Quarter and cow risk factors associated with a somatic cell count greater than 199,000 cells per milliliter in United Kingdom dairy cows

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ABSTRACT

Quarter and cow risk factors associated with a somatic cell count (SCC) >199,000 cells/mL at the next milk recording during lactation were investigated during a 12-mo longitudinal study on 8 commercial Holstein-Friesian dairy herds in Southwest England, United Kingdom. The individual risk factors studied on 1,677 cows included assessments of udder and leg hygiene, teat-end callosity and hyperkeratosis, body condition score (BCS), and measurements of monthly milk quality and yield. The outcome variable used for statistical analysis was the next recorded individual cow SCC >199,000 cells/mL. Statistical analysis included use of generalized linear mixed models. Significant covariates associated with an increased risk of SCC >199,000 cells/mL were increasing parity, increasing month of lactation, previous SCC (SCC 200,000 cells/mL and greater, odds ratio = 7.12), and cows with a BCS <1.5 (odds ratio = 2.09) or BCS >3.5 (odds ratio = 2.20). Significant covariates associated with a reduced risk of SCC >199,000 cells/mL were cows with contamination of the skin of the udder and quarters with mild (odds ratio = 0.65) and moderate (odds ratio = 0.62) hyperkeratosis of the teat-end. These results suggest that individual quarter and cow-level factors are important in the acquisition of intramammary infections as measured by SCC during lactation. Cow energy status, as measured by BCS, may influence the risk of intramammary infection during lactation.

Key words: somatic cell count, risk factor, body condition score, hyperkeratosis

INTRODUCTION

There has been a trend for the geometric mean bulk milk SCC to increase in the United Kingdom, with the estimated monthly mean bulk milk SCC recorded at

167,000 cells/mL in December 2001 and 181,000 cells/mL in December 2007 (www.mdcdatum.org.uk). In addition to direct financial implications to producers of a bulk milk SCC, there are indirect effects arising from elevated SCC, including reduced yield (Swinkels et al., 2005), potential for the spread of pathogens to uninfected cows (Zadoks et al., 2001; Barkema et al., 2006), and reduced fertility in early lactation (Schrack et al., 2001). Barkema et al. (2006) concluded that these indirect costs may become more important than the direct costs associated with management of high-SCC cows, such as antibiotic treatment, extra herds-person time in the parlor, and milk withdrawal.

The most important cause of variation in milk SCC is infection status (Brolund, 1985; Laevens et al., 1997; Schepers et al., 1997). Somatic cell count can indicate likely infection within the udder, and SCC of 200,000 cells/mL is generally regarded as being suggestive of bacterial infection (Brolund, 1985; Schepers et al., 1997), with sensitivity at this threshold between 74.5 and 83.4% (Schepers et al., 1997).

The causes of subclinical IMI in UK dairy cows are predominantly *Streptococcus uberis* and CNS (Bradley et al., 2007). Quarter level risk factors for IMI include teat position and shape (Weiss et al., 2004), low minimum teat height above the ground, acute teat-end lesions and traumatized teats (Sieber and Farnsworth, 1981), previous bacterial infection (Zadoks et al., 2001), and teat-end hyperkeratosis (HK). A UK study of 2,000 quarters showed that as the severity of HK increased, the likelihood of a quarter testing positive using the California Mastitis Test increased (Lewis et al., 2000). A longitudinal study of 2,157 cows found associations between increasing teat-end callosity (TEC) and clinical mastitis (CM; Neijenhuis et al., 2000); however, the effect of TEC on SCC was not reported.

Cow-level risk factors for IMI as measured by SCC include breed, lactation number (Brolund, 1985; Schepers et al., 1997), leaking milk between milkings (Sieber and Farnsworth, 1981), milk yield at drying off (Rajala-Schultz et al., 2005), cow cleanliness (Schreiner and Ruegg, 2003), and negative energy balance in

Received July 18, 2008.

Accepted March 13, 2009.

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early lactation (Suriyasathaporn et al., 2000). A US study confirmed a relationship between cleanliness of cows and the rate of subclinical mastitis, and demonstrated a linear relationship between dirty udders and SCC (Schreiner and Ruegg, 2003). The purpose was to investigate quarter and cow risk factors for SCC >199,000 cells/mL during lactation in UK dairy herds, particularly those related to cow hygiene, TEC, HK, and energy balance because these traits can be modified or improved to reduce the likelihood of infection.

MATERIALS AND METHODS

Herd Selection

A convenience sample of 8 commercial Holstein-Friesian dairy herds was selected from a milk-recording database (National Milk Records, Chippenham, UK). Inclusion criteria included location (within a 2-h drive of the School of Veterinary Science, University of Bristol, Langford, UK), a high incidence rate of CM (>0.5 cases per cow year), available monthly milk quality and individual cow SCC data, and likely compliance with data recording and sampling. No restrictions were placed at enrollment on bulk milk SCC because this could be manipulated by producers and may not accurately reflect current herd IMI status. None of the herds was managed under organic conditions. A summary of herd management details is presented in Table 1.

Bacteriological Samples

Milk samples for bacteriology were collected from 10 random quarters in each herd from cows recording 2 of the previous 3 recordings >199,000 cells/mL in accordance with an aseptic sampling technique at the beginning of the study. This process was repeated at 6 and 12 mo. In addition, farmers were requested to take milk samples from all cases of CM (defined as visible milk changes, swelling of the udder, or clinical signs of systemic illness in the cow, or their combination) that occurred before treatment and store them frozen for bacteriological analysis. After training, farmers performed sampling in accordance with a written standard operating procedure, using a supplied kit. This approach allowed cost-effective insight into causes of IMI for each herd. Financial constraints precluded the use of bacteriology on all quarters.

All milk samples collected were frozen and packaged and submitted for microbiological analysis at an accredited laboratory (Compton Paddock Laboratories, Newbury, Berkshire, UK) and analyzed using standard laboratory methods, with slight modifications, for the microbiological analysis of milk (National Mastitis

Table 1. Descriptive summary of the study herds at the beginning of the study

Herd	Herd size (n)	Mean parity	Calving pattern	Lactating cow housing	Average 305-d milk yield (L/cow)	Geometric mean BMSCC ¹ (cells/mL)	Prevalence of SCC >199,000 cells/mL (%)
1	92	3.4	Nonseasonal	Straw yards	7,442	152,000	21
2	226	3.4	Nonseasonal	Free stalls (sand)	10,938	148,000	26
3	198	3.3	Nonseasonal	Free stalls (chopped straw)	7,711	175,000	37
4	151	3.0	Seasonal ²	Free stalls (chopped straw)	8,535	76,000	7
5	266	3.1	Nonseasonal	Free stalls (sawdust)	8,370	233,000	27
6	218	2.4	Seasonal ³	Free stalls (paper)	9,966	157,000	24
7	146	2.7	Nonseasonal	Free stalls (chopped straw)	7,537	191,000	25
8	71	3.8	Nonseasonal	Free stalls (chopped straw)	8,343	151,000	16

¹Bulk milk SCC.

²Autumn and spring.

³Autumn.

Council, 1999). Ten microliters of secretion was inoculated onto blood agar and Edward's agar, and 100 μ L of secretion was inoculated onto MacConkey agar to enhance the detection of Enterobacteriaceae (National Mastitis Council, 1999). Plates were incubated at 37°C and read at 24, 48, and 72 h. Organisms were identified by gross colony morphology and gram stain and by further confirmatory techniques as necessary (Quinn et al., 1994). If a major or minor bacterial pathogen was isolated, it was recorded as an infection regardless of the number of colony-forming units (Green et al., 2004). The presence of >3 bacterial species was considered a contaminated result; more than 1 major pathogen was considered a mixed etiology with both organisms causal.

Visit Protocol

The cohort of farms was visited every month to collect quarter and cow-level data over 12 mo (June 2004 to May 2005), a total of 96 herd visits. Milking cows were observed during a milking and the number of cows in milk on the day of the visit was recorded. A dictaphone (a portable sound-recording device) was used to capture data at each visit and the information was later transcribed onto a paper system. All animals were initially identified by freeze brand and linked with their ear tag from milk recording information. For all scoring assessments, standardized procedures were produced, including laminated photographs to promote consistency. All measurements were made by 1 researcher.

Explanatory Variables—Data Collection

Hygiene scores were collected as each cow entered the parlor, and scores were recorded along with the freeze-brand number. Cow udder and leg hygiene were assessed, and scores were collected using a 4-point scale described in a recent study (Schreiner and Ruegg, 2002). An udder hygiene score (**UHS**) or leg hygiene score (**LHS**) of 1 indicated no contamination of the skin of the rear of the udder or the hind limb between the hock and coronary band, a score of 2 was slightly dirty (2 to 10% of the area covered in dirt), a score of 3 was moderately dirty (10 to 30% of the area covered in dirt), and a score 4 indicated caked-on dirt (>30% of these areas completely covered in dirt).

Immediately after cessation of milking and removal of the cluster but before the application of postmilking teat disinfection, all 4 teats were examined using a light source, and an assessment of TEC thickness and roughness was made using an 8-point scale (Neijenhuis et al., 2000). A score of N described a normal teat-end appearance; a score of 1A, 1B, or 1C described a thin,

moderate, or thick smooth callosity ring, respectively; and a score 2A, 2B, or 2C, and 2D described a thin, moderate, thick, or extreme (i.e., severe HK) rough callosity ring, respectively. The TEC data were converted into a cow-level score by assigning each TEC score a number from 1 to 8, so a score of N became 1, a score of 1A became 2, and so on. This allowed each cow to obtain a mean TEC score (an arithmetic mean of the 4 quarter TEC scores) and a maximum TEC score (the highest quarter TEC value) for each visit.

Cow BCS was measured using a 5-point scale (Edmonson et al., 1989) and was performed visually from behind the cow upon exit from the parlor. Milk recording data were downloaded from National Milk Records (www.nmr.co.uk) after obtaining written permission from the farmers and were imported into herd management software (Interherd, NMR Agrisoft, Harrogate, UK). This provided parity, calving date, monthly SCC, monthly recorded butterfat and milk protein percentages, yield information, and DIM at each monthly visit where individual cow data were collected.

Outcome Variable—SCC

The SCC was incorporated as a binary outcome, (i.e., a threshold level outcome, where an SCC >199,000 cells/mL = 1) because it was considered the most appropriate biologically plausible indicator of a likely IMI.

Statistical Analysis

All data were entered into a database (Microsoft Access, Microsoft Corp., Redmond, WA) and checked for incorrect entries. Covariates were individually assessed by chi-square tests or ANOVA (Petrie and Watson, 1999), as appropriate, using Microsoft Excel (Microsoft Corp.) and Minitab 13.30 (Minitab Inc., State College, PA). Generalized linear mixed models were specified (Goldstein, 1995) using MLwiN (Rasbash et al., 1999). The response variable was "next individual cow SCC >199,000 cells/mL." Random effects were included for quarter (level 2) and cow (level 3) to account for the correlated nature of the data; repeated measures within quarters and quarters within cow. Herd was included as a fixed effect. Parity and stage of lactation were investigated as potential confounding covariates and included in the final models. Covariates with a trend toward significance ($P < 0.25$) were initially carried forward for inclusion in subsequent models. The last step in model building was to individually reintroduce each covariate into the model to assess its impact on model parameters. This was carried out to ensure that previously discarded variables did not become signifi-

Table 2. Mastitis bacteriology for samples collected at the beginning, at 6 mo, and at the conclusion of the study period from cows with SCC >199,000 cells/mL and in all cases of clinical mastitis sampled

Mastitis diagnosis ¹	SCC >199,000 cells/mL		Clinical mastitis	
	Number of diagnoses (n = 240)	%	Number of diagnoses (n = 640)	%
Major pathogens				
<i>Streptococcus uberis</i>	31	12.9	121	18.9
<i>Escherichia coli</i>	8	3.3	171	26.7
Coagulase-positive staphylococci (including <i>Staphylococcus aureus</i>)	10	4.2	20	3.1
Yeast spp.	5	2.1	17	2.7
<i>Proteus</i> spp.	2	0.8	2	0.3
<i>Bacillus</i> spp.	2	0.8	8	1.3
<i>Serratia</i> spp.	1	0.4	0	0.0
<i>Pasteurella</i> spp.	1	0.4	0	0.0
<i>Streptococcus agalactiae</i>	0	0.0	0	0.0
<i>Aerococcus</i>	0	0.0	3	0.5
<i>Streptococcus dysgalactiae</i>	0	0.0	2	0.3
<i>Streptococcus</i> spp. (other)	0	0.0	2	0.3
<i>Klebsiella</i>	0	0.0	3	0.5
<i>Pseudomonas</i>	0	0.0	2	0.3
<i>Arcanobacterium pyogenes</i>	0	0.0	1	0.2
<i>Enterobacter</i>	0	0.0	1	0.2
Enterococci	0	0.0	1	0.2
<i>Lactococcus</i>	0	0.0	1	0.2
Minor pathogens				
CNS	26	10.8	29	4.5
<i>Corynebacterium</i> spp.	24	10.0	15	2.3
Mixed etiology	5	2.1	40	6.3
No growth	125	52.1	201	31.4
Contaminated	0	0.0	0	0.0

¹If a major or minor pathogen was isolated, a diagnosis of IMI was made regardless of the number of colony-forming units.

cant when added to the more complex model. This allowed biologically plausible interactions of significant covariates to be tested and remain in the model only if significant ($P < 0.05$).

The models took the general form

$$Y_{ijk} \sim \text{binary outcome (probability } \pi_{ijk}),$$

$$\text{logit}(\pi_{ijk}) = \text{intercept} + \beta_1 \text{herd}_k + \beta_2 \text{p}_k + \beta_3 \text{lm}_{ijk} + \beta_4 \text{X}_{ijk} + \beta_5 \text{X}_{jk} + \beta_6 \text{X}_k + v_k + u_{jk}.$$

The subscripts i , j , and k denote the i th sample time, the j th quarter, and the k th cow, respectively. Y_{ijk} is the outcome variable in the i th sample time, the j th quarter of the k th cow; π_{ijk} is the fitted probability of the outcome; β_1 to β_6 are the coefficients associated with each covariate; herd_k is the covariate “herd”; p_k is the covariate “parity” (parity 1, 2, or 3 and greater); lm_{ijk} is the covariate “lactation month” (lactation mo 1, 2, 3, 4, and 5 compared with 6 and greater) at the i th sample time for the j th quarter of the k th cow; X are the explanatory covariates at the sample time, quarter, or cow level; v_k is a random effect to reflect residual

variation for “cow”; and u_{jk} is a random effect to reflect residual variation for “quarter.”

For the final models, the significance probability was set at $P < 0.05$. Model fit was assessed using plots of accumulated level 1 and standardized level 2 residuals as described previously (Green et al., 2004).

RESULTS

Herd Characteristics and Bacteriology Data

Before initiation of the study, the annual geometric mean SCC across the herds varied from 76,000 to 233,000 cells/mL (mean 160, median 154) and herd size varied from 71 to 266 cows (mean 171, median 175). A total of 240 samples were collected from quarters with a SCC of >199,000 cells/mL (Table 2). The most common major pathogens isolated were *Strep. uberis* (31 isolates, 12.9%), coagulase-positive staphylococci (including *Staphylococcus aureus*; 10 isolates, 4.2%), and *Escherichia coli* (8 isolates, 3.3%). Coagulase-negative staphylococci and *Corynebacterium* were recorded in 10.8 and 10.0% of samples, respectively. A diagnosis of “no growth” was recorded for 52.1% of samples.

Table 3. Distribution of next SCC >199,000 cells/mL or <199,000 cells/mL at the next recording, by selected study variables

Variable	Next recorded SCC >199,000 cells/mL	
	0 (16,641)	1 (2,835)
Parity		
1	4,250 (28.58)	349 (12.42)
2	3,256 (21.89)	505 (17.97)
3	2,484 (16.70)	599 (21.31)
>3	4,881 (32.83)	1,358 (48.30)
Missing ¹	1,770	24
Lactation month		
1	1,119 (7.52)	176 (6.26)
2	1,129 (7.59)	141 (5.02)
3	1,079 (7.26)	170 (6.05)
4	1,070 (7.20)	196 (6.97)
5	1,055 (7.09)	177 (6.30)
6	1,016 (6.83)	216 (7.68)
>6	8,403 (56.51)	1,735 (61.72)
Missing	1,770	24
UHS ²		
1	7,848 (65.17)	1,698 (65.36)
2	2,599 (21.58)	539 (20.75)
3	1,123 (9.32)	245 (9.43)
4	473 (3.93)	116 (4.46)
Missing	4,598	237
BCS		
1.0	87 (0.75)	21 (0.86)
1.5	2,693 (23.28)	535 (21.99)
2.0	3,209 (27.74)	616 (25.32)
2.5	2,653 (22.93)	500 (20.55)
3.0	1,185 (10.24)	280 (11.51)
3.5	982 (8.49)	253 (10.40)
4.0	496 (4.29)	134 (5.51)
4.5	241 (2.08)	82 (3.37)
5.0	23 (0.20)	12 (0.49)
Missing	5,072	402

¹These SCC recordings were missing relevant information and discarded from the final models.

²Udder hygiene score.

A total of 929-quarter cases of CM were recorded in the 8 herds, of which 640 (69%) were sampled and available for analysis (Table 2). The environmental pathogens *E. coli* and *Strep. uberis* were isolated in 171 (26.7%) and 121 (18.9%) of cases sampled, respectively. The third most prevalent major mastitis pathogen was coagulase-positive staphylococci (including *Staph. aureus*; 20 isolates, 3.1%), followed by yeasts (2.7%). Minor pathogens (CNS and *Corynebacterium* spp.) were identified in 44 cases (6.8%). A diagnosis of “mixed etiology” was made in 40 cases, only 1 of which involved 3 major mastitis pathogens. No contaminated samples were recorded. A diagnosis of no growth was made in 201 cases (31.4%) for which a sample was available for culture.

Description of the Overall Risk Factor Data

A total of 1,677 cows were recruited from the 8 herds selected to participate, and a total of 61,959 quarter measurements were made during the 12-mo study.

Before any analysis, the data were cleaned to exclude quarters and cows with no available milk recording information (e.g., culled or died before the next test day). The distribution of SCC >199,000 cells/mL at the next milk recording by parity, lactation month, UHS, and BCS is shown in Table 3.

A total of 14,641 UHS and LHS were available for analysis (Figure 1). The majority of UHS were score 1 (free of contamination, 65%), with 5% of UHS recorded as score 4 (heavily contaminated). Five percent of LHS were recorded as score 1, with more than 70% of LHS scored as 3 or 4 (contaminated or heavily contaminated).

During the study, 55,271 quarters were available for TEC assessment. Of these, 619 were not categorized because of that quarter being dry or having severe teat-end trauma precluding categorization, and 1,285 scores were missed during the milking attended. Therefore, 53,367 quarter TEC measurements were assigned to the scores (Figure 2). Only 7% of TEC scores were classified as N. The majority of TEC scores were score 1A and 1B (thin and moderately smooth callosity ring); score 2D (extreme thickening, severe HK) was present in 1% of all teats scored. A total of 14,002 cow BCS were available (Figure 3). The BCS distribution was not normal; the data were positively skewed, with only 25% of cows scored at BCS >2.5.

Description of the TEC Data

The mean TEC scores were normally distributed with a right tail, and a greater proportion of cows were

Figure 1. Distribution of udder (black bars) and leg (gray bars) hygiene scores in all cow months [1 = completely free from or very little dirt; 2 = slightly (2 to 10% of the area) covered in dirt; 3 = moderately (10 to 30% of the area) covered in dirt; 4 = covered (>30% of the area) with caked-on dirt].

Figure 2. Distribution of teat-end callosity scores in all quarter months (N = normal teat end; 1A = thin, smooth callosity ring; 1B = moderately smooth callosity ring; 1C = thick, smooth callosity ring; 2A = thin, rough callosity ring; 2B = moderately rough callosity ring; 2C = thick, rough callosity ring; 2D = extremely rough callosity ring, severe hyperkeratosis of the teat end).

scored with a mean TEC score of >2 but <4 (Figure 4). Proportionally more cows with a mean TEC score of <2 or a mean TEC score of ≥ 4 were recorded with an increased ($>199,000$ cells/mL) SCC at the next recording. Proportionally fewer cows with a mean TEC score of ≥ 2 , but <4 were recorded with an increased ($>199,000$ cells/mL) SCC at the next recording.

The maximum TEC scores showed a distinct bimodal pattern, with a lower proportion of cows scored having a maximum TEC score of 4 (Figure 5). Proportionally more cows with a maximum TEC score of ≥ 5 were recorded with an increased ($>199,000$ cells/mL) SCC at the next recording. Proportionally fewer cows with a maximum TEC of 2 or 3 were recorded with an increased ($>199,000$ cells/mL) SCC at the next recording.

The mean log of the next recorded SCC increased with both increasing mean (Figure 6) and maximum (Figure 7) TEC scores ($P < 0.05$). The effect on the next recorded cow SCC was more pronounced using a maximum TEC score (Figure 7). This may be due to a relatively small number of teats scored as very severe HK, resulting in small numbers of high mean TEC scores displayed in Figure 6. The mean log of the next recorded SCC was reduced ($P < 0.05$) with TEC mean and maximum scores of 2 and 3.

Multilevel Models for SCC $>199,000$ Cells/mL in Lactation

Cows that were recorded with an SCC of $\geq 200,000$ cells/mL or an SCC between 100,000 and 199,000 cells/mL at the previous test date had increased odds (P

< 0.05) of SCC $>199,000$ cells/mL at the next milk recording in lactation, compared with cows with a previous SCC of between 0 and 99,000 cells/mL (Table 4). Cows that were recorded with a BCS >3.5 or <1.5 at a monthly visit had increased odds ($P < 0.05$) of SCC $>199,000$ cells/mL at the next milk recording in lactation, compared with other condition scores. Quarters recorded as a TEC score of 1A, 1B, 1C, 2A, or 2B had decreased odds ($P < 0.05$) of SCC $>199,000$ cells/mL at the next milk recording, compared with a TEC score of N. Cows with UHS 2, 3, and 4 had decreased odds ($P < 0.05$) of SCC $>199,000$ cells/mL at the next milk recording, compared with UHS 1. Cows in the first month of lactation had decreased odds ($P < 0.05$) of SCC $>199,000$ cells/mL at the next milk recording compared with lactation mo 6 and above. This trend continued with lactation mo 2 to 5. Parity 1 and 2 cows had decreased odds ($P < 0.05$) of SCC $>199,000$ cells/mL at the next milk recording compared with parity 3 cows and older; in addition, the odds were reduced for parity 1 animals compared with parity 2 animals.

DISCUSSION

This longitudinal study showed that individual cow factors were associated with an increased or decreased risk of SCC $>199,000$ cells/mL at the next milk recording during lactation. These factors may help explain some differing susceptibility to IMI among cows, as measured by SCC.

This study suggests an association between cow BCS and SCC $>199,000$ cells/mL. Cows that were recorded as BCS <1.5 or >3.5 at a farm visit were significantly more likely to have an SCC $>199,000$ cells/mL at the next milk recording. This supports the report of Berry et al. (2007), although those authors suggested that the effect of BCS on udder health may be small and

Figure 3. Distribution of cow BCS in all cow months.

Figure 4. Distribution of the mean quarter teat-end callosity (TEC) scores [1 (N) = normal teat end; 2 (1A) = thin, smooth callosity ring; 3 (1B) = moderately smooth callosity ring; 4 (1C) = thick, smooth callosity ring; 5 (2A) = thin, rough callosity ring; 6 (2B) = moderately rough callosity ring; 7 (2C) = thick, rough callosity ring; 8 (2D) = extremely rough callosity ring, severe hyperkeratosis of the teat end] and percentage of cows recording a next individual cow SCC >199,000 cells/mL (black bars) or <199,000 cells/mL (gray bars).

of limited biological significance. Although very severe HK of the teat end was clearly of importance when considering the risk of CM in dairy cows (J. E. Breen, unpublished results), this study showed that mild and moderate TEC were associated with a significantly decreased risk for SCC >199,000 cells/mL at the next

milk recording compared with normal teat ends. Severe HK of the teat end was not associated with a significant increase in the risk of an elevated cow SCC at the next recording in the final models. This result supports previous work (Sieber and Farnsworth, 1981; Lewis et al., 2000) and suggests a protective effect of mild and moderate HK of the teat end on the risk of an increased SCC compared with a normal teat end.

A hyperplastic stratum corneum, found in teats with an increased TEC score, leads to a roughened surface to which bacteria can adhere, making disinfection of the teat after milking more difficult and limiting its effectiveness (Neijenhuis et al., 2000). Suboptimal postmilking teat disinfection may result in a high herd prevalence of minor pathogens, which may confer protection against infections with major pathogenic organisms (Lam et al., 1997). An increased prevalence of mild and moderate TEC scores need not necessarily require alterations to the postmilking teat disinfection protocols, although an increase in major pathogen new infections would be expected if teat disinfection were poorly implemented, and perhaps further research is required to better understand the interactions between mild and moderate changes in TEC and risk of an increased SCC.

The findings showed udder contamination to be associated with a decreased risk of SCC >199,000 cells/mL at the next milk recording in lactation compared with clean udders. These results differ from studies showing

Figure 5. Distribution of the cow maximum quarter teat-end callosity (TEC) score [1 (N) = normal teat end; 2 (1A) = thin, smooth callosity ring; 3 (1B) = moderately smooth callosity ring; 4 (1C) = thick, smooth callosity ring; 5 (2A) = thin, rough callosity ring; 6 (2B) = moderately rough callosity ring; 7 (2C) = thick, rough callosity ring; 8 (2D) = extremely rough callosity ring, severe hyperkeratosis of the teat end] and percentage of cows recording a next individual cow SCC >199,000 cells/mL (black bars) or <199,000 cells/mL (gray bars).

Figure 6. Relationship between the mean log of the next recorded SCC and the cow mean teat-end callosity (TEC) score with 95% confidence intervals of the mean.

a linear relationship between UHS and SCC (Schreiner and Ruegg, 2003) and between composite UHS and LHS and SCC (Reneau et al., 2005). It is unclear why this study did not confirm a significant relationship between cow hygiene and SCC >199,000 cells/mL and may be due in part to differing pathogens involved in IMI in these herds, particularly *E. coli*, which produced a short peak on the SCC response after infection (de Haas et al., 2002).

Significant independent variables associated with the risk of an SCC >199,000 cells/mL included previous test-day SCC, parity of the cow, and the month of lactation. A previous study showed that the graph of SCC and DIM was flatter in cows of parity 1 compared with older animals (Schepers et al., 1997) and that more cows in their first lactation calved with spontaneously curing IMI than did older cows (Laevens et al., 1997). Periparturient heifers were less likely to succumb to a previous case of mastitis and were unlikely to be persistently infected and recorded as having an elevated SCC at subsequent milk recordings. Younger cows may be housed, fed, and milked as a separate group away from the main herd and may be less likely to have concurrent health issues such as lameness compared with older herd mates. Decreasing month of lactation was associated with a decreased risk for SCC >199,000 cells/mL, supporting previous work (Laevens et al., 1997).

During this study, methods of data collection that were easily reproducible in a clinical commercial setting were chosen and procedures had to be rapid and

simple, although teat-end scoring was performed in detail. Particular emphasis was placed on observational measurements, including hygiene scoring, teat-end scoring, and BCS, because these traits can be modified or improved to allow prevention of disease. These methods of cow health assessment were simple to perform and noninvasive, and their use has been encouraged within the current industry drive for herd health planning.

CONCLUSIONS

Individual cow factors influence the risk of increased (>199,000 cells/mL) SCC at the next milk recording in lactation. Very low or high cow BCS was associated with an increased risk of SCC >199,000 cells/mL, but mild and moderate TEC and udder contamination were associated with a decreased risk of SCC >199,000 cells/mL.

ACKNOWLEDGMENTS

This research was funded by the Milk Development Council (Cirencester, UK); James Breen is a Royal College of Veterinary Surgeons' Trust Resident in production animal medicine. We thank National Milk Records (Chippenham, UK) for providing data, Barbara Payne (Quality Milk Management Services, Wells, UK) for her work on the bacteriological samples, James Booth, MRCVS, for technical advice and support, and all the farmers and their veterinary surgeons for their enthusiasm and cooperation. Martin Green is funded by a Wellcome Trust intermediate clinical fellowship.

Figure 7. Relationship between the mean log of the next recorded SCC and the cow maximum teat-end callosity (TEC) score with 95% confidence intervals of the mean.

Table 4. Summary of the significant terms for SCC >199,000 cells/mL in the final lactation model¹

Variable	Next individual cow SCC >199,000 cells/mL				
	Coefficient	SEM	OR ²	Confidence interval	
				2.5%	97.5%
PrevSCC_199 ³	1.510	0.064	4.53	3.98	5.14
PrevSCC_200 ⁴	1.963	0.062	7.12	6.29	8.06
PrevSCC_none ⁵ (Reference PrevSCC_99 ⁶)	0.876	0.057	2.40	2.14	2.69
Parity 1	−2.199	0.189	0.11	0.08	0.16
Parity 2 (Reference parity 3 and above)	−0.905	0.137	0.40	0.31	0.53
Lactation mo 1	−1.068	0.085	0.34	0.29	0.41
Lactation mo 2	−1.411	0.081	0.24	0.21	0.29
Lactation mo 3	−1.025	0.080	0.36	0.31	0.42
Lactation mo 4	−0.938	0.078	0.39	0.33	0.46
Lactation mo 5 (Reference 6 and above)	−0.702	0.075	0.50	0.43	0.58
BCS >3.5	0.789	0.211	2.20	1.44	3.36
BCS <1.5 (Reference BCS 1.5 to 3.5)	0.737	0.106	2.09	1.69	2.58
TEC ⁷ 1A	−0.266	0.100	0.77	0.63	0.94
TEC 1B	−0.356	0.108	0.70	0.56	0.87
TEC 1C	−0.513	0.150	0.60	0.44	0.81
TEC 2A	−0.429	0.128	0.65	0.50	0.84
TEC 2B	−0.468	0.144	0.62	0.47	0.84
TEC 2C ⁸	−0.066	0.177	0.94	0.66	1.33
TEC 2D ⁸ (Reference TEC N)	0.157	0.250	1.17	0.71	1.93
UHS ⁹ 2	−0.364	0.056	0.69	0.62	0.78
UHS 3	−0.205	0.076	0.81	0.70	0.94
UHS 4 (Reference UHS 1)	−0.42	0.11	0.66	0.53	0.82

¹Herd was forced into the model as a categorical fixed effect.²Odds ratio.³Previously recorded SCC category, 100,000 to 199,000 cells/mL.⁴Previously recorded SCC category, ≥200,000 cells/mL.⁵No previously recorded SCC.⁶Previously recorded SCC category, 0 to 99,000 cells/mL.⁷Teat-end callosity score.⁸Both the covariates 2C and 2D were not significantly associated with the odds of SCC >199,000 cells/mL but are presented for completeness.⁹Udder hygiene score.

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