New Zealand Veterinary Journal

ISSN: 0048-0169 (Print) 1176-0710 (Online) Journal homepage: www.tandfonline.com/journals/tnzv20

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To cite this article: RA Laven, KE Lawrence, JF Weston, KR Dowson & KJ Stafford (2008) Assessment of the duration of the pain response associated with lameness in dairy cows, and the influence of treatment, New Zealand Veterinary Journal, 56:5, 210-217, DOI: 10.1080/00480169.2008.36835

To link to this article: https://doi.org/10.1080/00480169.2008.36835

Scientific Article

Assessment of the duration of the pain response associated with lameness in dairy cows, and the influence of treatment

RA Laven[*§], KE Lawrence[*], JF Weston[*], KR Dowson[*] and KJ Stafford[*]

Abstract

AIM: To assess the welfare impact of lameness on dairy cattle in New Zealand by measuring the duration of allodynia (decreased nociceptive threshold) and increased locomotion score, and to evaluate the influence of treatment on that duration.

METHODS: After lame cows were treated using corrective paring by a veterinarian, they were allocated to one of six treatment groups. If the veterinarian determined that additional elevation of the lesion was not required the cow was randomly allocated to receive one of four treatments, *viz* 2 mg/kg tolfenamic acid, a plastic shoe to elevate the lesion, both treatments, or no further treatment. Cows that required additional elevation were treated using a plastic shoe and then randomly allocated to two separate treatment groups, either 2 mg/kg tolfenamic acid or no further treatment. Assessments of locomotion score (based on posture and gait) and mechanical nociceptive threshold (using a pneumatically actuated blunt pin) were made prior to treatment, and 3, 8, 28 and 100 days later.

RESULTS: Data were collected from 149 lame cows from nine dairy farms. There were significant improvements in mean locomotion score and nociceptive threshold in all treatment groups. At all time-points after treatment, locomotion score and nociceptive threshold were significantly improved when compared with the previous time-point. Thus, in these cows, the deleterious effects of lameness persisted for longer than 28 days, despite treatment, as the mean locomotion scores and nociceptive threshold on Day 100 were better than those on Day 28. No significant long-term benefit of using tolfenamic acid at the time of treatment was observed on either locomotion score or nociceptive threshold, nor was there any benefit in using a plastic shoe in cases where it had been determined that such treatment was not necessary.

CONCLUSIONS: This study demonstrated that the welfare impact of lameness on dairy cattle in New Zealand is of long duration even when treated effectively. In contrast to previous studies, no significant long-term benefit of using non-steroidal anti-inflammatory drugs (NSAID) at the time of treatment was observed, probably because unlike those previous studies the nociceptive threshold improved in the cattle which did not receive an NSAID, perhaps because treated cattle were kept on pasture rather than housed.

CLINICAL RELEVANCE: The long duration of increased allodynia after treatment demonstrates that prevention of lameness rather than therapeutic treatment is the key to reducing its impact on the welfare of dairy cows.

KEY WORDS: *Cattle, lameness, veterinary treatment, non-steroidal anti-inflammatory drug, plastic shoe*

Introduction

Lameness has a major impact on the productivity of dairy cattle, reducing milk production, decreasing fertility, increasing the likelihood of other diseases such as mastitis, and increasing the risk of culling (Peeler *et al.* 1994; Sprecher *et al.* 1997; Rajala-Schultz and Gröhn 1999). It also causes significant suffering and compromises the welfare of cattle (Anonymous 1997). Despite this, there are only limited published data from New Zealand on the impact of lameness on the productivity and welfare of the dairy cow. There is a need to better assess the effect of lameness on welfare, particularly as changes in the management of dairy cattle in New Zealand, such as increased herd size and greater use of housing, are likely to increase the incidence of lameness (Blowey 2005; Laven and Holmes 2008).

Indirect assessment of the pain felt by the lame cow is the only feasible measure of the welfare impact of lameness and response to treatment. The most commonly used indirect measure is locomotion score, based on observing gait and posture. Many different schemes are available but all have two significant disadvantages. Firstly, locomotion scoring is subjective, leading to noticeable differences between observers (Amory *et al.* 2006). Secondly, it is a relatively insensitive measure of pain as cattle with painful hoof lesions can have apparently normal locomotion scores (Dyer *et al.* 2007), while reductions in apparent response to pain may not be reflected in improvements in locomotion score (Whay *et al.* 2005). More objective and sensitive measures are needed.

One indirect measure less commonly used is measurement of the mechanical nociceptive threshold. As a result of the sensitisation of peripheral nerve endings, lame cattle have an exaggerated sensitivity to and perception of pain, i.e. hyperalgesia (Whay *et al.* 1998). They thus react to stimuli sooner than would be expected in a normal subject. A painful response to a stimulus that does not normally elicit pain is termed allodynia. This response, and by extension the presence of hyperalgesia, can be identified and quantified by measuring the pressure required to elicit limb withdrawal (Whay *et al.* 1997). Measurement of the nociceptive threshold is not a direct measure of pain. Firstly, the level of the nociceptive threshold is not necessarily related to pain perception (France *et al.* 2002). Secondly, allodynia may persist even when the original painful stimulus has disappeared (Ley *et al.* 1995). Nevertheless, Whay *et al.* (2005) concluded that measurement of the nociceptive threshold was a more objective measurement than

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AIC Akaike's information criterion
NSAID Non-steroidal anti-inflammatory drug(s)

locomotion score and was also a more sensitive predictor of the presence of lameness-associated pain.

Research undertaken in the United Kingdom (UK) has shown that the hyperalgesia associated with lameness is long-lasting. Despite remedial hoof-paring, the nociceptive threshold of cattle with claw-horn lesions did not increase significantly over a period of 28 days (Whay *et al.* 1998). A later study showed that the use of NSAID could significantly reduce the duration of this hyperalgesia; 3 days of treatment with a short-acting NSAID, ketoprofen, resulted in a significant increase in nociceptive threshold over a 28-day period (Whay *et al.* 2005). The direct relevance of these studies to the New Zealand situation is unclear as the aetiology and pathogenesis of lameness in dairy cows in New Zealand are markedly different from those in the UK (Laven and Lawrence 2006; Chesterton *et al.* 2008), as is the management of cows. This study was thus designed to evaluate the effect of lameness on nociceptive threshold under New Zealand conditions, and to assess the effectiveness of current lameness treatment regimes in reducing the hyperalgesia associated with lameness.

Materials and methods

Selection of animals

The study was undertaken between November 2006 and February 2007. During this period, farm staff on nine dairy farms in the Manawatu district, in the southern half of the North Island of New Zealand, were asked to identify lame cattle. These cattle were then examined by a veterinarian to ensure that the case met the study selection criteria of foot lameness due to claw-horn disease, e.g. white-line disease or sole penetration. Cattle with infectious foot disease, i.e. footrot, were excluded. Cattle were not excluded if more than one foot was affected. All measurements, and thus all analyses, were made on an individual cow basis. All procedures involving the experimental use of cattle were approved by the Massey University Animal Ethics Committee, Palmerston North, New Zealand.

Initial recording

All measurements of locomotion score or nociceptive threshold were made by one of two people, to ensure minimum effect of operator; >95% of measurements were made by one of these two.

Locomotion score was recorded for all cattle using the method described by Sprecher *et al.* (1997), which takes into account gait as well as limb and back posture. With this method, the score ranges from 1 for a cow with normal gait and posture to 5 for a cow that is unable, or extremely reluctant, to bear weight on one or more limbs. The affected foot was recorded, and the primary lesion classified. Lesions were divided into three categories, *viz* white-line lesions, sole lesions, and other (Chesterton *et al.* 2008). The primary lesion was also given a subjective severity score of either moderate or severe, based on the extent of the lesion.

Prior to treatment, the nociceptive threshold of the affected cows was measured using a pneumatically actuated blunt pin, 2 mm in diameter (Chambers *et al.* 1995). The pin was pressed against the dorsal aspect of the metatarsus, and the pressure required to produce a response from the cow identified. For cows with lameness of the hind foot, the lame limb was used to avoid forcing the cow to bear weight on its unsound limb. For cows which were lame on the forelimb, the contralateral hindlimb was used for the same reason. The pressure required to produce a response was recorded in kPa. Each animal was tested at 2-min intervals until three consistent responses were obtained.

Nociceptive threshold of non-lame cattle

On the first occasion each farm was visited, a non-lame cow was selected from the herd, and its nociceptive threshold measured. This provided a comparison on Day 0 between the nociceptive threshold of the lame cows and the non-lame cows in the same herd, to demonstrate that the cows selected as lame on Day 0 did have allodynia.

Treatment

The primary treatment in all cases was corrective hoof-paring, focussing on providing drainage of abscesses, removal of all underrun wall and sole horn, and reduction of weight-bearing at the primary lesion site.

After the corrective paring had been completed, an assessment was made as to whether the reduction in weight-bearing at the affected site was sufficient or whether a plastic shoe with a thickened sole (CowSlip; Dairystar Ltd, Auckland, NZ) needed to be applied to the unaffected claw of the same foot, to further reduce weight-bearing at the affected site. Cattle which did not require such a shoe were then randomly allocated, using a pre-prepared random allocation table, to one of four treatments, as follows. Treatment 1 comprised a single injection of tolfenamic acid (Tolfedine; Ethical Agents Ltd, Auckland, NZ), an NSAID, at 2 mg/kg (weight estimated by eye); Treatment 2 was as per Treatment 1, with the addition of the application of a plastic shoe; Treatment 3 was application of the plastic shoe alone; and Treatment 4 comprised no additional treatment.

If a cow, because of the site and/or the extent of the lesion, did require a plastic shoe to elevate the lesion, this shoe was applied prior to allocation to further treatment. Cows which required a plastic shoe were randomly allocated to two further separate treatment groups, either an injection of 2 mg/kg tolfenamic acid (Treatment 5) or to no additional treatment (Treatment 6). Treatment 5 thus differed from Treatment 2, and Treatment 6 from Treatment 3, because the cows in Treatments 5 and 6 were thought to require treatment to elevate the lesion.

In addition to the treatments described above, antibiotics were given if the veterinarian treating the case considered that the drainage produced by paring was not sufficient to eliminate infection, e.g. if there was significant heat and swelling around the coronary band. Such treatment was recorded, and did not exclude the cow from the study. However, cattle were excluded if amputation of the digit was thought to be the best method of treatment.

Further measurements

Additional measurements were made on Days 3, 8, 28 and 100 after treatment. For each lame cow, the locomotion score and the nociceptive threshold were measured as on Day 0. Records were kept for all cows, to identify if further treatment for lameness was required between Day 0 and Day 100. Further treatment with either antibiotics or NSAID did not exclude the animal from the study.

Statistical analysis

Data collected during the study were recorded and maintained using Microsoft Excel (Microsoft Corp, Redmond WA, USA), and were checked for errors against the written records prior to analysis. All statistical analyses were completed using SAS v9.1 (SAS Institute, Cary NC, USA) or R v2.4.1 (R Development Core Team, 2004; R Foundation for Statistical Computing, Vienna, Austria).

The data were characterised by longitudinally repeated measures of nociceptive threshold and locomotion score recorded for each cow at the initial and follow-up visits. The visits were irregularly spaced in time, being at Days 0, 3, 8, 28 and 100, respectively. The object of the analysis was to use the repeated measures to characterise a response profile for each treatment group over time.

A mixed linear model was generated to quantify the impact of treatment on nociceptive threshold (PROC MIXED; SAS v9.1). The distribution of the nociceptive threshold recordings was first normalised by using a square-root transformation. The covariance structure for the repeated measure was selected by comparing the Akaike's information criterion (AIC) for each covariance structure tested, and selecting that structure which gave the smallest AIC, which in this case was the first-order autoregressive structure (Littell *et al.* 2006).

A multinomial logistic model was fitted for the ordinal dependant variable, locomotion score, with a cumulative logit-link function, and a multinomial error distribution (PROC GENMOD; SAS v9.1). By default, this procedure can only model independence for multinomial response data, and modelled the probabilities of levels of locomotion score having lower ordered values in the response profile table.

Both models were similarly built. Farm, treatment, visit and a baseline measure of nociceptive threshold (PROC MIXED) or locomotion score (PROC GENMOD) recorded at the first visit were all included as *a-priori* fixed effects. Other variables were tested in each model and retained at a significance level of 0.05, or if they caused a change of >15% in the coefficient of a variable already included in the model. Biologically sensible interactions were tested for in both models. The final model for locomotion score contained only the *a-priori* variables and an interaction between visit and treatment whereas the model for nociceptive threshold additionally contained the variable describing severity (either moderate or severe), the variable describing either fore- or hind-limb, an interaction between farm and severity, and an interaction between limb and visit.

The association between locomotion score, nociceptive threshold and time were analysed using univariate ANOVA, with the Tukey test to identify *post-hoc* differences.

Unless otherwise stated, $p<0.05$ was selected as the level for statistical significance.

Results

Data were collected from 149 lame cattle from nine farms. The number of lame cows per farm varied from two to 38. Of the nine herds two comprised predominantly Jersey cows, and the remainder were predominantly Friesian. Treatment of lame cows was undertaken by all four of the veterinarians in the Massey farm practice. One veterinarian treated only five cases; the remainder of the cases were equally divided amongst the remaining three.

Table 1 summarises the data in regard to the number of cows allocated to treatment, the lesions seen, and the affected feet. There were no significant differences between Treatments 1 to 4, or between Treatments 5 and 6, in the proportion of cases with sole or white-line lesions or with fore or hind feet affected.

At the time of treatment, on all farms, lame cattle had nociceptive thresholds that were markedly lower than those of the sound cattle (mean 22 kPa *vs* 45 kPa), consistent with the 149 treated cows having allodynia at the time of treatment.

Overall, it was considered that 44% of cattle examined required a plastic shoe. There were differences in the distribution of lesions seen in this group of cattle, which were assigned to Treatments 5 and 6, and those which were not thought to require a plastic shoe and which were thus allocated to Treatments 1 to 4. The former had a higher proportion of white-line lesions (82 *vs* 75%) and hind-foot lesions (72 *vs* 63%) but these differences were not significant ($p>0.2$ for both).

Antibiotics were used on Day 0 in nine cases (6%). In seven of these cases, antibiotics were given to cattle which had been allocated to Treatment 5 or 6. During the study, seven cows (4.6% of cases) required re-treatment for lameness. Two of these were on Day 8, both of which were given antibiotics in addition to paring; four were on Day 28, of which only one was given antibiotics; and one was on Day 90, when it was given antibiotics.

Effect of treatment on locomotion score and nociceptive threshold

Figure 1 shows the change in nociceptive threshold and locomotion score over the100-day period of the study for all cows in all treatment groups. At each time-point each of the models showed that there was a significant improvement in nociceptive threshold and locomotion score compared with the previous time-point, such that the nociceptive threshold on Day 100 was significantly higher than that on any other day, while the locomotion score was significantly lower. These differences were large and biologically

Table 1. Distribution between treatment groups of lame dairy cows in the number of cases and type and site of lesion.

Treatment[a]	Elevation of lesion required	No. of cases	No. of sole lesions[b]	No. of white-line lesions[b]	Feet affected: fore / hind / both	Proportion of severe lesions[b]
1	No	24	5	13	11 / 12 / 1	6/21
2	No	21	2	15	7 / 13 / 1	5/19
3	No	18	6	11	5 / 13 / 0	6/17
4	No	18	5	13	6 / 12 / 0	4/17
5	Yes	35	5	30	12 / 22 / 1	22/35
6	Yes	33	7	26	7 / 26 / 0	19/33

[a] Cattle were divided into two sets prior to the allocation of treatments. Cattle which were not thought to require elevation of the lesion in addition to corrective hoof-paring were randomly allocated to one of four treatments, *viz* Treatment 1 = 2 mg/kg tolfenamic acid, Treatment 2 = Treatment 1 plus plastic shoe, Treatment 3 = plastic shoe alone, and Treatment 4 = no additional treatment. Cattle which, after hoof-paring, were thought to require elevation of the lesion had a plastic shoe applied, and were then randomly allocated to one of two additional treatment groups, *viz* Treatment 5 = 2 mg/kg tolfenamic acid, and Treatment 6 = no additional treatment

[b] Details not available for all cases

significant. For example, the OR of a cow having a lower locomotion score at Day 3 than on Day 0 was 10.3 (95% CI=6.0–17.5), while the OR for Day 100 being better than Day 28 was 4.7 (95% CI=1.8–12.2).

Figures 2 and 3 show the response in terms of nociceptive threshold and locomotion score for Treatments 1 to 4, i.e. those cows where the veterinarian considered that a plastic shoe was not required. As in Figure 1, all graphs show a continuous improvement from Day 0 to Day 100. There were no significant differences between treatments in the change in nociceptive threshold or locomotion score.

Figure 4 shows the response to treatment for cattle where the veterinarian considered that the nature of the lesion required the application of a plastic shoe to reduce weight-bearing. As with the previous figures, there was a continued improvement with time. The model for nociceptive threshold identified no significant

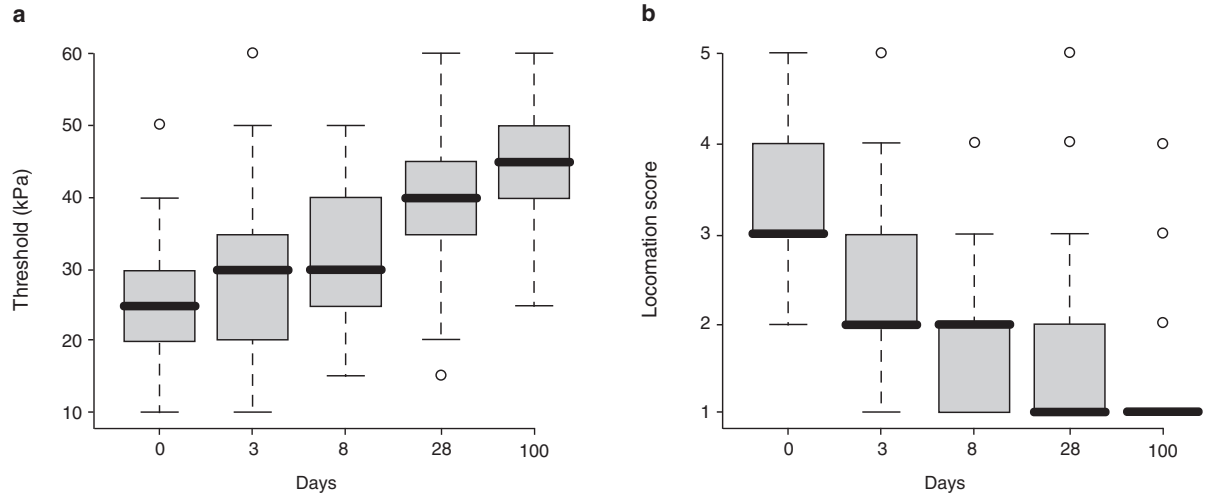

Figure 1. Boxplots of (a) nociceptive threshold (kPa) *vs* days after corrective paring, and (b) locomotion score *vs* days after corrective paring, for all cows irrespective of treatment allocation for lameness. Interpretation of boxplots: The central box spans the quartiles; the line in the box marks the median. Observations more than 1.5x interquartile range are plotted individually as possible outliers (open circles). Lines extend from the box to the smallest and largest observations that are not outliers.

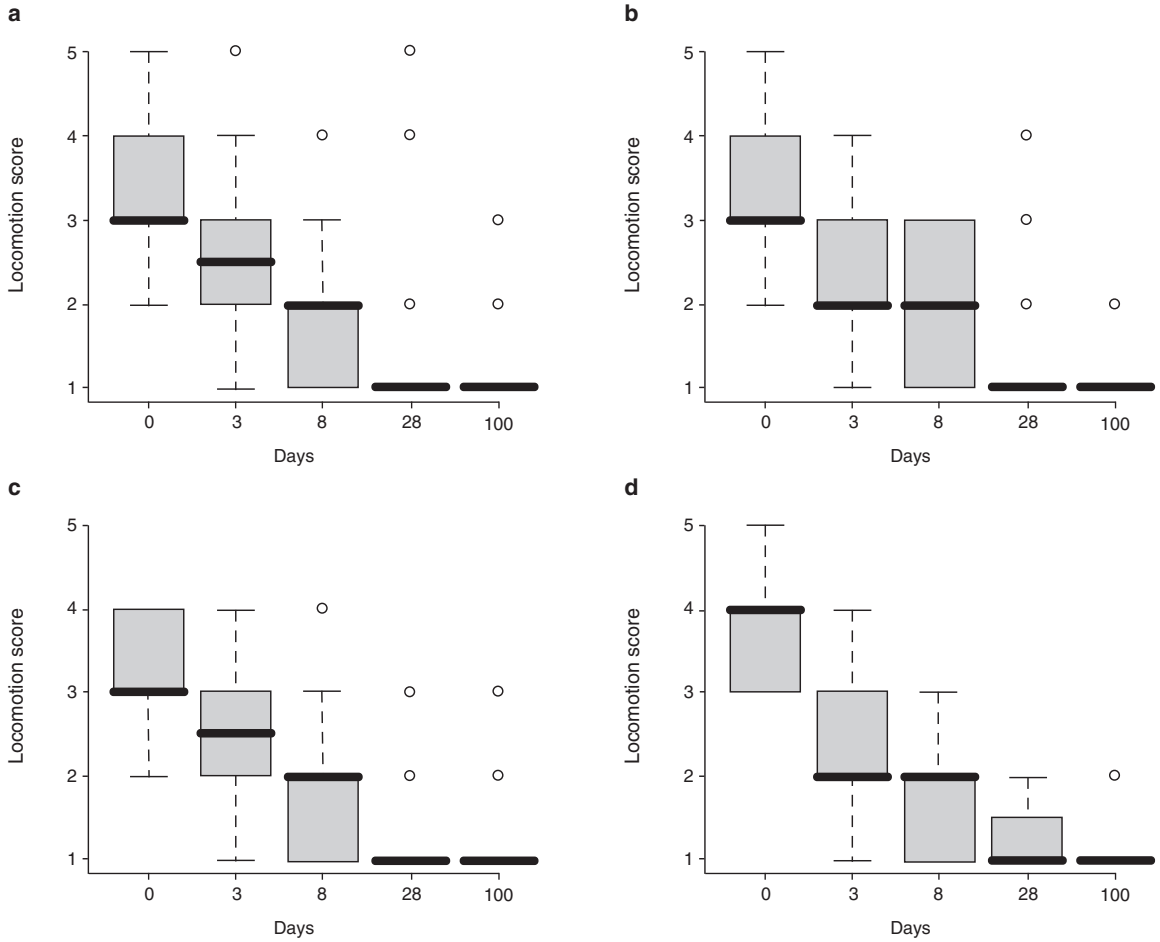

Figure 2. Boxplots of locomotion score *vs* days after treatment by corrective paring for all lame cows which did not require elevation of the lesion with a plastic shoe. Cows were allocated randomly to additional treatment with (a) 2 mg/kg tolfenamic acid, (b) tolfenamic acid plus a plastic shoe, (c) a plastic shoe only, or (d) no additional treatment. Interpretation of boxplots: see caption for Figure 1.

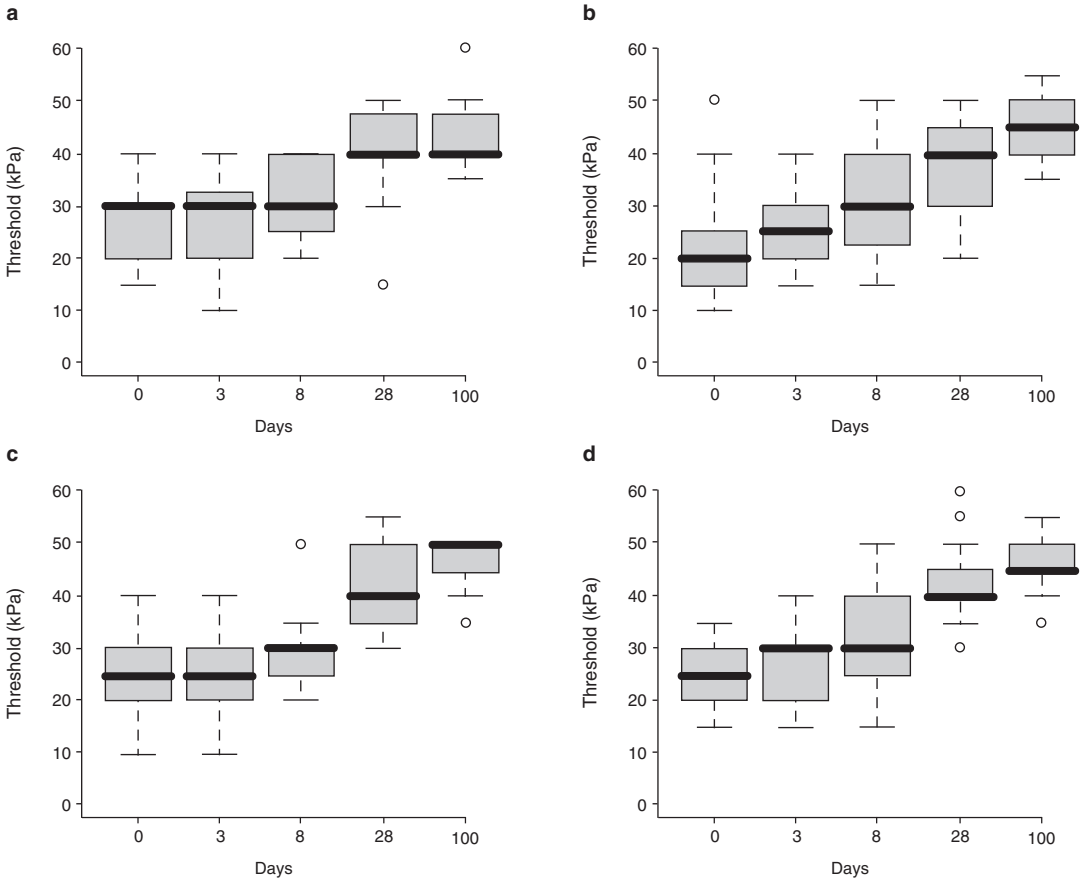

Figure 3. Boxplots of nociceptive threshold (kPa) *vs* days after treatment by corrective paring for all lame cows which did not require elevation of the lesion with a plastic shoe. Cows were allocated randomly to additional treatment with (a) 2 mg/kg tolfenamic acid, (b) tolfenamic acid plus a plastic shoe, (c) a plastic shoe only, or (d) no additional treatment. Interpretation of boxplots: see caption for Figure 1.

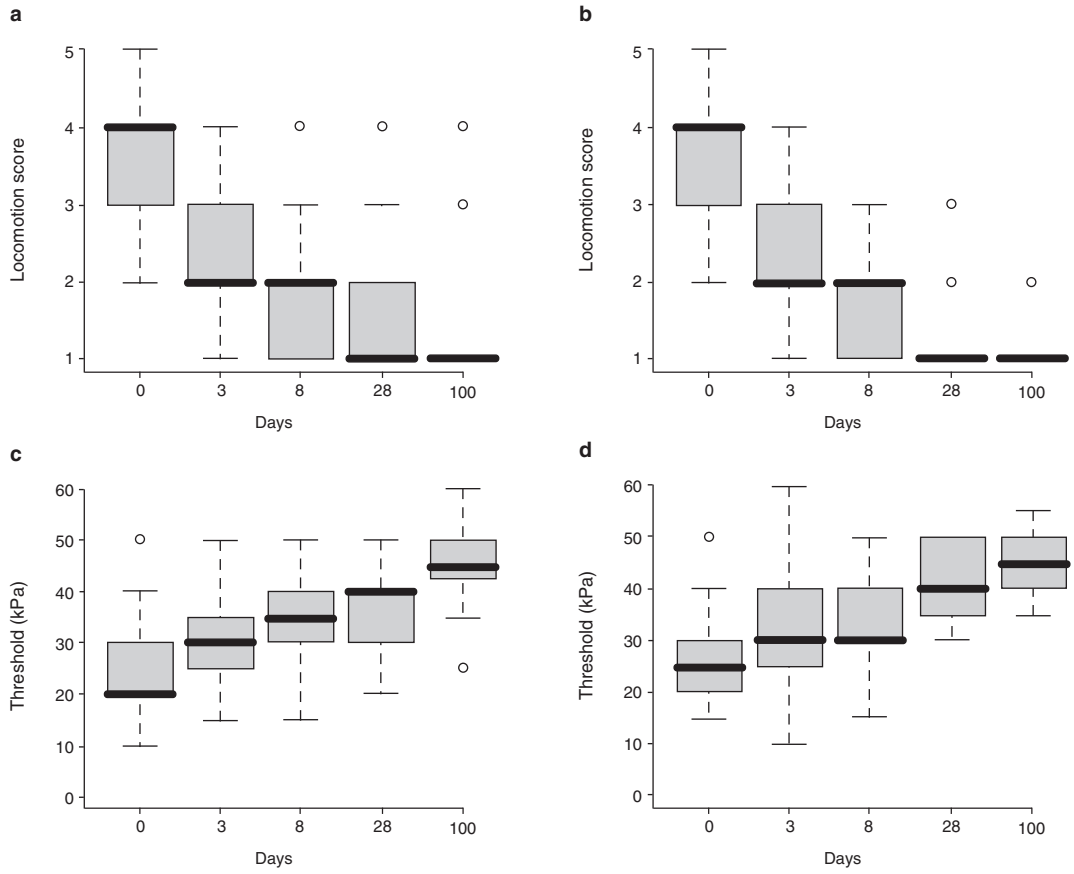

Figure 4. Boxplots of (a) and (b) locomotion score, and (c) and (d) nociceptive threshold (kPa) *vs* days after treatment by corrective paring for all lame cows which required elevation of the lesion with a plastic shoe. Cows were allocated randomly to additional treatment with (a) and (c) 2 mg/kg tolfenamic acid, or (b) and (d) no additional treatment. Interpretation of boxplots: see caption for Figure 1.

benefit of treatment with tolfenamic acid over the 100-day period. For locomotion score, the model indicated that cattle which were treated with tolfenamic acid (Treatment 5) tended to have a higher locomotion score than cows which received no additional treatment (Treatment 6), though this effect was small (OR=2.0; 95% CI=1.3–3.1).

There was a significant interaction between treatment and visit for the nociceptive threshold model. At the second visit (Day 3) the nociceptive threshold for Treatment 5 (p=0.015) and Treatment 6 (p=0.074) was higher than the nociceptive threshold for Treatments 1 to 4 at the same visit. This difference was not observable at later visits (Figure 5).

Effect of farm on response to treatment

Differences between farms were apparent from the raw data, but as the farms were purposively rather than randomly sampled the study was not designed to statistically evaluate such differences; farm was included as a fixed effect in the main models.

Effect of lesion type on response to treatment

There was no significant effect of lesion type, i.e. sole or white-line disease, on the response to treatment (p=0.34 for nociceptive threshold; p=0.14 for locomotion score).

Effect of leg on response to treatment

Whether the lesion was on the fore- or hind-limb had no effect on nociceptive threshold, however there was a significant effect on locomotion score. Fore-limb lesions had an OR of 2.1 ((95% CI=1.2–3.5) of having a lower locomotion score compared with hind-limb lesions. There was also a significant interaction with visit, indicating that the effect of leg on locomotion score changed with visit.

Effect of lesion severity on response to treatment

There were no obvious differences in the response to treatment of cattle with lesions categorised as severe compared with those which had moderate lesions. Both groups improved markedly between Day 0 and Day 100; 4/80 moderate cases and 3/62 severe cases required re-treatment. However, cattle that were categorised by the veterinarian as having moderate lesions on Day 0 tended to have a lower locomotion score throughout the study period (OR=1.9; 95% CI=1.4–2.7), and a non-significant lower nociceptive threshold (p=0.16), compared with severe lesions.

Effect of other factors on response to treatment

No differences were observed between cows treated by different veterinarians (p>0.1).

Relationship of locomotion score to nociceptive threshold

When data from all time-points were included there was a significant inverse relationship between nociceptive threshold and locomotion score (r^2=0.26). Cattle with a locomotion score of 1 had a significantly higher nociceptive threshold than those with a locomotion score of ≥2 (p<0.05), while the same was true of cattle with a locomotion score of 2 when compared with those with a score of ≥3, and for cattle with a locomotion score of 3 when compared with those with a score of ≥4. There was no significant difference between the nociceptive threshold of cattle with locomotion scores of 4 and 5.

There was also a significant effect of time on the relationship between nociceptive threshold and locomotion score (Figure 6). The figure demonstrates that as cows recovered and the allodynia reduced a locomotion score of ≤3 at later visits was associated with a much higher nociceptive threshold than cows given the same locomotion score at an earlier visit. However, for cows achieving a locomotion score of 4, which would equate with poor response to treatment, there was no visible relief of allodynia.

Discussion

In all six treatment groups, corrective trimming, with or without other treatments, resulted in a significant improvement in gait and posture as well as modulation of the allodynia associated with lameness. Notably, the improvement in both locomotion score and nociceptive threshold continued between Day 28 and Day 100, confirming under New Zealand conditions the chronic impact of lameness on the welfare of dairy cattle.

This study has also shown that antibiotics are not necessary in the great majority of cases of lameness. Only 6% of cases were given antibiotics on Day 0, and only seven of the 149 cases required re-treatment for lameness during the subsequent 100 days, even though the cattle were relatively closely monitored as a result of the study. The results of this study thus strongly support the sug-

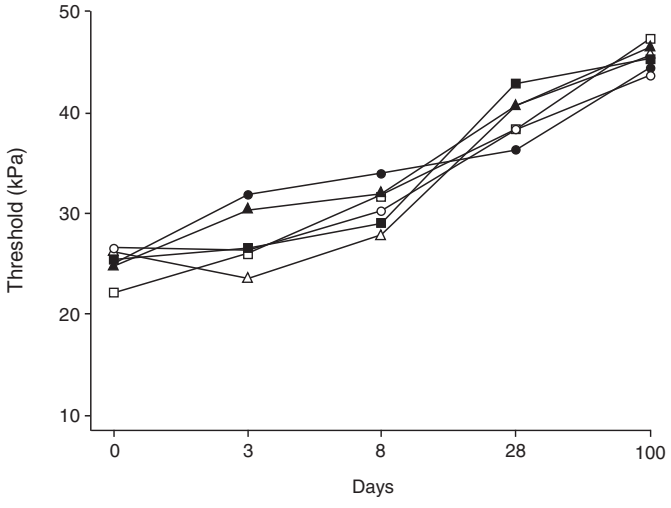

Figure 5. Effect of time on nociceptive threshold (kPa) for lame cows which did not require elevation of the lesion with a plastic shoe and which were treated with 2 mg/kg tolfenamic acid (○), tolfenamic acid plus a plastic shoe (□), a plastic shoe only (△), or no additional treatment (■); or which did require elevation of the lesion with a plastic shoe and which were treated with 2 mg/kg tolfenamic acid (●), or no additional treatment (▲). Day 0 was the day when all lame cows were treated by corrective paring.

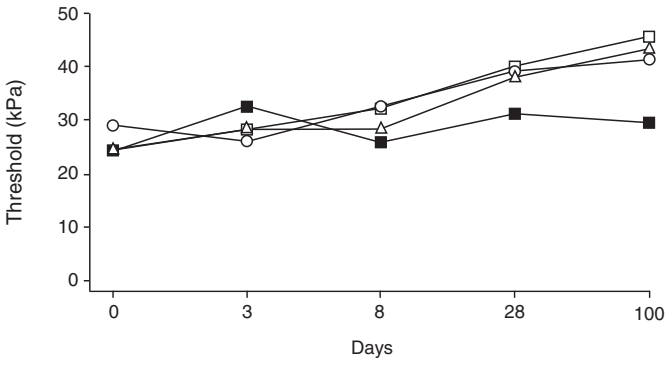

Figure 6. Effect of time on the relationship between nociceptive threshold (kPa) and locomotion scores (1= □, 2=○, 3=△, 4=■), of lame dairy cows. All cows were included, but there were insufficient data for locomotion score 5. Day 0 was the day when all lame cows were treated by corrective paring.

gestion by Chesterton (1995) that judicious use of shoes or blocks to elevate the lesion after trimming will greatly reduce the requirement for antibiotics.

White-line disease is probably more difficult to treat than sole injury (Chesterton *et al.* 2008). However, this study found no significant impact of lesion type on the response of the nociceptive threshold to treatment. Further research is required to establish whether this effect on nociceptive threshold was due to insufficient power in the study.

None of the treatments evaluated in this study significantly improved the response of the nociceptive threshold to corrective trimming over the long term. Thus, based on these results, if corrective trimming results in no or only limited weight-bearing on the lesion site there is no benefit from the application of a plastic shoe. However, this does not mean that elevating an injured claw by gluing a block or shoe to the sole of the healthy claw is of limited value. Of the 149 lame cows treated in this study, 65 were thought to require a plastic shoe. We believe that this figure (approximately 45%) indicates the proportion of lame cows which need such treatment, and that rates of use appreciably below this indicate that correct treatment is not being given.

Similarly, this study found no evidence that the use of tolfenamic acid had a significant long-term benefit on nociceptive threshold. There was an apparent short-term benefit as on Day 3 cattle in Treatment 5, which required a plastic shoe and which were treated with tolfenamic acid, had a significantly higher nociceptive threshold than cattle which did not require elevation of the lesion (Treatments 1 to 4). However, it is likely that much of this effect was due to the tendency of cattle which required a plastic shoe to respond better to treatment than those which did not. The nociceptive threshold of cattle in Treatment 6 was also elevated compared with Treatments 1 to 4, and was not significantly different from that of cattle in Treatment 5 .

In contrast, Whay *et al.* (2005) reported that the use of ketoprofen for 3 days at the time of treatment did modulate allodynia over a 28-day period. However, their conclusion was based on a significant improvement in cattle treated with ketoprofen and the absence of such an improvement in cows treated with saline. In the study presented here, a significant improvement in nociceptive threshold occurred in cattle which received tolfenamic acid as well as those which did not. Thus, the difference between the two studies was in the control group not in the cattle treated with the NSAID. This was further emphasised by the fact that on a direct comparative basis the mean nociceptive threshold of cattle treated with ketoprofen was never significantly greater than that of the control cows (Whay *et al.* 2005), the same result obtained by our study.

There are several potential reasons for this difference between the two studies. Firstly, it is possible that the corrective trimming used in the cattle in the present study was more effective than that reported by Whay *et al.* (2005), either because of greater veterinary skill or because the diseases treated in this study were less severe. The former is unlikely because the corrective trimming described by Whay *et al.* (2005) was undertaken by veterinarians working at the University of Bristol farm practice. Those veterinarians would be expected to be of similar skill to those who undertook the treatments in our study.

Ascertaining whether there was a difference in lesion severity is more complex. In our study, all lesions were in the claw horn whereas Whay *et al.* (2005) included acute digital diseases, such as footrot, which have a much shorter-lasting impact on hyperalgesia than claw-horn diseases (Whay *et al.* 1998). The lesions treated in our study were thus, on average, likely to have a greater impact on nociceptive threshold than the cattle studied by Whay *et al.* (2005). However, differences in farming systems between New Zealand and the UK may mean that the claw-horn lesions seen in our study had been identified at an earlier stage (Laven and Holmes 2008), but the clinical appearance of many of the lesions treated in our study was not suggestive of early lesions. In particular, >25% of cases had abscesses which had spread from the original lesion and burst out either at the heel or at the coronary band, a markedly higher proportion than would be expected in a similar population of lame cows in the UK (RA Laven and KE Lawrence, unpubl. obs.). Further research into the pathogenesis of lameness of dairy cattle in New Zealand is required. In particular, it should focus on the development of clinical lesions, identifying the point at which they produce hyperalgesia and how this relates to lameness that is detectable by the farmer.

Another potential explanation for the difference between the two studies is that the environment the cattle were put into after treatment was somehow 'better' in our study than that encountered by the cows assessed by Whay *et al.* (2005). None of the cows in our study was housed after treatment; indeed, most were kept for varying periods in the paddocks near to the milking parlour. In contrast, a significant proportion of the lame cows studied by Whay *et al.* (2005) were housed after treatment. Environment can have a major impact on the length of time for which cows are lame. For example, cattle kept in cubicles bedded with sand had a lower prevalence of lameness than cattle housed in similar yards bedded using rubber mattresses, probably because lame cows spent significantly more time lying down in the sand-bedded yards (Cook *et al.* 2004). Increased cow comfort after treatment, i.e. pasture *vs* housing, may have led to the better response seen in the control group in our study. This suggestion is supported by the results of a study in Canada, where it was found that keeping mildly lame cattle on pasture rather than in cubicle yards with concrete passageways significantly improved gait (Hernández-Mendo *et al.* 2007). Such a study needs repeating under New Zealand conditions. In particular, the benefits of keeping lame cattle in the paddocks near the milking parlour rather than in the main herd need to be properly evaluated, particularly on farms which house their cattle (Laven and Holmes 2008).

The current study evaluated the long-term benefit of tolfenamic acid on nociceptive threshold. As such, the absence of such a benefit is not evidence that NSAID are of no benefit in the treatment of lameness. Tolfenamic acid has proven analgesic and anti-inflammatory effects in cattle (Deleforge *et al.* 1994; Landoni *et al.* 1995) but our first measurement of nociceptive threshold was made 72 hours after the injection of tolfenamic acid, 24 hours longer than the dosage interval recommended in the product datasheet (Ethical Agents Ltd). Further research is required to quantify the short-term benefits of treating lame cattle with NSAID; in particular, data are needed on whether different products have significantly different benefits.

In the study presented here, the response to treatment in terms of locomotion score was very similar to that seen with nociceptive threshold, and similar to that reported by Whay *et al.* (2005). The only exception was that in cattle which required a plastic shoe, treatment with tolfenamic acid resulted in a higher locomotion score than cows that were not treated. However, this effect was small (OR=2), and was not biologically significant or plausible, so was probably an artefact.

This is the first study which has evaluated the effect of lameness in the fore- or hind-limbs on nociceptive threshold and locomotion score. In this study, cattle identified with forelimb lameness tended to have the same nociceptive threshold as cattle with hindlimb lameness. This was despite cattle with forelimb lameness having the stimulus applied to a non-lame leg (contralateral hindlimb). This suggests that the allodynia associated with lameness is central in origin rather than peripheral (Anderson and Muir 2005). In contrast, there was an effect of (lame) leg on locomotion score. The cause of this is unclear but it could be that the gait changes resulting from forelimb lameness are more subtle, and therefore scored at a lower level. These differences and the change seen in this study in the relationship between locomotion score and nociceptive threshold after treatment highlight the difference between these two measures and support the suggestion that nociceptive threshold may be a better measure of response to treatment than locomotion score (Whay *et al.* 2005).

In conclusion, this study showed that under New Zealand conditions veterinary treatment of lameness was effective at improving locomotion score and reducing allodynia. However, it again emphasised that the impact of lameness is long term even when treated effectively. Thus, prevention has to remain the key if the impact of lameness on cattle welfare is to be reduced.

Acknowledgements

This study was funded by MAF/Biosecurity New Zealand. The authors would like to thank all the farmers who allowed their cattle to be used for this study, and Paul Chambers for the loan of the nociceptive threshold measuring device. We are also grateful for the donation of the tolfenamic acid by Ethical Agents Ltd, and of the CowSlips by Dairystar Ltd.

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Submitted 07 November 2007

Accepted for publication 05 August 2008

[*] Non-peer-reviewed