Effect of Electric and Magnetic Fields (60 Hz) on Production, and Levels of Growth Hormone and Insulin-Like Growth Factor 1, in Lactating, Pregnant Cows Subjected to Short Days

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ABSTRACT

Electric and magnetic fields (EMF) are generated by the transmission of electricity through high tension lines traversing rural areas. Previous studies showed increased dry matter intake (DMI) and fat corrected milk in dairy cows exposed to EMF. Because EMF exposure has been shown to suppress pineal release of melatonin in some species, it was hypothesized that EMF effects resemble those of exposure to long days. Previous studies have shown that DMI and milk production increase in dairy cattle in response to long day photoperiods, and this has been observed in association with increased circulating insulin-like growth factor 1 (IGF-1), but not growth hormone (GH). The hypothesis that EMF act by modifying the response to photoperiod was tested by subjecting dairy cows to controlled EMF exposure while keeping them under short-day conditions. Sixteen lactating, pregnant Holstein cows were exposed to a vertical electric field of 10 kV/m and a horizontal magnetic field of 30 μ T in a crossover design with treatment switchback. Two groups of eight cows each were exposed to EMF for 16 h/d in either of two sequences. Each sequence consisted of three consecutive 28-d periods. All animals were maintained under short day conditions (8 h light, 16 h dark) during the trial. DMI and plasma IGF-1 were increased ($P < 0.01$) during EMF exposure (17.03 vs. 16.04 kg/d, SE = 0.4; 137 ± 6 ng/ml vs 126 ± 6 , respectively). The mean GH concentration was not affected, but a treatment $\times$ hour interaction was detected, with GH lower for the EMF exposed animals during the first 16 h of the sampling period, and higher for the last 8 h. Overall, the yield of milk or its components was not affected by EMF exposure, but milk

yield was significantly higher for the exposed animals during wk 4 of treatment.

(Key words: electric field, magnetic field, prolactin, melatonin)

Abbreviation key: EMF = electric and magnetic fields, MLT = melatonin, PRL = prolactin, GH = growth hormone.

INTRODUCTION

Previous studies (Burchard et al., 1996; 1998) have suggested that dairy cows respond with certain physiological changes when exposed to electric and magnetic fields (EMF) similar to those generated by high-tension lines. Burchard et al. (1996) showed an increase in DMI and FCM in lactating, pregnant dairy cows exposed to EMF (10kV/m, 30 μ T). That particular experiment was designed to mimic a worst-case scenario, where cows would be continuously standing directly under a 735-kV AC line with the maximum load of current of approximately 2000 amperes.

Exposure to low frequency EMF may suppress the synthesis of the indoleamine hormone melatonin (MLT) in the pineal gland of some species (Reiter, 1993; Kato et al., 1994; Yellon, 1994). This effect of EMF on pineal function is similar to that of light, which is the main environmental cue mediating the response to photoperiod in mammals and birds. Light inhibits pineal N-acetyl transferase, a rate-limiting enzyme in the synthesis of melatonin from serotonin. As a result, MLT levels are low during the photophase and high during the scotophase. The duration of the nocturnal MLT signal appears to be the main factor that codes for day length in seasonal mammals, such as the ewe (Reiter, 1980; Bittman and Karsch, 1984; Yellon et al., 1985). The response of feed consumption and milk production to photoperiod in dairy cows has been studied extensively. The subject was recently reviewed by Dahl et al. (2000). Peters et al (1978a and 1978b) first reported that artificial exposure to long days increased milk production in cows compared with

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exposure to the natural photoperiod, between December and April. This observation has since been confirmed by Stanisiewski et al. (1985), Bilodeau et al. (1989), Evans and Hacker (1989), Dahl et al. (1997), and Reksen et al. (1999), among others. The effects of long-day exposure on milk production were not always accompanied by increases in feed intake.

There is evidence suggesting that seasonal changes in circulating concentrations of IGF-1 are driven by changes in photoperiod. In ruminants, there appears to be a positive relationship between IGF-1 levels and day length. MLT implants decreased concentration of IGF-1 in plasma of red deer (Suttie et al., 1992). Lactating dairy cows exposed to long days had increased plasma concentration of IGF-1 (Dahl et al., 1997).

Increases in circulating growth hormone (GH), either via endogenous secretion or by exogenous administration of bST, are associated with increased milk yield in cattle. The increase in milk production observed in dairy cows treated with bST has been associated with a concomitant increase in circulating levels of IGF-1 (Davis et al., 1987; Cohick et al., 1989; Prosser et al., 1989; Zhao et al., 1994). A direct effect of IGF-1 on milk secretion has been suggested. However, most authors report that photoperiod has no effect on circulating concentrations of GH (Peters et al., 1978; Peters et al., 1980; Zinn et al., 1986; Borromeo et al., 1994).

The objective of this study was to test the hypothesis that if EMF exposure resembles light, long exposures to EMF will emulate long days. Therefore, an increase in DMI and milk yield concomitant with higher circulating concentrations of IGF-1, in the absence of an increase in GH, would be expected.

MATERIALS AND METHODS

Sixteen multiparous, lactating, pregnant Holstein cows weighing 690 ± 55 kg, at 170 ± 37 DIM and 91 ± 32 d in gestation (means $\pm$ SE) were housed in an EMF exposure chamber built by Hydro-Québec in the Dairy Cattle Complex of Macdonald Campus, McGill University, where EMF can be generated under controlled conditions (Nguyen et al., 1995; Burchard et al., 1999). The animals were divided into two groups (replicates) of eight animals each, according to a crossover design with treatment switchback. Each group was exposed to EMF according to one of two sequences of three periods each: for the first group, 28 d nonexposed, followed by 28 d exposed and then 28 d nonexposed (OFF-ON-OFF); for the second group, 28 d exposed, 28 d nonexposed, and 28 exposed (ON-OFF-ON). The light regimen emulated a short photoperiod (8 h light, 16 h dark). During the ON periods, the animals were exposed to EMF (10 kV/m, 30μ T) for 16 h (8 h of the light

Table 1. Average nutrient composition (Mean $\pm$ SD) of the total mixed ration.

Variable	Mean $\pm$ SD
Dry Matter (%)	57.3 $\pm$ 4.7
Crude protein (%)	15.9 $\pm$ 0.4
NE _i (Mcal/Kg)	1.58 $\pm$ 0.02
NDF (%)	28.3 $\pm$ 1.2
ADF (%)	18.4 $\pm$ 0.3
Ca (%)	0.87 $\pm$ 0.09
P (%)	0.43 $\pm$ 0.03

period plus the first 8 h of the dark period). Light intensity in the EMF chamber during the light period was 321.40 ± 13.56 lux.

The animals were fed a TMR twice daily, which was formulated to meet NRC requirements (NRC, 1989). The diet consisted of forages, corn and commercial protein and mineral supplements. The DM content of forages and TMR were determined weekly. The diet formulation was adjusted accordingly. Forages were sampled weekly, and a monthly composite sample was analyzed. The average composition of the diet is described in Table 1. Water and feed were available ad libitum.

Milking was performed twice daily. Feed intake and milk production were measured daily. Samples of morning and afternoon milk were collected weekly and submitted for analysis of milk fat, milk protein, and somatic cell count to the local dairy herd analysis program laboratory (Programme d'analyse des troupeaux laitieres du Québec, Ste. Anne de Bellevue, QC). Body weight was recorded at the end of each 28 d period.

On the last day of each period, blood samples were collected hourly for 24 h. Jugular catheters (vialon catheter, Becton and Dickinson, Franklin Lakes, NJ) were fitted and connected to extensions (Tygon, Northon Performance Plastics, Akron, OH), fed into the adjacent laboratory, and filled with saline solution containing 1 IU/ml heparin (Hepalan, Organon Technika, Scarborough, ON) to allow remote collection of blood. This procedure avoided disturbing the EMF and lighting schedule during sample collection. Samples for IGF-1 and GH determination were collected into heparinized tubes, centrifuged, and the plasma frozen and stored at -20°C pending analysis.

The concentrations of GH and IGF-I were determined using double antibody radioimmunoassays, as previously described by Petittclerc et al., (1987) and Lapierre et al., (1990), respectively. Intra- and interassay coefficients of variation for IGF-1 and GH were 3.2%, 4.4%, and 5.7% and 6.13%, respectively.

The results were analyzed using the mixed model procedure of SAS as a crossover design with treatment switchback (Oman and Seiden, 1988). The data for GH

Table 2. Feed intake and selected production measures in lactating, pregnant cows exposed or not exposed to EMF under short-day conditions.

Variable	Not exposed Mean	Se	Exposed Mean	SE	<i>P</i> > <i>t</i>
Dry Matter intake (kg/d)	16.04	0.4	17.03	0.4	0.004
Milk yield (kg/d)	18.7	0.2	19.2	0.2	0.212
%Fat	3.94	0.05	3.69	0.04	0.003
%Protein	3.17	0.02	3.16	0.02	0.802
SCC ($\times 1000$)	149.9	7.7	154.6	7.1	0.668
Fat yield (kg/d)	0.727	0.014	0.704	0.013	0.284
Protein yield (kg/d)	0.593	0.007	0.603	0.007	0.299
4% FCM (kg/d)	18.4	0.3	18.3	0.3	0.672
Average Body Weight (kg/animal)	673	13	701	13	0.005

were transformed to a logarithmic scale to stabilize the variance among treatments. Repeated measurement analysis was used to study treatment effects on hormone concentrations across time (Litell et al., 1998).

RESULTS AND DISCUSSION

One animal aborted and was removed from the experiment at the end of her second period.

Exposure to EMF increased DMI (Table 2). This was consistent with previous reports (Burchard et al., 1996). Overall, the yield of milk and milk components was not affected by EMF. The percentage of fat in milk was significantly greater during the non-EMF exposure sequences, but this was offset by a numerical ($P > 0.05$) increase in milk volume produced during EMF exposure sequences. As a result, milk fat yield did not differ between treatments. The interaction between treatment and week of exposure was not significant for milk yield ($P = 0.15$). However, on wk 4 of treatment, a significant ($P < 0.01$) difference in mean yield between treatments was detected (Figure 1). This suggests that by the end of the experimental period, milk yield had declined less rapidly in the exposed than in the nonexposed animals. This observation is consistent with previous reports indicating that the milk yield response to long photoperiods becomes detectable in approximately 4 wk (Dahl et al., 1997). Conversely, the yield of milk components did not show a similar trend in the present study, and failed to show any significant response to the treatment throughout the experiment.

After conducting a similar analysis in the data from the previous experiment by Burchard et al. (1996), a similar numerical trend was observed, but the contrast on wk 4 was only significant for FCM and not for uncorrected milk yield, as opposed to the present experiment.

The choice of 28-d experimental periods was a limitation of this study that was imposed by the constraints of the switch back design (need to accommo-

date three consecutive periods in one lactation) and the availability of cows meeting the trial criteria. This choice was considered acceptable based on the results of Burchard et al. (1996), who was able to detect overall differences in corrected milk yield using a similar design. However, in that experiment, a photoperiod of 12 h light was used, and thus the intervals between milkings were balanced (0600 h, 1600 h). In the present experiment, the short day treatment imposed a constraint on the milking schedule, since the animals had to leave the EMF exposure chamber to be milked. As a result, the interval between the afternoon and the next morning milking was over 16 h. In these animals, in mid to late lactation, the extended periods without milking might have resulted in a decreased persistency in both treatment groups. This factor may

Figure 1. Means for milk yield of lactating, pregnant dairy cows exposed and non-exposed to EMF under short day conditions, for each of the weeks of the experimental periods. Each bar represents the mean ($\pm$ SE of the difference). Asterisks represent differences between treatments (** $P < 0.01$).

Figure 2. Plasma IGF-1 concentrations (Mean $\pm$ SE) over 24 h in lactating, pregnant dairy cows exposed and not exposed to EMF under short day conditions.

have imposed further limitations on milk production, beyond the physiological alterations induced by treatment.

An increase in BW for the EMF treated group was observed in the present experiment. Tucker et al. (1984) postulated that cattle subjected to shorter photoperiods have increased fat deposition and decreased protein accretion. Longer photoperiods tend to stimulate milk yield and body growth and reduce fat accretion in the carcass (Tucker and Merkel, 1987). It could be speculated that, in the present experiment, the extra energy resulting from the increased DMI associated with EMF exposure may have been partitioned differently than in Burchard et al. (1996) as a result of the short day length and EMF exposure conditions, and resulted in additional weight gain.

Electric and magnetic fields increased mean plasma IGF-1 levels (126 ± 6 ng/ml for the control vs 137 ± 6 ng/ml, $P < 0.03$). Concentrations of the growth factor did not show a clear circadian pattern of changes during the 24 h sampling period. Figure 2 summarizes plasma IGF-1 concentrations over 24 h for the treatment and control groups. All measurements are well within the physiological concentration ranges for the species.

These results support the concept of a photoperiod-like effect of EMF exposure. There is evidence that long-day photoperiods increase IGF-1 levels in cattle. Spicer et al. (1994) reported increased circulating IGF-1 in prepubertal heifers exposed to day photoperiods of

16 h light, 8 h dark when compared to those exposed to 8 h light, 16 h dark. Dahl (1997), found increased IGF-1 in lactating dairy cows exposed to long day photoperiods (18 h light, 6 h dark) when compared to cows on natural photoperiods of 10–13 h light per day.

However, some conflicting results have also been reported. Miller et al. (1999), found no effects of exposure to long-day photoperiod on IGF-1 circulating concentrations in dairy cows treated or untreated with bST in a 140-d experiment starting at the winter solstice. Similarly, Ringuelet et al. (1989) failed to observe an effect of photoperiod on IGF-1 in dairy heifers.

The increase in IGF-1 observed in response to EMF is also consistent with the hypothesis of EMF inhibition of MLT secretion, since changes in MLT may directly influence IGF-1 secretion. Smith et al. (1997) fed MLT in the middle of the photo phase to prepubertal heifers subjected to artificially long days (16 h light, 8 h dark) and found that this prevented the increase in IGF-1 concentrations observed in control (long-day) heifers over the 2 mo of the experiment.

There is evidence that exposure to EMF may suppress the synthesis of MLT in the pineal gland of some species, in a fashion similar to light (Reiter, 1993; Yellon, 1994; Kato et al., 1994). This effect has recently been observed in the cow. An earlier study from our laboratory failed to show a relationship between EMF exposure and nocturnal MLT levels in this species (Burchard et al., 1998), but that study measured only nocturnal concentrations. In more recent studies, a numerical decrease in circulating MLT, which was non-significant for the scotophase but significant for the photophase, was observed in lactating pregnant cows, as well as in nonlactating, nonpregnant cows exposed to EMF while subjected to short photoperiods (Rodriguez et al., 1998, Rodriguez et al., in preparation).

Suppression of MLT by EMF may account for the increased IGF-1 levels observed in this experiment. Previous work suggests that MLT has an inhibitory effect on IGF-1. Short-day photoperiod induces a significant depression in IGF-1 in female Syrian hamsters, which pinealectomy partially prevents (Vaughan et al., 1994). Conversely, MLT administration increased IGF-1 concentrations in male Syrian hamsters (Vriend et al., 1988). In MLT implanted red deer, the interruption of MLT treatment resulted in a shift in the seasonal pattern of IGF-1 levels (Suttie et al., 1992). In the reindeer, increased day length induced an increase in circulating IGF-1, which was believed to be associated with the growth spurt observed in this species in the spring (Suttie et al., 1991). Most results suggest that MLT may have an inhibitory effect

Figure 3. Plasma growth hormone concentrations (Mean $\pm$ SE, log transformed) over 24 h in lactating, pregnant dairy cows exposed and not exposed to EMF under short day conditions.

on IGF-1, which would be consistent with the observations in this experiment.

In the present study, the mean circulating concentrations of growth hormone were not different between treatments. The mean values $\pm$ SE (log ng/ml) were 1.11 ± 0.03 and 1.09 ± 0.03 for the control and exposed animals, respectively. However, a treatment $\times$ hour interaction was observed. For the first 16 h of the sampling period, GH concentrations were generally lower for the exposed group, whereas, for the last 8 h, GH was higher in the exposed animals (Figure 3).

The secretory pattern of GH in the bovine, basal levels, and number, magnitude and amplitude of significant secretory peaks seem to be independent and not affected by season, as opposed to prolactin secretion. Prolactin secretion patterns show basal levels, number and magnitude of the secretory peaks to be greater in summer than in winter (Borromeo et al., 1994).

There is little evidence of photoperiod-induced changes in circulating concentrations of growth hormone in the bovine. Petitclerc et al. (1983) reported a tendency for higher growth hormone levels in Holstein heifers subjected to short days than in those subjected to long days, but others have failed to find a relationship. Peters and Tucker (1978) did not find an effect of photoperiod on GH concentrations in heifers. Leininger et al., (1980) did not find a response in prepubertal bulls. Zinn et al., (1986) failed to see an effect of daylength on secretion and clearance rate of GH in heifers. The IGF-1 fluctuations with photoperiod appear to be independent of GH changes.

The existence of a circadian rhythm in GH synthesis in the cow, reflected by the peripheral circulating con-

centrations of the hormone, has been suggested, but the subject is still controversial. Vasilatos and Wangness (1981) and Mollet and Malven (1982) did not find a consistent circadian pattern for GH concentrations in the circulation. More recently, Lefcourt et al. (1995) described a consistent sinusoidal circadian rhythm, with a zenith at around 0630 h and a nadir at around 1830 h, in lactating dairy cows kept under a long day photoperiod (lights on from 0700 to 2300 h). This circadian profile roughly resembles the pattern observed for the EMF-exposed group in the present experiment. The lowest GH concentrations occurred at 1900 h, and then a sustained increase occurred, with levels remaining relatively high for the remaining of the dark period (Figure 2). No information was found on the circadian profile of growth hormone concentrations in cows subjected to short day conditions.

CONCLUSIONS

These results add to previous findings suggesting that EMF exposure may have an impact on the physiology of the dairy cow. An increase in IGF-1 circulating concentrations was observed, which was comparable to that reported in some experiments subjecting dairy cattle to artificial long day photoperiods. Also, EMF appeared to have an influence on the timing of changes observed in the concentrations of GH in the circulation over a 24 h cycle, and appeared to be associated with an increase in milk yield, which became apparent only toward the end of the experimental period. An effect of EMF on the yield of milk components was not observed.

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