Health and Metabolic Responses of Young Calves Housed at -30° C to -8° C

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ABSTRACT

Newborn, male, Holstein calves, were continuously housed for three weeks in calf hutches at 17° C or in a thermal environment which varied rhythmically on a daily basis either between -20° C and -8° C (experiment A) or between -30° C and -18° C (experiment B). Compared to warm-housed calves, cold-housed calves in experiment A had metabolic rates which were significantly higher ($p < 0.001$) in a standing position but which were not significantly different ($p > 0.05$) in a recumbent position. Recumbent and standing cold-housed calves in experiment B had an increased ($p < 0.05$) metabolic rate compared to warm-housed controls. Heat loss was less ($p < 0.05$) for recumbent cold-housed calves in experiment B than for standing calves in a thermoneutral environment. Localized subcutaneous hemorrhages of hindlimbs were a consistent necropsy finding among all cold-housed calves. Average daily gains of cold-housed calves were not significantly different from warm-housed controls. Clinical, physiological and pathological findings indicated that cold treatments used in the present study did not cause serious harm to calves. It was concluded that calves housed in properly managed hutches are remarkably cold tolerant.

RÉSUMÉ

Cette étude portait sur 15 veaux Holstein, mâles et nouveau-nés, que les auteurs placèrent dans des cages individuelles, pour une période de trois semaines. Ils gardèrent les témoins à la température de 17° C, mais ils soumirent les autres à une température ambiante qui variait quotidiennement, de la façon rythmique suivante: de -20° C à -8° C, pour le groupe A, et de -30° C à -18° C, pour le groupe B. Comparativement aux témoins, les veaux du groupe A affichèrent un taux de métabolisme significativement plus élevé ($p < 0,001$), lorsqu'ils étaient debout, mais non significativement différent ($p > 0,05$), lorsqu'ils étaient couchés. Les veaux du groupe B, debout ou couchés, affichèrent un taux de métabolisme plus élevé ($p < 0,05$) que celui des témoins. La perte de chaleur s'avéra moindre ($p < 0,05$) chez les veaux couchés du groupe B que chez les témoins debout. La nécropsie des veaux des groupes A et B révéla constamment des hémorragies focales, dans le tissu sous-cutané de leurs membres postérieurs. Leur gain de poids quotidien moyen ne différa pas significativement de celui des témoins. Les observations cliniques, physiologiques et pathologiques révélèrent que les températures froides expérimentales ne causèrent pas d'inconvénient sérieux aux veaux. Les auteurs conclurent par conséquent que les veaux gardés dans des cages adéquatement entretenues tolèrent très bien le froid.

INTRODUCTION

Reports of unacceptably high mortality among dairy calves are not uncommon (1-3). In an effort to combat these losses many producers raise calves individually in calf hutches (4) which serve to isolate calves from each other and from older cattle which may act as carriers of pathogenic organisms. This strategy aids in the prevention of exposure of susceptible calves to lethal doses of virulent microorganisms.

During winter, however, calves housed in hutches may be exposed to severe cold since temperatures inside hutches are not significantly different from outdoor ambient temperatures (5,6). It has been suggested that temperature is the single most important environmental factor affecting calves (7,8). High mortality rates in winter are frequently reported (8,9). Benefits of raising calves in hutches may be outweighed by costs of chronic cold exposure including energy malnutrition accompanied by weight loss, ill health, hypothermia, or death (10).

The effect of acute exposure of calves to cold which quickly produced

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hypothermia has been extensively studied (11-21). Despite the economic importance of raising healthy dairy calves (22), little information exists concerning the effects of chronic exposure of calves to very low environmental temperatures which, under field conditions, have the potential for producing hypothermia in calves. Small and Eales have suggested that hypothermia among calves may be more common than is generally recognized (23). However, it is not clear that temperature alone is responsible for poor responses of some calves during periods of severe cold.

This investigation was carried out in two phases. After observing the successful responses of calves in experiment A, a colder temperature range was selected which would more closely represent temperatures found in many northern regions of the world. The objective was to study the effect of chronic exposure to severely cold temperatures on health and metabolic responses of healthy, young dairy calves housed in calf hutches.

MATERIALS AND METHODS

ANIMALS AND HOUSING MANAGEMENT

The guidelines included in the Guide to the Care and Use of Experimental Animals, Canadian Council on Animal Care, were followed in this study. Fifteen newborn, male, Holstein calves were purchased from a local dairy farm on which a successful herd health program had been in effect for several years. Each calf received a minimum of 2.4 L of warmed, pooled colostrum as soon after birth as possible followed by the feeding of 2.4 L of pooled colostrum twice daily for the first 48 h of life. Subsequently, all calves received milk replacer (Land O'Lakes, Calf Nursing Formula, all-milk source, nonmedicated, 20% fat) (40.6°C) at the rate of 420 g in 2.4 L water per 45 kg body weight twice daily. This quantity of feed is approximately 20% higher than published guidelines for feeding of dairy calves under conditions of cold stress (24) and was instituted in order to assure adequate caloric intake. Within 24 hours of birth calves were assigned to one of three groups and placed individually into calf hutches which were installed in each of two environmental chambers (Conviron Model No. C1011-99). Thermal protection from the concrete floor of the chambers was provided by a 15 cm layer of wood shavings. Hutches were then bedded with one full bale of straw. Both shavings and straw were replaced every seven days in order to prevent accumulation of moisture in bedding.

Temperature in the chamber which housed the control group of calves was maintained at a constant 17°C, a temperature known to be above the lower critical temperature of newborn calves (25). Air temperature inside a second environmental chamber was made to cycle on a daily basis from either -20°C (experiment A) or -30°C (experiment B) at 0600 h rising 1°C per h to -8°C or -18°C, respectively, at 1800 h, then falling again in like manner to the low temperature. Lights were automatically turned on at 0500 h and off at 2000 h in both chambers. Calves were maintained in hutches under the described conditions without interruption (except for weighing) for the first three weeks of life.

CLINICAL ASSESSMENT OF HEALTH

Calves were fed at 0700 and 1600 h. Thirty minutes after each morning feeding, health of all calves was assessed clinically. General appearance and behavior, body weight, heart rate and respiratory rate were utilized as indicators of health status and were monitored on a daily basis. Rectal temperature was taken daily with an electronic clinical thermometer (Model #M216 Hi-Speed Digital Thermometer, GLA Agric Electronics, Montclair, California). Upon arrival from the farm and three mornings per week thereafter (weekly for calves in experiment B), blood was drawn by jugular venipuncture for determination of the following: red blood cell count (RBC), white blood cell count (WBC), packed cell volume (PCV), hemoglobin concentration, and serum concentrations of glucose, sodium, potassium, chloride, calcium and thyroxine (T_4).

METABOLIC RATES

Expired air was collected from calves in both standing and recumbent positions on three mornings per week using a tightly fitting face mask equipped with a three-way valve (Triple "J" valve, No. 21015, Warren E. Collins, Inc., Braintree, Massachusetts). The position of the calf was not forced (i.e. calves were not "thrown" or tied in order to collect a sample during recumbency). Presence or absence of shivering was recorded, along with a score for behavior of the calf during the collection period. A behavior score of -0- was given to calves which were very still. Movement of the head or one limb resulted in a score of -1-. If the calf exhibited activity beyond this, the sample was discarded and a second attempt at collection was made after a short interval.

Collection was made into a Douglas Bag (Warren E. Collins, Inc., Braintree, Massachusetts) for 5 min and expired air was analyzed for O_2 and CO_2 concentration with a Scholander gas analysis apparatus (26). After warming to 25°C, volume of gas collected was measured with a gas meter (Instrumentation Associates, Inc., New York), then corrected to conditions of standard temperature and pressure. Heat production was then calculated (27) in $kcal \cdot day^{-1} \cdot kg^{-.75}$ based upon these measurements.

NECROPSY

All calves were killed with intravenous barbiturate and were subjected to necropsy examination at the conclusion of the three week experimental period. Both gross and microscopic examinations were conducted, including selective tests for parasites, bacteria and viruses. Tissues subjected to histopathology included sections of brain, pituitary, auricular pinnae, Gasserian ganglion, thyroid, thymus, ventricular and atrial myocardium and adipose tissue near the coronary groove, lung, liver, spleen, adrenal, kidney, perirenal fat, ileum, colon and mesenteric lymph nodes.

STATISTICS

Statistical analysis of data was performed using Student's *t*-test or analysis of variance of a split plot design with repeated measures to determine differences between treatment groups and to identify significant alterations with age (28). The main effect of the split plot analysis was the

warm or cold chamber, the period effect was age, and the repeated measures were calves. Metabolic rate data were analyzed using multiple regression by the method of least squares (29). Differences between means were considered significant at the $p = 0.05$ level.

RESULTS

No differences between groups regarding general appearance, behavior, appetite or aggressiveness at feeding were observed. Clinical data are shown in Table I. While statistically significant alterations in rectal temperature (experiment A only) and heart rate were found in association with cold treatment, no clinical importance was attached to these changes as indications of ill health or inadequate thermoregulation. Mean respiratory rate decreased with age in all groups. Heart rate of all cold-housed calves increased significantly between birth and seven days of age and then remained steady but there was no significant change in heart rate with age among warm-housed calves. Cold-housed calves had lower respiratory rates although rates were not statistically different from warm-housed controls.

Average daily gain (ADG) was expected to be an important indicator of overall performance. Although warm-housed controls had higher ADG than cold-housed calves, this difference was not statistically significant.

Metabolic rate was analyzed using multiple regression procedures. As described above, a behavior score, position of the calf, and the presence or absence of shivering were recorded during the collection of expired air from each calf. These factors, all of which affect metabolic rate, were used to adjust the regression equation modelling metabolic rate versus age to obtain a good fit to the data. In order to stabilize variances, data were transformed to logarithms. The regression equation for experiment A was ($r = 0.82$):

$$\begin{aligned}\text{Log(MR)} = {} & 2.1494 - 2.9535 \times 10^{-3}(\text{AGE}) \\ & + 4.6491 \times 10^{-2}(\text{POSITION}) \\ & + 5.2080 \times 10^{-2}(\text{POSITION} \times \text{CHAMBER}) \\ & + 7.0967 \times 10^{-2}(\text{SHIVERING}) \\ & + 4.1580 \times 10^{-2}(\text{BEHAVIOR})\end{aligned}$$

For experiment B, the regression equation was ($r = 0.80$):

$$\begin{aligned}\text{Log(MR)} = {} & 2.1313 - 2.2256 \times 10^{-3}(\text{AGE}) \\ & + 3.5485 \times 10^{-2}(\text{CHAMBER}) \\ & + 5.3811 \times 10^{-2}(\text{POSITION}) \\ & + 7.1429 \times 10^{-2}(\text{POSITION} \times \text{CHAMBER}) \\ & + 4.5605 \times 10^{-2}(\text{BEHAVIOR})\end{aligned}$$

Where:

MR = metabolic rate in kcal·day^{-1}·body weight in kg$^{-0.75}$

Age = age of calf in days

Behavior = behavior score, 0 or 1, as described above

Position = position of the calf: recumbent = 0, standing = 1

Chamber = calves in warm chamber = 0, calves in cold chamber = 1

Shivering = shivering absent = 0, shivering present = 1

Other terms and interactions, such as behavior and position, behavior and age, or shivering and behavior did not significantly improve the fit of the equations.

For comparisons, resting metabolic rate (RMR) was defined herein as the rate measured while the calf was either standing or recumbent, with behavior that would be scored as a zero and not shivering. In this case the variables BEHAVIOR and SHIVERING were set to 0 and hence dropped out of the equations. Regression lines for resting metabolic rate are shown in Figs. 1 and 2, transformed from logarithms to kcal·day^{-1}·body weight in kg$^{-0.75}$.

Experiment A — Resting metabolic rate decreased by 12.7% during the first three weeks of life in both controls and calves housed in the cold chamber. The 11.3% difference in RMR between values determined while warm-housed calves were recumbent versus standing is a measure of the metabolic cost of standing in a thermoneutral environment. The metabolic cost to calves standing in the cold chamber was much higher in that they exhibited an increase in RMR of 25.5%. Cold exposure in itself did not necessarily have an effect on RMR. As long as cold-housed calves remained in the recumbent position, their RMR was equal to that of controls in the same position.

Experiment B — Resting metabolic rate decreased by 9.7% during the first three weeks of life in both controls and calves housed in the cold chamber. In contrast to experiment A, recumbent cold-housed calves in experiment B had an 8.5% higher metabolic rate when compared to recumbent warm-housed calves. Metabolic rate of warm-housed calves rose 13.2% upon standing. Calves standing in the cold chamber had an increase in RMR of 33.4% over RMR in recumbency.

TABLE I. Clinical Data for Five Warm-housed Calves, Five Cold-housed Calves at -20° to -8° C (Experiment A), and Five Cold-housed Calves at -30° to -18° C (Experiment B) for the First Three Weeks of Life

	Warm-housed	Cold-housed	
		Experiment A	Experiment B
Rectal temperature (C)	39.0 ± 0.1 (38.3 - 40.3)	38.7 ± 0.1[a] (36.6 - 39.6)	38.7 ± 0.2 37.8 - 39.6)
Respiratory rate (min^{-1})	33 ± 4 (14 - 128)	27 ± 5 (12 - 115)	29 ± 4 (16 - 72)
Heart rate (min^{-1})	119 ± 5 (72 - 192)	155 ± 6[a] (86 - 220)	145 ± 6[a] (100 - 184)
Average daily gain (kg/day)	0.65 ± 0.06 (0.58 - 0.90)	0.58 ± 0.05 (0.41 - 0.70)	0.49 ± 0.10 0.10 - 0.67)

Data expressed as mean ± SEM. Figures within parentheses represent the range of values measured
[a] = mean was significantly different from warm-housed controls, $p < 0.05$

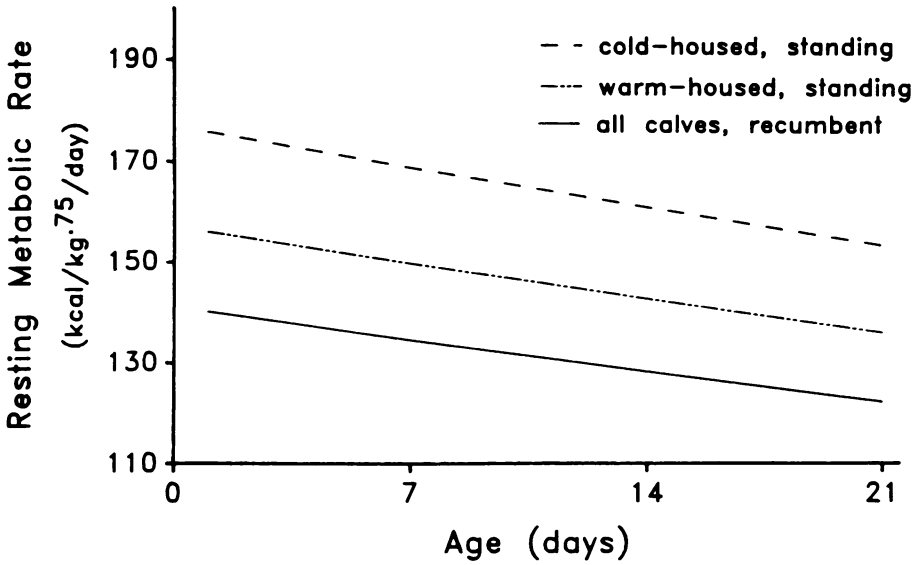

Fig. 1. Resting metabolic rates for five warm-housed calves and five cold-housed (-20° to -8°C) calves in recumbent or standing positions.

Means and ranges of serum chemical values for warm-housed controls and cold-housed calves are summarized in Table II. No significant differences due to treatment or age were found in mean values of serum sodium or potassium. In experiment A, there was no difference in serum chloride concentration between treatments, although cold-housed calves in experiment B had lower chloride concentrations than controls. Chloride concentration increased with age in both experiments and there was a significant interaction between treatment and age. Serum glucose and calcium concentrations of cold-housed calves in both experiments were not different from controls but, in experiment A, decreased significantly with age. Glucose concentrations below 60 mg/dL (found in one warm-housed control and one cold-housed calf in each experiment) were not associated with any clinical signs such as lack of aggressiveness, difficulty in nursing, lethargy, or hypothermia. Thyroxine concentrations did not change significantly with age and were not affected by cold treatment.

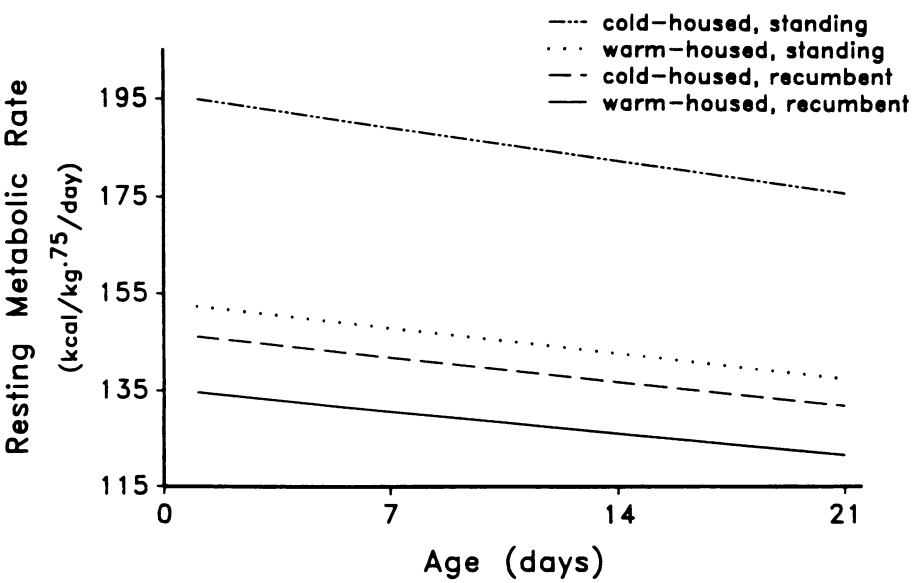

Fig. 2. Resting metabolic rates for five warm-housed calves and five cold-housed (-30° to -18°C) calves in recumbent or standing positions.

Hematological data are shown in Table III. Cold-housed calves in experiment A had a lower WBC and calves in experiment B had a higher WBC than warm-housed calves. There was no significant effect due to age in either experiment. White blood cell count fluctuated considerably but there was no indication of a trend in either experiment. Absence of infectious disease was inferred from daily clinical examinations and confirmed by necropsy.

Hemoglobin concentration and PCV significantly increased with age but were not affected by cold exposure. Red blood cell count also increased in all groups with age but was higher than controls only in experiment B. In no case did RBC fall below 4 million/μL. Packed cell volume less than 25% and hemoglobin concentration less than 8.0 g/dL were found in three calves, one warm-housed control and one cold-housed calf in each experiment. Each calf had a PCV greater than 25% and hemoglobin concentration greater than 8.0 g/dL within 15 days of age.

At necropsy warm-housed calves were found to be free of gross lesions. In contrast, all cold-housed calves had a varied extent of subcutaneous hemorrhage in the region of the hock posterior to the tuber calcis and hindlimb fetlock joints (Fig. 3). In life, these lesions were not accompanied by swelling, lameness, or any indication of tenderness upon palpation. Also, the distal 1-3 cm of auricular pinnae in four of five cold-housed calves in experiment B was cool and slightly thickened. Perirenal fat in all cold-housed calves was markedly diminished and more brown. Quantity of fat in coronary grooves did not seem to be affected by cold exposure. Other gross lesions were not detected.

A small growth of nonhemolytic *Escherichia coli* without evidence of the presence of the attachment antigens was frequently obtained from the small intestine of warm-housed controls and cold-housed calves in experiment A. *Pasteurella multocida* was isolated from the umbilicus and

TABLE II. Serum Chemical Values for Five Warm-housed Calves, Five Cold-housed Calves at -20° to -8° C (Experiment A), and Five Cold-housed Calves at -30° to -18° C (Experiment B) for the First Three Weeks of Life

	Warm-housed	Cold-housed Experiment A	Cold-housed Experiment B
Na (mEq/L)	142.6 ± 0.6 (138.0 - 145.0)	143.3 ± 0.5 (138.0 - 147.0)	142.7 - 0.4 (136.0 - 146.0)
K (mEq/L)	5.1 ± 0.1 (4.4 - 6.5)	4.8 ± 0.1 (3.9 - 5.7)	5.0 ± 0.1 (4.5 - 6.7)
Cl (mEq/L)	101.6 ± 0.8 (97.0 - 109.0)	99.9 ± 0.7 (95.0 - 108.0)	97.8 - 0.8[a] (94.0 - 102.0)
Ca (mg/dL)	11.17 ± 0.18 (10.00 - 12.00)	11.30 ± 0.16 (9.00 - 12.90)	11.29 ± 0.11 (10.30 - 12.30)
Glucose (mg/dL)	100.3 ± 3.4 (56.0 - 157.0)	101.0 ± 4.0 (38.0 - 154.0)	108.4 ± 5.9 (43.0 - 149.0)
Thyroxine (μg/dL)	8.8 ± 0.7 (5.4 - 16.0)	8.52 ± 1.07 (2.70 - 24.00)	12.0 ± 1.7 (6.5 - 23.3)

Data expressed as mean ± SEM. Figures within parentheses represent the range of values measured
[a] = mean was significantly different from warm-housed controls, $p < 0.05$

spleen of one cold-housed calf in experiment A. This calf had not exhibited fever, poor appetite, lethargy or other signs of illness prior to necropsy. No evidence for the presence of cryptosporidial or coccidial organisms, rotavirus, coronavirus, or the viruses of bovine virus diarrhea or infectious bovine rhinotracheitis was detected in any calf.

The adipose connective tissue cells in the cold-housed calves were rarely filled with lipid; most of them contained a moderate amount of eosinophilic cytoplasm. Examination of the subcutaneous tissues near the hock and fetlock joints revealed that redness was due to hemorrhage characterized by massive numbers of extravasated erythrocytes. Lesions were not detected in other tissues.

Based on clinical signs, hemic values and information obtained at necropsy, three warm-housed calves fully recovered from a diarrhea before the end of the three week period. These episodes were characterized only by diarrhea and were not accompanied by any other signs of disease such as fever, lethargy, or poor appetite. Two of the three calves received an oral electrolyte replacement solution (ReSorb, Beecham Laboratories, Bristol, Tennessee), warmed to 40.6°C, for two to five days. The third calf exhibited diarrhea for one day only, received no treatment, and recovered without incident.

DISCUSSION

Comparison of the effects of chronic cold exposure in the present study and of acute cold exposure, documented previously (11-21), is of interest. Calves acutely exposed to cold temperature which quickly produced hypothermia had signs of physical weakness, depression, loss of vigor, difficulty in nursing and were reluctant to stand or walk (13).

In contrast, all calves in the present study maintained good vigor and aggressiveness. Respiratory rates tended to be lower in cold-housed calves in accord with other work involving cattle (30), sheep (31), pigs (32) and reindeer (33). The large variance in respiratory rate among warm-housed calves was probably responsible for the lack of a statistically significant treatment effect. No signs of respiratory disease were detected. Increased heart rate in cold exposed cattle and sheep has been reported previously (30,31).

While rectal temperature was affected by cold exposure in experiment A, mean values did not fall outside a clinically normal range. Four low (< 37.7°C) rectal temperatures were observed in two cold-housed calves in experiment A on two consecutive days. Rectal temperature in each calf spontaneously rose to 38.0°C or higher the following day. This recovery was coincident with replacement of the bedding.

Ranges of hematological or serum chemistry values in the present study indicated few clinically important effects due to three weeks of cold exposure of calves. Mean WBC for cold-housed calves was lower in experiment A but higher in experiment B. In other studies, WBC tended to decrease when calves were acutely cold stressed (19), although no changes in leukocyte function have been observed in calves exposed to moderate cold (21). Although observed changes were statistically significant, they appeared to have no clinical significance as indicators of ill health.

Concentrations of T_4 found in the present study of calves receiving milk replacer in excess of maintenance, were in agreement with other findings. In chronically cold-exposed, outdoor housed steers on high feeding levels, T_4 concentrations were not affected when compared with steers on a similar feeding level but housed at 15°C (34).

TABLE III. Hematological Values for Five Warm-housed Calves, Five Cold-housed Calves at -20° to -8° C (Experiment A), and Five Cold-housed Calves at -30° to -18° C (Experiment B) for the First Three Weeks of Life

	Warm-housed	Cold-housed Experiment A	Cold-housed Experiment B
Total WBC x 10^3 (μL^{-1})	8.5 ± 0.6 (4.7 - 18.9)	6.6 ± 0.7[a] (2.4 - 10.8)	10.9 ± 0.8[a] (6.4 - 19.6)
Total RBC x 10^6 (μL^{-1})	7.5 - 0.3 (4.00 - 10.86)	7.72 ± 0.54 (4.85 - 9.93)	8.7 ± 0.3[a] (6.8 - 10.6)
PCV (%)	34.2 ± 1.9 (17.5 - 44.0)	32.3 ± 2.2 (20.0 - 40.0)	34.3 ± 0.2 (27.0 - 40.0)
Hemoglobin (g/dL)	11.0 ± 0.6 (5.7 - 13.9)	10.2 ± 0.7 (6.2 - 12.7)	11.4 ± 0.3 (7.9 - 13.0)

Data expressed as mean ± SEM. Figures within parentheses represent the range of values measured
[a] = mean was significantly different from warm-housed controls, $p < 0.05$

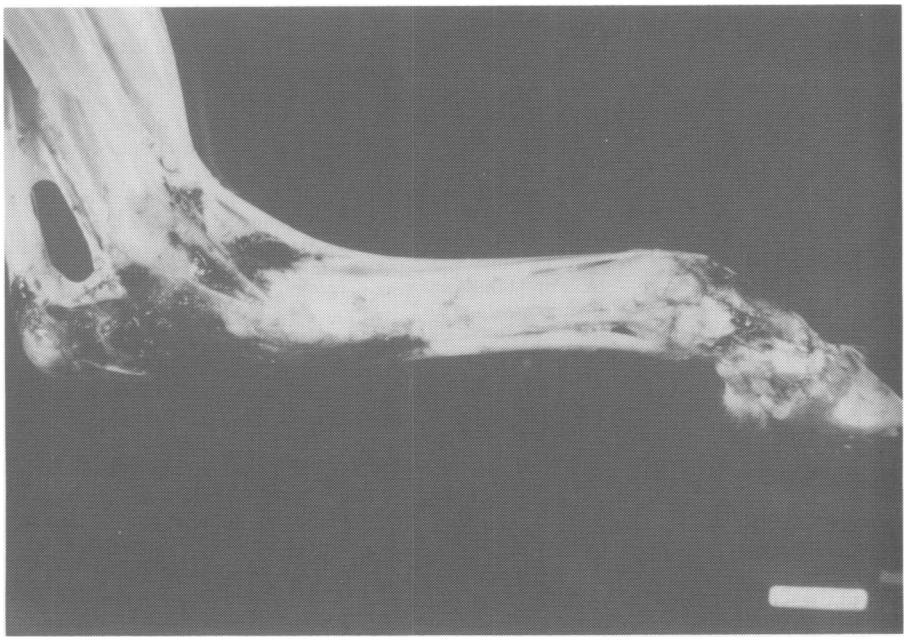

Fig. 3. Hindlimb of cold-housed calf showing subcutaneous hemorrhage in fetlock and hock region.

Subcutaneous hemorrhage and edema of the hindlimbs has been observed clinically in association with "weak calf syndrome" (35). In the laboratory, similar lesions have been induced by severe cold stress (13). The pathogenesis of the hemorrhage has not been elucidated. All cold-housed calves in the current study had these lesions at necropsy. Evidence of an inflammatory process was not detected in any case. The lesions did not seem painful because the calves did not object to walking and jumping or to palpation and manipulation of the limbs. Hemorrhages were quite apparent at necropsy but their clinical importance was unclear.

Other reports of the metabolic response of young calves housed in hutches and chronically exposed to cold could not be found. Previous studies of the metabolism of calves involved young calves at thermoneutral temperatures in metabolism stalls (36) or bedded on sawdust (37), young calves in a respiration chamber above freezing (25), three to four day old calves subjected to wind and wetting of the coat on an acute basis (38), or older calves subjected to outdoor environments (39).

The finding that metabolic rate declined with age was in accord with previous studies (25). The metabolic cost of standing in a thermoneutral environment was consistent with data obtained using older cattle (40,41). Although it was expected that cold-housed calves would have elevated metabolic rates while standing, moving, or shivering, the surprising effectiveness of the hutch and straw bedding in reducing heat loss while calves were in the recumbent position was not anticipated. Two points emanate from this observation. First, metabolic rates of calves which are determined in one microenvironment are not necessarily applicable to other environments. Based on data collected in metabolism chambers (25), metabolic rates of calves housed in hutches at -20° to -8°C would be expected to be markedly elevated. However, such was not the case for recumbent calves in the present study. Second, alteration in the quality of the microenvironment (i.e. wet bedding) may compromise the cold tolerance of the calf.

Because of their age and size, young dairy calves are expected to be more susceptible to cold stress than older cattle (42). Hence, care must be taken that management practices not oppose the natural thermoregulatory mechanisms which serve to protect the calf from cold. In the present study, bedding was replaced weekly to minimize effects of accumulated moisture. Therefore, the conclusion that calves are cold tolerant to the degree observed in the present study is only valid for calves housed in hutches in which bedding is kept dry. Studies have been conducted which examined the effect of ambient temperature, wind, rain and shelter on the performance of cattle and calves (38,43,44). Unfortunately, little attention has been given to the quality of bedding in calf hutches.

Although ADG of cold-housed calves tended to be lower, the difference was not statistically significant. Under the conditions of the experiment, the energetic demand of a fluctuating thermal environment between temperatures as low as -30° and -18°C was not sufficient to produce a difference between the warm- and cold-housed groups. It was believed that the microenvironment, consisting of the hutch and straw bedding, was of crucial importance since the ambient temperature to which calves were exposed was well below the value for lower critical temperature (13°C) for newborn calves previously reported in the literature (25). That metabolic rates of recumbent cold-housed calves were not different from or only minimally higher than those of recumbent warm-housed calves supports the conclusion that the lower critical temperature of cold-housed calves was reduced when calves were recumbent. Consequently, through behavioral (i.e. spending more time in recumbency) and physiological thermoregulatory mechanisms, a healthy calf housed in a properly managed hutch during severely cold weather would expend no more energy on a daily basis than a calf housed at a thermoneutral temperature.

It seems that three weeks of exposure to a fluctuating environmental temperature between either -20° and -8°C or -30° and -18°C was not detrimental to the growth and health of young dairy calves. This conclusion was made possible, in part, because care was exercised in obtaining calves born to dams which were part of an ongoing herd health program and in maintaining calves disease free during the postnatal period. As a result, infectious disease

was not a confounding factor. In addition, weekly bedding changes minimized the influence of moisture. As a consequence of the design of the experiment, inadequate energy intake, infectious disease, precipitation, drafts and wet bedding were not confounding factors and effects of cold exposure alone could be studied.

Based on the findings of the present study, chronic exposure of calves to the severely cold temperatures found in many areas of the world is not a sufficient explanation for higher mortality among calves in winter. Poor response of calves housed in hutches during severely cold winter weather is likely due to additional environmental and management related factors but not to cold temperature in and of itself. These factors, either alone or in addition to cold temperature, must be present before health and well-being of calves are affected.

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