, 2007). Few studies have evaluated the efficacy of CuSO₄ footbaths. Laven and Hunt (2002) compared 2% CuSO₄ footbath solution with 3 products and reported no significant difference. Copper sulfate has questionable efficacy in the treatment of existing DDL. Hernandez et al. (1999) concluded that the topical use of oxytetracycline solution was a significantly more effective treatment of DDL compared with CuSO₄ solution. Therefore, the effectiveness of CuSO₄ as a footbath agent is likely attributed to its ability to prevent the incidence of new DDL. In our study, a relatively high concentration of CuSO₄ was used (10% solution), which can partially explain the observed effectiveness. A major concern regarding the use of CuSO₄ footbath is the accumulation of copper on the soil. Footbath water is typically discarded into the manure lagoon, increasing the copper levels of the manure applied to fields. Flis et al. (2006) reported an 18-fold increase in the concentration of copper in manure slurry after CuSO₄ footbaths were used.

For study 1 there were a total of 4 treatment pens for Dragonhyde and another 4 pens for formalin, whereas for study 2 there were 4 treatment pens for Dragonhyde and another 4 pens for CuSO₄. Unfortunately, we were unable to perform a third study comparing formalin and CuSO₄ because of the limited availability of identical free stall pens. Although the design of our studies does not allow for a direct comparison between formalin and CuSO₄, it is reasonable to infer that CuSO₄ footbath could be more effective than formalin given that formalin was worse than Dragonhyde and CuSO₄ was as good as Dragonhyde. Comparison between formalin and CuSO₄ based on this study should be avoided and future field trials should be conducted to determine the relative efficacy of formalin and CuSO₄.

CONCLUSIONS

The motivation for the present study arose from the need to replace the current footbath chemicals, forma-

lin and CuSO₄, by a less harmful yet equally effective alternative. In conclusion, the performance of 3 hoof care products showed better performance of Dragonhyde over formalin and no difference between CuSO₄ and Dragonhyde.

REFERENCES

- Alho, J. M. 1992. On prevalence, incidence, and duration in general stable populations. *Biometrics* 48:587–592.
- Bicalho, R. C., F. Vokey, H. N. Erb, and C. L. Guard. 2007. Visual locomotion scoring in the first seventy days in milk: Impact on pregnancy and survival. *J. Dairy Sci.* 90:4586–4591.
- Bicalho, R. C., L. D. Warnick, and C. L. Guard. 2008. Strategies to analyze milk losses caused by diseases with potential incidence throughout the lactation: A lameness example. *J. Dairy Sci.* 91:2653–2661.
- Clarkson, M. J., D. Y. Downham, W. B. Faull, J. W. Hughes, F. J. Manson, J. B. Merritt, R. D. Murray, W. B. Russell, J. E. Sutherst, and W. R. Ward. 1996. Incidence and prevalence of lameness in dairy cattle. *Vet. Rec.* 138:563–567.
- Collighan, R. J., and M. J. Woodward. 1997. *Spirochaetes and other bacterial species associated with bovine digital dermatitis*. FEMS Microbiol. Lett. 156:37–41.
- Cornelisse, J. L., D. J. Peterse, and E. Toussaint Raven. 1981. A digital disorder in dairy cattle. *Dermatitis digitalis?* Tijdschr. Diergeneesk. 106:452–455.
- Divers, T. J., and S. F. Peek. 2008. *Rebhun's Diseases of Dairy Cattle*. 2nd ed. Saunders Elsevier, St. Louis, MO.
- Edmonson, A. J., I. J. Lean, L. D. Weaver, T. Farver, and G. Webster. 1989. A body condition scoring chart for Holstein dairy cows. *J. Dairy Sci.* 72:68–78.
- Epperson, B., and L. Midla. 2007. Copper sulfate for footbaths—Issues and alternatives. In *Proc. Tri-State Dairy Nutrition Conference*. <http://tristatedairy.osu.edu/Proceedings%202007/Epperson.pdf> Accessed Apr. 5, 2010.
- Flis, S. A., C. S. Ballard, M. A. LeVitre, R. M. Conant, and E. D. Thomas. 2006. Changes in copper sulfate use on northeastern New York and Vermont farms between 2002 and 2005. *J. Dairy Sci.* 89(Suppl. 1):184.
- Green, L. E., V. J. Hedges, Y. H. Schukken, R. W. Blowey, and A. J. Packington. 2002. The impact of clinical lameness on the milk yield of dairy cows. *J. Dairy Sci.* 85:2250–2256.
- Hernandez, J., J. K. Shearer, and J. B. Elliott. 1999. Comparison of topical application of oxytetracycline and four nonantibiotic solutions for treatment of papillomatous digital dermatitis in dairy cows. *J. Am. Vet. Med. Assoc.* 214:688–690.
- Kyllar, V., J. Ryjacek, J. Sterc, and S. Cech. 1985. Incidence and treatment of dermatitis digitalis in dairy cows. *Vet. Med. (Praha)* 30:585–594.
- Laven, R. A., and H. Hunt. 2002. Evaluation of copper sulphate, formalin and peracetic acid in footbaths for the treatment of digital dermatitis in cattle. *Vet. Rec.* 151:144–146.
- Lucey, S., G. J. Rowlands, and A. M. Russell. 1986. The association between lameness and fertility in dairy cows. *Vet. Rec.* 118:628–631.
- Melendez, P., J. Bartolome, L. F. Archbald, and A. Donovan. 2003. The association between lameness, ovarian cysts and fertility in lactating dairy cows. *Theriogenology* 59:927–937.
- Murray, R. D., D. Y. Downham, M. J. Clarkson, W. B. Faull, J. W. Hughes, F. J. Manson, J. B. Merritt, W. B. Russell, J. E. Sutherst, and W. R. Ward. 1996. Epidemiology of lameness in dairy cattle: Description and analysis of foot lesions. *Vet. Rec.* 138:586–591.
- NRC. 2001. *Nutrient Requirements of Dairy Cattle*. 7th rev. ed. Natl. Acad. Press, Washington, DC.
- Peterse, D. J. 1985. Laminitis and interdigital dermatitis and heel horn erosion. A European perspective. *Vet. Clin. North Am. Food Anim. Pract.* 1:83–91.

- Read, D. H., and R. L. Walker. 1998. Papillomatous digital dermatitis (footwarts) in California dairy cattle: Clinical and gross pathologic findings. *J. Vet. Diagn. Invest.* 10:67–76.
- Sullivan, H. M., and New Mexico State University Cooperative Extension Service. 2005. Hairy foot warts. Cooperative Extension Service, College of Agriculture and Home Economics, New Mexico State University, Las Cruces.
- Thomsen, P. T., J. T. Sorensen, and A. K. Ersboll. 2008. Evaluation of three commercial hoof-care products used in footbaths in Danish dairy herds. *J. Dairy Sci.* 91:1361–1365.
- Warnick, L. D., D. Janssen, C. L. Guard, and Y. T. Grohn. 2001. The effect of lameness on milk production in dairy cows. *J. Dairy Sci.* 84:1988–1997.