Effects of Feeding Beef Females Supplemental Fat During Gestation on Cold Tolerance in Newborn Calves[1]

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ABSTRACT: Effects of prepartum fat supplementation of the dam on cold tolerance of calves were determined in two studies. In Exp. 1, 22 F1, crossbred heifers gestating F2 calves received diets containing either 1.7 or 4.7% dietary fat starting at d 230 ± 2 d of gestation. Safflower seeds (*Carthamus tinctorius*) containing 37% oil with 79% linoleic acid were the supplemental fat source in isocaloric-isonitrogenous diets. Calves were separated from their dams at birth, fed pooled dairy-cow colostrum, muzzled to prevent sucking, and returned to their dams in a heated (22°C) barn for 3.5 h. At 4 h of age, a jugular catheter was inserted. At 5 h of age, calves were placed in a 0°C room for 140 min and rectal temperatures and blood samples were obtained at 10- and 20-min intervals. Blood was assayed for glucose, cortisol, and cholesterol. In Exp. 2, 18 multiparous, crossbred beef cows bred to Murray Grey sires were randomly assigned to receive diets containing either 1.7 or 3.1% dietary fat starting at 235 ± 2 d gestation. Safflower seeds were used as the supplemental fat source in isocaloric-isonitrogenous diets. At d 260 of gestation, premature parturition was induced in one-half of the cows from each diet group by feeding Ponderosa pine (*Pinus ponderosa*) needles. Experimental protocols were the same as in Exp. 1, except that cold exposure was at 9°C for 200 min. Rectal temperatures were affected in Exp. 1 by time and diet × time (both $P < .01$) and diet × calf sex ($P < .05$) and in Exp. 2 by calf age ($P < .05$), time, and calf age × time (both $P < .01$). Plasma cortisol concentrations were affected by time ($P < .01$) and calf sex × time ($P < .05$) in Exp. 1 and by time ($P < .01$) in Exp. 2. Cholesterol concentrations in Exp. 1 were affected by diet × time ($P < .05$) and in Exp. 2 by time ($P < .05$). Plasma glucose concentrations were affected in Exp. 1 by diet ($P < .05$) and in Exp. 2 by calf age, time, and calf age × time (all $P < .01$). We conclude from Exp. 1 that feeding heifers supplemental fat during late gestation increased glucose concentrations in the newborn calf, resulting in favorable responses in body temperature in the cold-stressed newborns. This increase in substrate availability suggests a potential positive effect on heat generation in newborns during sustained periods of cold stress. In Exp. 2, premature calves had compromised cold tolerance possibly due to impaired shivering or brown adipose tissue thermogenesis.

Key Words: Fats, Pregnancy, Newborn Animals, Cold Tolerance, Heat Production

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Introduction

The controlled uterine environment ends at parturition, and survival of newborn calves depends on rapid adaptation to new environmental conditions. As environmental temperature decreases, neonatal mortality increases (Patterson et al., 1987; Azzam et al., 1993). Total neonatal mortality has been estimated to be approximately 9% (Cundiff et al., 1982), with 7% of this mortality due to cold stress (Bellows et al., 1987). Calf survival is variable among years and states. In 1995, ranchers in Montana lost approximately 23,000 calves because of severe weather (Stockgrowers Newsletter, 1996). Calf losses resulting from cows ingesting needles from Ponderosa pine

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Table 1. Design and subgroup numbers for Experiment 1

Gestation diet	% fat	Calf sex		Total number
		Male	Female	
Low fat	1.7	3	8	11
High fat[a]	4.7	3	8	11

[a]Added safflower seeds.

trees (*Pinus ponderosa*) are in the million-dollar range (Lacey et al., 1988). Losses are caused by deaths of premature calves and reduced fertility of the dams caused by retention of placental membranes (James et al., 1989). Inducing parturition by feeding pine needles offers a model for studying premature calves.

Manipulation of the gestation diet of the dam could potentially improve calf survival rate (Alexander, 1962, 1978; Carstens et al., 1987). Studies conducted with rats demonstrated that fat supplementation during gestation increased brown adipose tissue thermogenesis of pups (Nedergaard et al., 1983). Cook et al. (1972) reported that linoleic acid content of the perirenal fat in steers increased after 2 wk of consuming diets high in linoleic acid. Supplementing beef cows with fat increased blood concentrations of cholesterol and progesterone (Hawkins et al., 1995). Godfrey et al. (1991) and Stanko et al. (1991) demonstrated an increase in blood lipids in calves exposed to cold, suggesting involvement of lipids in thermogenesis. The objective of these experiments was to evaluate effects of feeding supplemental fat to gestating beef females on cold tolerance in full-term and premature newborn calves.

Materials and Methods

Experiment 1

Twenty-two, crossbred, primiparous heifers (Line 1 Hereford sire × three-way composite, ¼ Charolais, ¼ Tarentaise, and ½ Red Angus dams backcrossed to similar F1 sires) were randomly assigned by breeding date to receive diets containing either 1.7% (n = 11; low fat; **LF**) or 4.7% (n = 11; high fat; **HF**) crude dietary fat (Table 1). Safflower (*Carthamus tinctorius* L 'Centennial') seeds containing 37% oil with a composition of 79.1% linoleic, 6.2% palmitic, 2.1% stearic, and 10.3% oleic fatty acid were used as the supplemental fat source. Diets were formulated to be approximately isocaloric and isonitrogenous and for the heifers to gain .4 kg/d (Table 2). Heifers calved from March 17 through April 10, 1996, and were group fed the respective diets from d 230 of gestation until calving ($\bar{x}$ = 53 ± 3 d). At d 230 of gestation, heifers averaged 436 ± 12 kg in body weight and 5.3 ± .2 in body condition score (1 = thinnest to 10 = fattest); 24 h after calving, weights and scores averaged 441 ± 12 kg and 5.3 ± .2, respectively.

Heifers were observed for signs of parturition every 2 h and were observed continuously once parturition started. Within 20 min after calving and before nursing, newborn calves were weighed and fed 30 mL/kg of birth weight 38°C pooled colostrum (obtained from a local dairy) via esophageal tube and were placed back with their dams in a heated barn (22°C) for 3.5 h. During this time, nursing was prevented by placing muzzles on the calves. At 4 h of age (birth = 0 h) and 60 min before cold exposure, an indwelling catheter (Teflon; .11 cm i.d.) was inserted into the jugular vein using local anesthesia and aseptic procedures. A 1-m extension was connected to the catheter to allow blood collection without disturbing the calves. After cannulation, calves were maintained away from the dam in a 22°C environment for 1 h.

At 5 h of age and 60 min after catheter insertion, calves were placed in a 0°C controlled-temperature room for 140 min. All placental fluid had evaporated, and the calves were dry when placed in the cold room. Cold room dimensions were 2.1 m wide × 5.3 m long × 3.1 m high. Calves were restrained in metal sheep metabolism stalls with wooden floors (Clay Equipment, Cedar Falls, IA) during the cold-room exposure. Stall dimensions were adjusted to 43 cm wide × 91 cm long × 91 cm high to comfortably accommodate the calf but prevent excessive movement. The room was cooled by a thermostatically controlled refrigeration unit with condensing coil and air circulation fan (Copeland, Sidney, OH). Calves were protected from air currents generated by the unit and fan by a wooden partition. Temperature variations during the experimental period were less than 1°C.

Rectal temperatures (digital thermometer; Becton-Dickinson, Franklin Lakes, NJ) and 10-mL blood samples were taken at 0 (when placed in cold room) 10, 20, 30, 40, 50, 60, 80, 100, 120, and 140 min. Blood volume (10 mL) was replaced with 38°C sterile

Table 2. Diet composition (DM basis) for Experiment 1

Item	Diet	
	Control (1.7% fat)	High fat (4.7% fat)
Ingredient, % of total diet		
Corn silage	37.5	38.1
Alfalfa hay, ground	48.1	48.6
Safflower seeds	—	6.7
Soybean meal	2.9	—
Corn grain, cracked	12.5	7.6
Analyses, actual %		
DM	53.1	52.3
CP	11.3	11.0
TDN	52.5	51.9

Table 3. Design and subgroup numbers for Experiment 2

Gestation diet	Fat, %	Calf maturity		Total number
		Premature	Term	
Control	1.7	5	4	9
High fat[a]	3.1	5	4	9

[a]Added safflower seeds.

physiological saline solution (.9% NaCl). After collection, blood was placed into test tubes containing heparin (5 mg). Blood was processed to yield plasma, which was kept at –20°C until cortisol, glucose, and cholesterol concentrations were determined. Plasma cortisol (kit 031; Pantex, Santa Monica, CA) concentrations were determined using enzymatic reaction kits and the intra- and interassay CV were 4.4 and 10.8%, respectively. Spectrophotometric techniques were used to determine glucose (kit 1520; DMA, Arlington, TX) and cholesterol (kit 2340; Pantex) concentrations.

Experiment 2

Twenty-three multiparous, crossbred beef cows (three-way ¼ Charolais, ¼ Tarentaise, and ½ Red Angus composite) 4 to 7 yr of age were artificially inseminated to one of three Murray Grey sires. At d 235 ± 2.6 of gestation, cows were randomly assigned by breeding date within sire to receive either 1.7 (LF) or 3.1% (HF) crude dietary fat (Table 3). Safflower seeds (same as used in Exp. 1) containing 37% oil were used as the supplemental fat source. Diets were formulated to be approximately isocaloric and isonitrogenous and for cows to gain .6 kg/d (Table 4). At d 235 of gestation, cows averaged 705 ± 43 kg in body weight and 7.8 ± .7 in body condition score; 24 h after calving, cows averaged 685 ± 35 and 7.6 ± .7, weights and scores, respectively. At d 260 of gestation, cows within each diet group received either 0 or 2 kg of Ponderosa pine needles to induce premature parturition. Cows receiving pine needles calved within 5 d (premature calves; Table 3) and cows receiving no pine needles calved at normal term (283 ± 1.6 d; term calves; Table 3). Cows calved from August 27 through September 19, 1996. Cows receiving the pine needles were on the LF and HF dietary treatments for 28 ± 1.8 d, whereas cows carrying their calves to term were on the LF and HF dietary treatments for 50 ± 3 d. Cows were observed for signs of parturition every 2 h, and they were observed continuously once parturition started. Within 20 min after calving and before nursing, newborn calves were weighed, fed 38°C pooled colostrum (30 mL/kg BW) via esophageal tube, and an indwelling catheter (Teflon; .11 cm i.d.) was inserted into the jugular vein using local anesthesia and aseptic procedures. A 1-m extension was connected to the catheter to allow blood collection and saline infusion without disturbing the calves. After cannulation, calves were maintained in a 22°C room for 1 h, and rectal temperature measurements and a blood sample were taken (digital thermometer; Becton-Dickinson) at 60 min before calves were taken into the cold environment. Calves were then placed into a 9°C room for 200 min, and rectal temperatures were taken at 0 (when placed in cold room), 20, 40, 60, 120, and 200 min. We estimated that approximately 90% of the placental fluid had evaporated when the calves were placed in the cold room. All other management protocols and analytical procedures were the same as described for Exp. 1. Cortisol intra- and interassay CV were 4.2 and 9.7%, respectively.

Statistical Analysis. Rectal temperature, metabolite, and hormone data were analyzed by statistics for repeated measures (Gill and Hafs, 1971) as a split plot in time with effects of diet, calf sex, and their interactions in the whole plot with birth weight used as a covariate. Whole-plot error was the pooled variation among calves treated alike (Error A). Time and interactions with time were in the subplot and tested with the residual mean squares (Error B). Birth weights were analyzed using standard GLM procedures. Similar statistical analyses were conducted in Exp. 2 with the exceptions that gestational age of calf at birth was added in the statistical model, and data were pooled over calf sex due to missing cells and lack of calf sex main effects in Exp. 1. Data from Exp. 2 were analyzed with and without birth weight as a covariate. Main effects and two-way interactions were tested for significance in Exp. 1 and 2. Higher-order interactions were not significant in preliminary analyses and were absorbed into the error term for final analyses. All statistical analyses were performed using GLM procedures for analysis of variance. Mean separation was accomplished using the PDIFF option (SAS, 1994).

Table 4. Diet composition (DM basis) for Experiment 2

Item	Diet	
	Control (1.7% fat)	High fat (3.1% fat)
Ingredient, % of total diet		
Ground wheatgrass hay	57.4	80.6
Corn silage	38.0	10.2
Safflower seeds	—	9.2
Soybean meal	4.6	—
Calculated analyses, %		
DM	56.7	73.6
CP	10.9	7.8
TDN	55.2	55.5

Results

Experiment 1

Statistical analyses and main-effect means are summarized in Tables 5 and 6, respectively. Calf birth weights were affected by diet, calf sex, and the diet × calf sex interaction (all $P < .01$). Calves from heifers on the HF diet were 1.4 kg heavier at birth than were calves from dams on the LF diet, and male calves were 2.6 kg heavier than females. The interaction effect was caused by birth weights of female calves from LF dams being lighter than males (30.7 vs 35.5 kg) compared with essentially no sex difference in calves from HF dams (34.4 vs 34.7 kg, female vs male, respectively).

Rectal temperature was affected by time ($P < .01$) and the diet × sex ($P < .05$) and diet × time ($P < .01$) interaction. Means for the time main effect are summarized in Table 6 and indicate that the peak rectal temperature occurred after 40 min of cold exposure and then decreased to approximately the preexposure values. However, this main effect must be interpreted in the light of the interaction with diet. The diet × time values are summarized in Figure 1 and show that all calves had increased rectal temperature during the 1st 30 min of cold exposure. Calves born to LF diet cows had higher rectal temperatures than did calves from HF diet dams during the 1st 50 min, but there were no significant differences during the last 80 min of cold exposure. In addition, the cold-induced increase in temperature was greater for calves from HF heifers (.41°C) than in calves from LF heifers (.24°C). After rectal temperature peaked, calves from HF dams seemed to maintain the increased temperature longer than did calves from LF dams because the decrease was .50°C in calves from LF heifers compared with .15°C for calves from HF dams.

The interaction of diet × calf sex ($P < .05$) resulted from higher rectal temperatures in male than in female calves from dams on the LF diet (39.2 vs 38.9°C), but the reverse was true for calves from dams on the HF diet (38.6 vs 39.1°C). We offer no explanation for this interaction and recognize that it may be a chance occurrence.

Plasma cortisol concentrations were affected by time ($P < .01$) and the sex × time interaction ($P < .05$). In general, means for the time main effect (Table 6) indicated low cortisol concentrations when the calf was placed in the cold room, followed by an increase through the 1st 40 min of cold exposure and then a return to approximately initial concentrations after 80 min of exposure. Interpretation of this main effect must also be done in light of the sex × time interaction ($P < .05$). Plotting this interaction (Figure 2) shows that the initial increase in cortisol concentration was greatest in male calves, and male calves maintained higher concentrations than females throughout the cold exposure.

Plasma cholesterol concentrations were affected by the diet × time interaction ($P < .05$) with the effect of time approaching significance ($P = .10$). Plotting the diet × time interaction (Figure 3) showed cholesterol changes over time that differed between calves from dams that received the LF or the HF diet. Cholesterol concentrations decreased in calves from LF dams after 50 min of cold exposure and after 80 min of cold exposure in calves from HF dams. Cholesterol concentrations then tended to increase more in calves from LF dams. The main effect of time, which approached significance ($P = .10$), was caused by a trend for differences in cholesterol concentrations at the various sampling times (Table 6).

Plasma glucose concentrations were affected by diet ($P < .05$). Mean values (Table 6) show that glucose concentrations in calves from LF dams averaged 26.9 mg/dL lower than in calves from HF dams throughout the cold exposure sample period. We have chosen to also show this difference in Figure 4 by plotting the diet × time interaction. This interaction was not significant but clearly depicts that the difference in glucose concentrations in calves from the LF and HF dams was present at the beginning of cold exposure and was maintained throughout the cold exposure sampling period.

Table 5. Analyses of variance, mean squares, and significance for Experiment 1

Source	df	Birth wt	Rectal temp	Cortisol	Cholesterol	Glucose
Diet	1	92.40**	1.97	17.57	211.52	32,073.67*
Sex	1	320.72**	.17	4,094.71	329.57	3,825.51
Diet × sex	1	236.35**	5.64*	.12	.75	14,888.20
Time	10	—	.18**	1,692.12**	5.13†	73.90
Diet × time	10	—	.10**	68.09	6.51*	53.47
Sex × time	10	—	.02	164.94*	3.19	44.71
Error A	18	13.53	.88	2,181.18	326.93	6,718.72
Error B	189	—	.02	87.76	3.18	62.56

*$P < .05$.
**$P < .01$.
†$P = .10$.

Table 6. Least squares mean values for main effects in Experiment 1[a]

Main effect and item	No.	Birth weight, kg	Rectal temp, °C	Cortisol, ng/mL	Cholesterol, mg/dL	Glucose, mg/dL
Diet						
Low fat	11	33.1	39.1	54.8	26.2	66.5
High fat	11	34.5	38.9	54.2	24.2	93.4
Sex						
Female	16	32.5	39.0	49.9	26.5	84.6
Male	6	35.1	38.9	59.1	23.9	75.3
Time						
0	22	—	38.8	47.5	26.2	77.7
10	22	—	38.9	68.2	24.7	79.1
20	22	—	39.0	63.2	24.7	80.1
30	22	—	39.1	67.7	25.3	84.1
40	22	—	39.1	62.3	25.3	82.4
50	22	—	39.0	58.9	24.6	81.3
60	22	—	39.0	53.5	25.0	80.6
80	22	—	39.0	46.2	24.7	79.3
100	22	—	38.9	43.3	25.5	77.8
120	22	—	38.9	43.5	25.4	79.4
140	22	—	38.9	45.0	26.0	77.6

[a]See Table 3 for statistical significance.

Experiment 2

Statistical analyses and least squares mean values are summarized in Tables 7 and 8, respectively. As was expected, birth weights of the premature calves were lower than those of term calves (30.0 vs 37.3 kg, $P < .01$). The main effect of diet was not significant, but the interaction of diet × calf age ($P = .06$) was caused by lower birth weights in premature calves from dams on the HF diet (30.4 vs 29.6 kg) compared with higher birth weights in mature calves from HF dams (36.7 vs 38.0 kg; values LF vs HF, respectively).

Calf rectal temperatures were affected by calf age ($P < .05$), time, and the time × age interaction ($P < .01$). Temperatures of term calves averaged .8°C higher than temperatures of premature calves, and

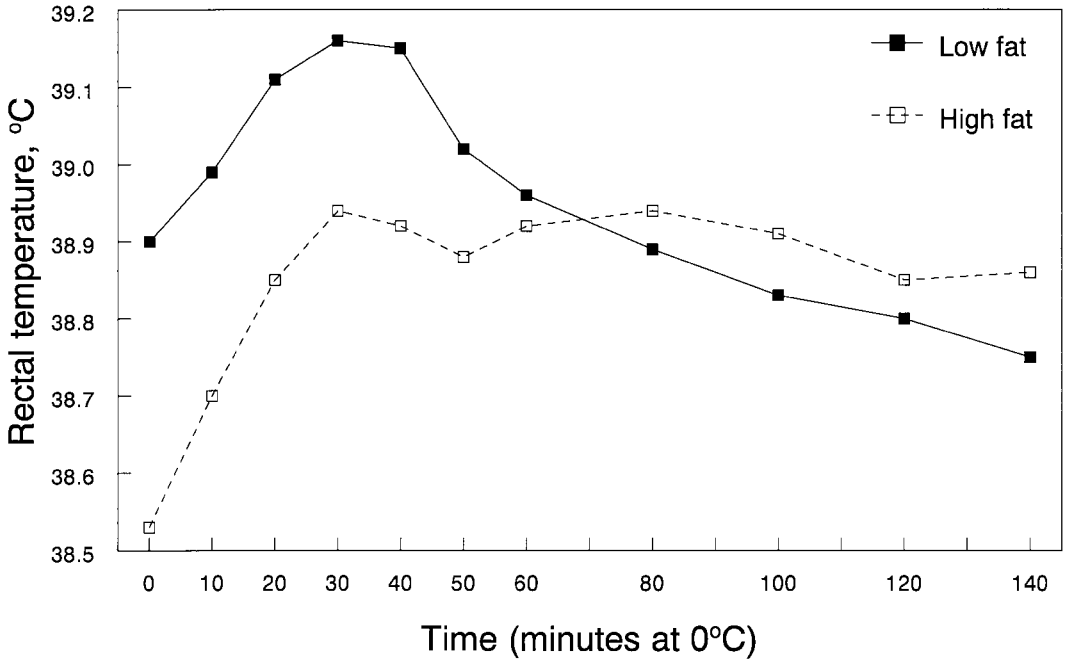

Figure 1. Least squares mean plot (pooled SEM = .04) of rectal temperatures of neonatal calves exposed to 0°C for 140 min from dams receiving 1.7 (low fat) or 4.7% (high fat) dietary fat prepartum as affected by diet × time interaction ($P < .01$; n = 22).

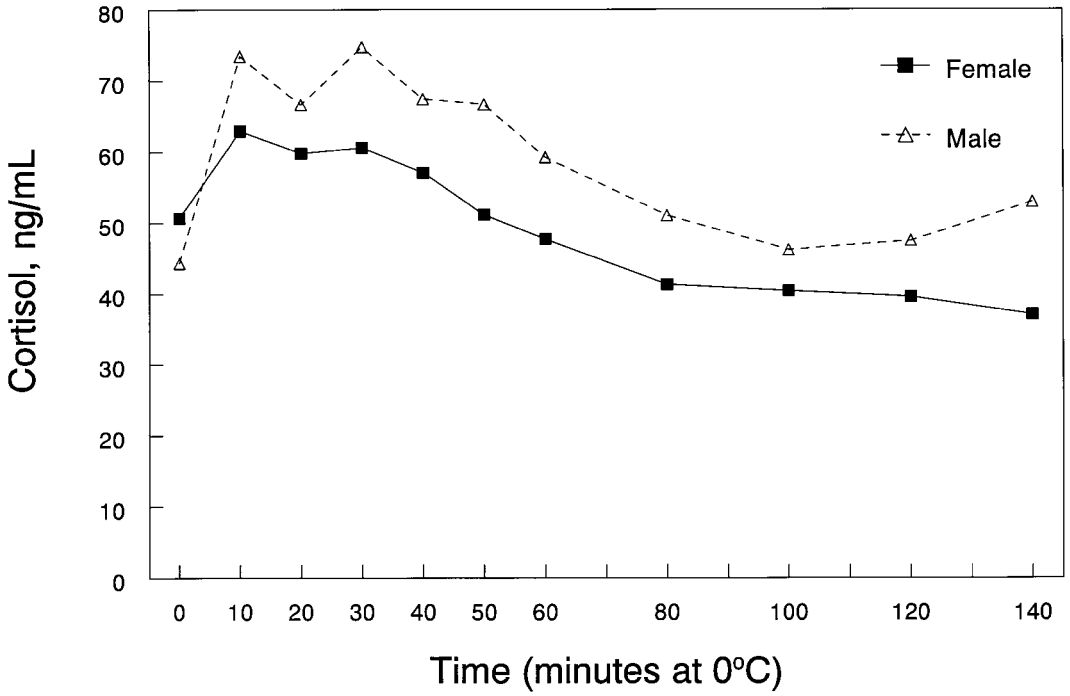

Figure 2. Least squares mean plot (pooled SEM = 3.09) of plasma cortisol concentrations of male and female neonatal calves exposed to 0°C for 140 min as affected by sex × time ($P < .05$; n = 22).

the average temperatures tended to decrease with time in the cold room. Plotting the time × age interaction (Figure 5) shows that temperatures of premature calves dropped more rapidly following birth and did not rise as high as those of term calves when exposed to cold. In addition, temperatures of the premature calf continued to drop after 60 min of cold exposure, whereas temperatures of term calves tended to remain stable.

Plasma cortisol concentrations were affected by time ($P < .01$). Concentrations (Table 8) were variable, with the highest value detected 60 min before the calves were placed in the cold room and then tending to decrease to the lowest concentration after 40 min of cold exposure. Blood samples obtained 60 min before cold exposure were taken before cannulation, but this high cortisol concentration may have been created by removing the calf from the dam and the resulting stress. Concentrations dropped to a relatively low level when calves were placed in the cold room and then tended to increase until the end of cold exposure.

Plasma cholesterol concentrations were also affected by time ($P < .05$). Cholesterol concentrations before cold exposure did not change, but tended to rise throughout the cold exposure sampling period (Table 8).

Plasma glucose concentrations were affected by age ($P < .01$), time ($P < .01$), and the age × time interaction ($P < .01$). Glucose concentrations of premature calves averaged 23.5 mg/dL less than those in term calves (Table 8). The time effect was variable with concentrations increasing through the 1st 60 min of cold exposure and then decreasing for the last two samples. The time × age interaction effect is shown in Figure 6. Glucose concentrations in term and premature calves reached their peak values at the 60-min cold-exposure sampling. Concentrations in both age groups then dropped, but the decrease was greater in term than in premature calves. The age difference in glucose concentrations between premature and term calves is also apparent.

Discussion

Rectal temperatures increased during the 1st 30 min of cold exposure in both experiments. Jessen (1990) showed that thermoreceptors present in the skin, spinal cord, and hypothalamus perceive cold and stimulate thermogenesis and increased body temperatures. Results of Exp. 1 indicated that rectal temperature of calves from HF dams averaged lower than in calves from LF dams (Table 6). However, the cold-induced increase in rectal temperature was greater for calves from HF heifers (.41°C) than calves from LF heifers (.24°C), and the decrease in rectal temperature from peak values was greater in calves from LF heifers (.50°C) than in calves from HF heifers (.15°C). Feeding rats diets containing high concentrations of linoleic acid resulted in fetuses with brown adipose tissue (**BAT**) containing higher concentra-

tions of linoleic acid (Derry, 1972), pups with increased BAT activity (Schwartz et al., 1983), and increased BAT thermogenesis (Nedergaard et al., 1983). In the present experiments, glucose concentrations in calves from HF-diet dams exceeded those of calves from LF-diet dams throughout the cold exposure period. This difference may indicate that muscle and liver glycogen content may also have been higher.

Glucocorticoids play an indirect role in supporting cold thermogenesis through lipid and glycogen mobilization to provide energy substrates for thermogenesis (Himms-Hagen, 1990). Increased blood glucose and NEFA concentrations in calves exposed to cold environments have been reported (Godfrey et al., 1991), indicating possible associations of these metabolites with thermogenesis. Robertson et al. (1981) demonstrated in sheep from 30 d before to approximately 2 d after parturition, that fetal perirenal adipose tissue had a high rate of lipogenesis, and that acetate, glucose, and lactate contributed to the formation of fatty acid synthesis at rates of 50, 17, and 33%, respectively. We conclude from the literature that blood glucose concentrations play an important role in thermogenesis in the neonatal calf. The difference in maintenance of increased rectal temperatures between calves born to HF- and LF-diet heifers may be associated with 1) shivering thermogenesis associated with higher concentrations of plasma glucose or 2) nonshivering thermogenesis associated with increased concentrations of linoleic acid in BAT and increased BAT thermogenic activity. Verifying this latter pathway awaits further work. Because calves from HF dams had higher glucose concentrations and maintained a relatively constant rectal temperature during the last 80 min of cold exposure, we suggest that these calves may have been more cold-tolerant had they been exposed to more severe cold temperatures and(or) a longer period of cold exposure.

The lack of effect of dietary treatment on rectal temperature in Exp. 2 could be because 1) the higher cold room temperature was not sufficient to challenge the term calves, 2) the 3.1% fat content of the HF diet may not have been high enough to elicit a response, which may have been confounded by the lower than anticipated crude protein content of the diet, 3) the age of dam and calf genotype differences between the studies, and 4) the major differences in environmental temperatures between the two studies. We chose a higher cold room temperature for Exp. 2 as a precaution to reduce death loss of the premature calves. Diet composition differences encountered were not planned. The HF diet was formulated to have higher fat and protein content, but chemical analyses found this was not attained. We suspect that this discrepancy was due to unanticipated composition changes in the corn silage. Dams in Exp. 1 were first-calf heifers and mature cows in Exp. 2. Calves on Exp. 1 were 50% Line 1 Hereford and 50% Murray Grey in Exp. 2. Whether there may be dam age and(or) calf

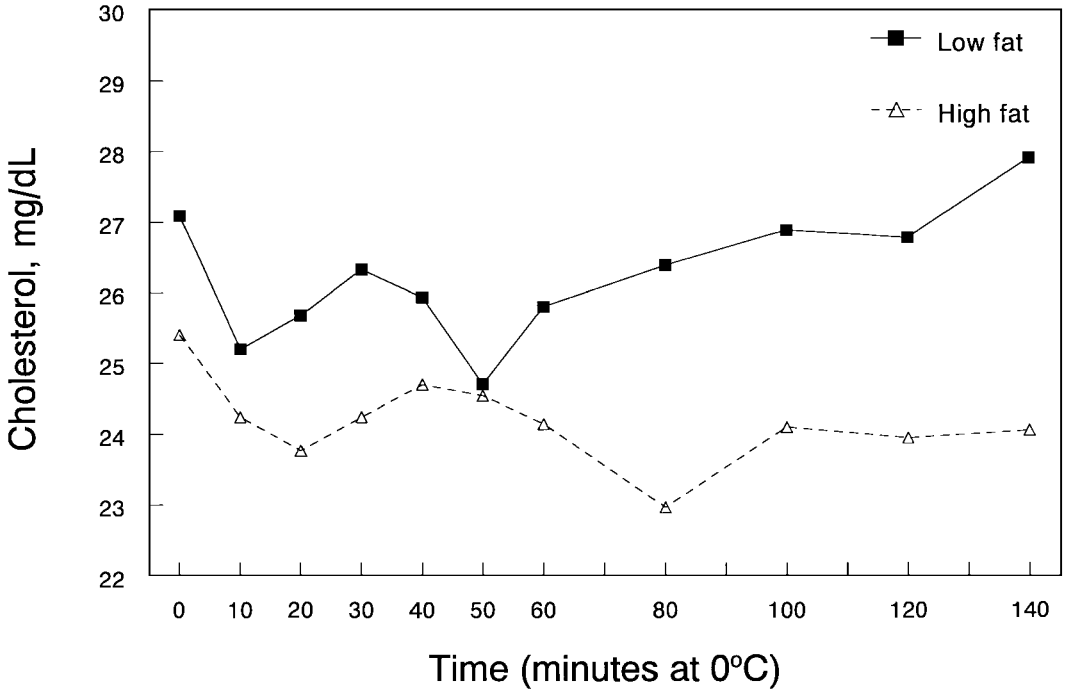

Figure 3. Least squares mean plot (pooled SEM = .71) of plasma cholesterol concentrations of neonatal calves exposed to 0°C for 140 min from dams receiving 1.7 (low fat) or 4.7% (high fat) dietary fat prepartum as affected by diet × time interaction ($P < .05$; n = 22).

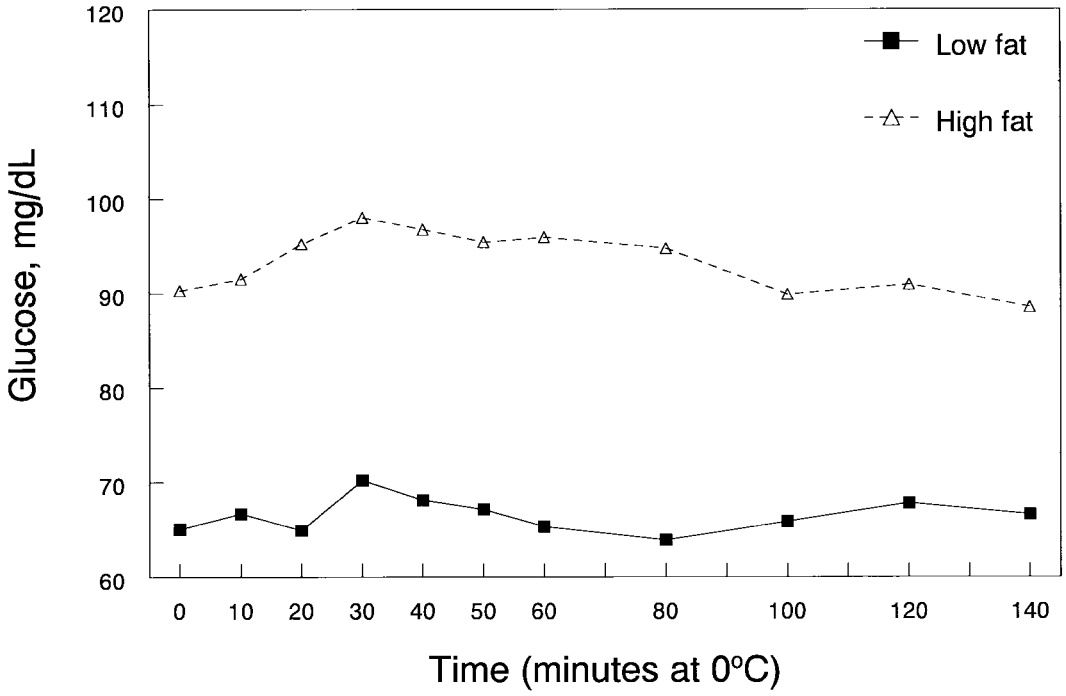

Figure 4. Least squares mean plot (pooled SEM = 2.65) of plasma glucose concentrations of neonatal calves exposed to 0°C for 140 min from dams receiving 1.7 (low fat) or 4.7% (high fat) dietary fat as affected by diet × time interaction (P = .58; shown for illustration purposes only).

genotype effects on the response to fat supplementation is unknown and awaits further study. The environmental temperature differences between the two studies may be important. Experiment 1 was conducted during late winter and early spring, whereas Exp. 2 was conducted during late summer. Daytime environmental temperatures ranged from –28 to 3°C during Exp. 1 and from 21 to 35°C during Exp. 2. What effect this temperature difference may have had on the results is unknown, but it suggests that prevailing environmental temperatures might affect fat-supplement-induced response. Data from the present studies do not allow determination of the importance of these various possibilities but do suggest opportunity for future work.

The drop in rectal temperature observed in Exp. 2 during the time period when calves were held in a room at 22°C may have been caused by evaporation of amniotic fluid from the body and heat loss from the respiratory tract. This decrease may have been a response to the relatively warm, constant temperature and be a reflection of decreased stress. This possibility is supported by the decrease in cortisol that occurred during this time period. These results are similar to the findings in calves reported by Vermorel et al. (1989) and Laburn et al. (1994), who reported that

Table 7. Analyses of variance for Experiment 2

		Variable				
Source	df	Birth wt	Rectal temp	Cortisol	Cholesterol	Glucose
Diet	1	2.62	1.12	1,063.70	49.32	3.86
Age	1	1,669.29**	18.09*	39.65	30.74	17,049.72**
Diet × age	1	31.74†	.96	2,930.24	155.87	.77
Time	6	—	.63**	2,056.03**	9.36*	1,151.34**
Diet × time	6	—	.03	289.99	3.24	18.74
Age × time	6	—	.21**	247.32	2.16	359.94**
Error A	14	9.01	3.57	1,177.04	60.58	1,343.49
Error B	90	—	.04	253.32	4.05	84.10

*P < .05.
**P < .01.
†P = .06.

Table 8. Least squares mean values for main effects in Experiment 2[a]

Main effect and item	No.	Variable				
		Birth wt, kg	Rectal temp., °C	Cortisol, ng/mL	Cholesterol, mg/dL	Glucose, mg/dL
Diet						
Low fat	9	33.5	38.9	69.0	24.3	73.5
High fat	9	33.8	39.1	63.0	25.5	73.1
Age						
Premature	10	30.0	38.6	65.5	25.4	61.6
Term	8	37.3	39.4	66.6	24.4	85.1
Time						
–60	18	—	39.4	88.8	24.2	59.3
0	18	—	39.0	59.2	24.2	69.8
20	18	—	39.2	68.2	24.7	75.1
40	18	—	39.1	58.0	24.5	80.6
60	18	—	39.0	59.2	25.0	82.7
120	18	—	38.9	66.3	25.7	77.3
200	18	—	38.8	62.5	26.1	68.5

[a]See Table 7 for statistical significance.

the newborn could lose from .5 to 1.5°C when placed in a controlled temperature room.

The calf maturity × time interaction showed that term calves were capable of maintaining higher rectal temperatures than premature calves. Larger calves had a smaller surface area:body weight ratio, thus potentially reducing heat loss. Calf birth weight has been shown to be directly proportional to thermoneutral metabolic rates (Okamoto et al., 1986; Carstens et al., 1987; Young et al., 1989). There is a high positive correlation in neonatal calves between birth weight and the time required to reduce core body temperature when immersed in cold water (Okamoto et al., 1986). Because premature calves were lighter ($P < .01$) than term calves (30.0 vs 37.3 kg), birth weight may have played a role in differences in cold tolerance. However, when birth weight was used as a covariate in a separate statistical analysis, the differences between premature and term calves remained significant. Therefore, we suggest that birth weight was not the only factor involved and that thermogenic capability was compromised in the premature calves.

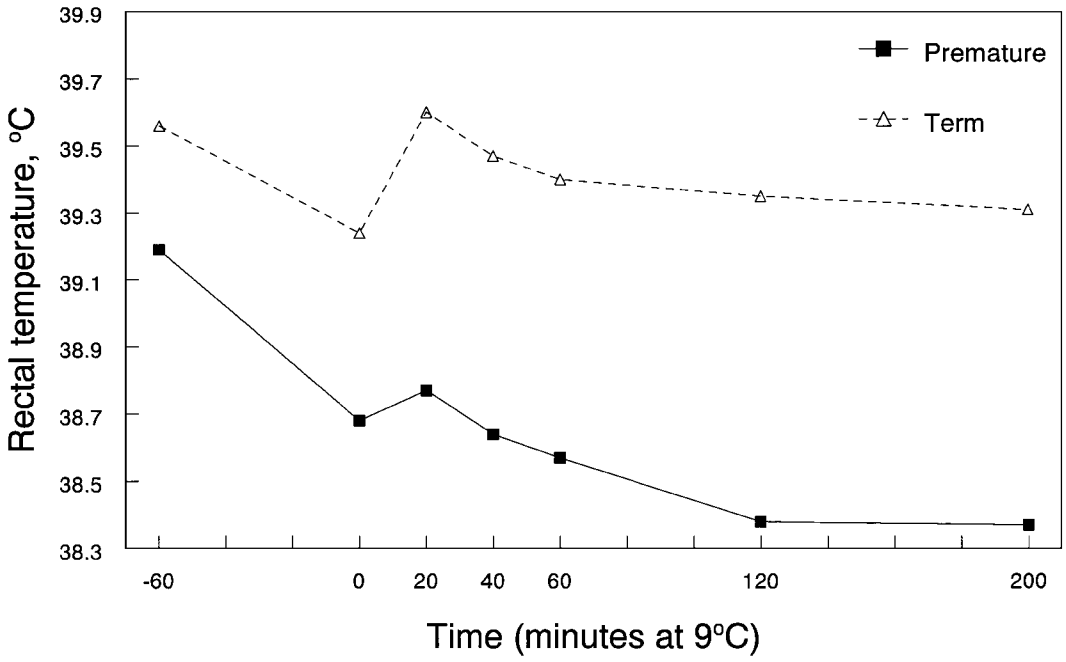

Figure 5. Least squares mean plot (pooled SEM = .06) of rectal temperatures of premature and term neonatal calves exposed to 9°C for 200 min as affected by calf age × time interaction ($P < .01$; n = 18).

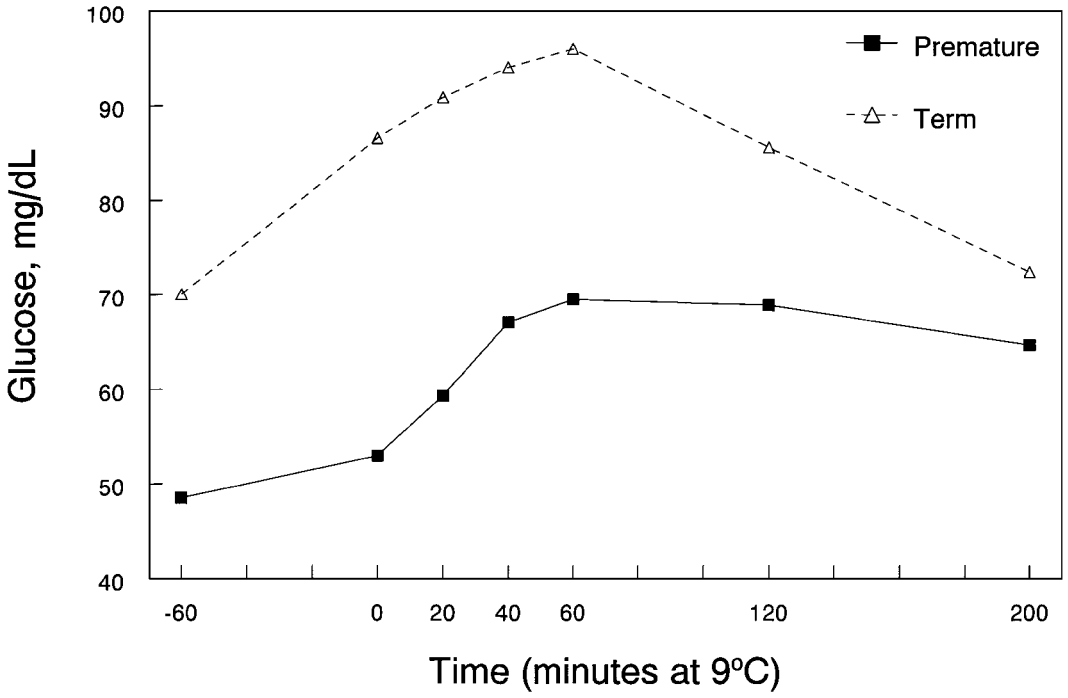

Figure 6. Least squares mean plot (pooled SEM = 2.32) of plasma glucose concentrations of premature and term neonatal calves exposed to 9°C for 200 min as affected by calf age × time interaction ($P < .01$; n = 18).

Casteilla et al. (1987) reported that most of the growth of BAT in cattle occurred in the last 28 d of gestation, indicating that differences in thermogenesis between term and premature calves could have resulted from differences in the amount of BAT and(or) the thermogenic capacity of BAT present at the time of birth. If this is the case, one could hypothesize from this experiment and others that the quantity and(or) the thermogenic capacity of BAT plays a major role in cold tolerance of the newborn calf.

Differences in plasma concentrations of cortisol indicated that changes over time were affected by calf sex. Elevated cortisol concentrations in cold environments have been reported to be involved in thermogenesis by providing substrates from lipid and glycogen stores and BAT (Bassett and Alexander, 1971; Bell and Thompson, 1979). Thus, differences in plasma cortisol concentrations could have affected substrate mobilization and(or) cold stress, and these were different for male and female calves.

Cows supplemented with fats prepartum have been reported to have higher blood concentrations of cholesterol than cows that received no supplemental fat (Hawkins et al., 1995). In addition, Godfrey et al. (1991) and Stanko et al. (1991) found an increase in concentration of blood lipids in calves exposed to cold environments compared with calves exposed to warm environments, further suggesting the involvement of blood lipids in cold thermogenesis.

Implications

Feeding pregnant heifers supplemental fat high in linoleic acid for approximately 8 wk before parturition increased plasma glucose concentrations and increased the ability of the calf to maintain body temperature. Premature calves were less cold-tolerant and had lower plasma glucose concentrations than did term calves. We hypothesize that improved cold tolerance in newborns resulting from feeding supplemental fat during the last trimester could result in improved calf survival.

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