ABSTRACT

Metabolic heat production and rectal temperature were measured in 19 newborn calves (41.8 ± 3.7 kg) during hypothermia and recovery when four different means of assistance were provided. Hypothermia of 30°C rectal temperature was induced by immersion in 18°C water. Calves were rewarmed in a 20 to 25°C air environment where thermal assistance was provided by added thermal insulation or by supplemental heat from infrared lamps. Other calves were rewarmed by immersion in warm water (38°C), with or without a 40-ml drench of 20% ethanol in water. Resting (prehypothermia) and cold-induced summit metabolism of the calves was 2.5 ± .1 and 8.2 ± .22 W/kg and occurred at rectal temperatures of 39.5 ± .06 and 36.2 ± .26°C, respectively. During cooling, metabolic heat production declined at the rate of .65 W/kg per °C decline in rectal temperature. The time required to regain euthermia from a rectal temperature of 30°C was longer for calves with added insulation and those exposed to heat lamps than for the calves in the warm water and warm water plus ethanol treatments (90 and 92 vs 59 and 63 ± 6.4 min, respectively). During recovery, the calves rewarmed with the added insulation and heat lamps produced more heat metabolically than the calves rewarmed in warm water. Total heat production during recovery was 34.1, 31.1, 18.3, and 16.9 ± 1.07 kJ/kg for the calves with added insulation, exposed to the heat lamps, in warm water and in warm water plus an oral drench of ethanol, respectively. By immersion of hypothermic calves in warm (38°C) water, euthermia was regained most rapidly and with minimal metabolic effort; no advantage was evident from oral administration of ethanol.

(Key Words: Hypothermia, Heat Transfer, Heat Production, Calves, Heat Regulation, Ethanol.)
mentary heat from immersion in 45°C water, from heat pads or from heat lamps with calves that were allowed to recover without assistance.

The objective of the present study was to measure the metabolic heat production of conscious neonatal calves during induction of and recovery from acute hypothermia. Assistance in thermal recovery was provided by four means to compare their effectiveness for rewarming hypothermic calves.

**Experimental Procedure**

*Animals.* Nineteen healthy *Bos taurus* calves (birth weight 41.8 ± 3.7 kg) were used. Immediately after parturition and before being tested the calves were maintained in a heated stable area (18°C) and were either allowed to suckle or were offered up to 1.5 kg of warmed colostrum. The calves were between 6 and 24 h of age when tested.

*Cooling Procedure.* A controlled-temperature, water immersion system (Young et al., 1988) was used to reduce rectal temperature (Tr) of the calves to 30°C. During this period the calves were secured to a padded support frame and immersed to their necks in continually circulated water. The initial water temperature was 38°C. Resting metabolism was measured after the calves had stabilized in the warm water for a minimum of 20 min. Water temperature then was reduced to 18°C, where it was maintained for a maximum of 2 h. If a Tr of 30°C was not achieved during exposure to 18°C, the water temperature was reduced further to 10°C. Cooling was halted when Tr reached 30°C.

*Rewarming Procedures.* The hypothermic calves were allocated to one of four treatment groups for evaluation of rewarming assistance: added insulation, heat lamp, warm water or warm water plus ethanol. Calves receiving rewarming assistance as added (thermal) insulation were removed from the water bath as soon as their Tr reached 30°C and were immediately dried by vigorous rubbing with a cotton cloth. They then were wrapped in a dry cotton blanket and placed in lateral recumbency in a rewarming box. The floor area of the box was 50 cm × 150 cm, and the sides were 60 cm high. The back, bottom and two sides were of plywood; the front and top were open. The air temperature in the box during rewarming ranged from 20 to 25°C. A similar procedure was used for the calves in the heat lamp treatment, except instead of covering the calves with a blanket, two 250-watt infrared heat lamps were placed .5 to .8 m above the midside of the calves. Calves receiving the warm water or warm water plus ethanol treatments remained in the water bath. As soon as their Tr reached 30°C, the cool water was replaced with 38°C water and maintained at 38°C during rewarming. Replacement of water took about 5 min. The calves receiving warm water plus ethanol treatment were treated the same as calves receiving the warm water treatment but were given an oral drench of 40 ml of 20% ethanol in water. Administration of alcohol has been suggested as a recovery aid for hypothermia. The ethanol-water mixture used in the present study was prepared as an 1:1 dilution of commercial brandy with water.

The calves were maintained in the stable area (18°C) for at least 12 h after testing and were fed colostrum before being returned to the main herd.

*Measurements.* Rectal (Tr), water and air temperatures were measured every 2 min to within ± .1°C using copper/constantan thermocouples and an electronic digital display thermometer. The polyethylene-covered temperature probe used to measure Tr was inserted 12 cm into the rectum and secured in place by attachment to the animal’s hair coat.

An open circuit system with a face mask was used to continuously monitor rate of respiratory oxygen uptake (Young et al., 1988). This system was calibrated by the “Fe-burner” method (Young et al., 1984). Rate of metabolic heat production, in watts (1 watt = 1 joule/s), was calculated from oxygen consumption, integrated over intervals of 2 min, using the equation of McLean (1972). Resting metabolism was determined while the calves were initially stabilized in 38°C water. Cold-induced summit metabolism was determined as the highest level of metabolic heat production measured over 10 consecutive minutes during the cooling phase. For further discussion of the measurements of resting and summit metabolisms, see Young et al. (1988).

*Statistics.* The data were analyzed by least squares regression procedures and one-way analysis of variance using the SPSS package.

---

4 Model BAT8, Bailey Instruments, Saddle Brook, NJ.

1 SPSS Inc., Chicago, IL.
Unless stated otherwise, values are expressed as means ± SE. Differences between means were tested using the Student-Newman-Keuls' test (Steel and Torrie, 1981).

Results

Pre-Cooling and Cooling Phases. The calves quickly calmed and settled into a restful state during the initial immersion in 38°C water. Average resting metabolic rate was 2.5 ± .1 W/kg and occurred when the calves had an average Tr of 39.5 ± .06°C.

The calves initially responded to the lowered water temperature by struggling; however, this was replaced by intense shivering within a few minutes. Summit metabolism was 8.2 ± .2 W/kg and was recorded when the calves had an average Tr of 36.2 ± .2°C. Beyond the point at which summit metabolism was recorded, metabolic heat production declined as Tr declined. The pooled rectilinear relationship, for all 19 calves, between maximum metabolic rate (MM; W/kg) and Tr between 35°C and 31°C was

\[ MM = -14.9 + .65 \text{ Tr} \]

This slope of the equation was significant (P < .001) and had a standard error of estimate of ± 1.0 W/kg. The exposure time in cold water required to reduce Tr of the calves to 30°C was 167 ± 7.2 min.

Though body cooling via cold water immersion was halted as soon as Tr reached 30°C, the Tr of the calves continued to decline as they were established in the rewarming test situations and before body heat balance became positive. The period required for Tr to return to 30°C was referred to as the transition phase. The calves that were removed from the water bath, dried and provided with added insulation or supplementary heat from heat lamps had lower minimal Tr and took longer time to regain a Tr of 30°C than the calves that remained in the bath (Table 1). Also, the calves in the added insulation and heat lamp treatments were both restless than the calves that remained in the water bath; the increase in their Tr usually was delayed until intense shivering was apparent. Small differences in the time required to establish the calves in the respective rewarming treatments seemed not to be a factor in the severity or duration of the transition phase. Comparison of the rewarming procedures were made from the time each calf regained a Tr of 30°C.

Rewarming Phase. The calves rewarmed with added thermal insulation and under the heat lamps occasionally struggled as rewarming occurred, and some attempted to stand as their Tr approached euthermia. In contrast, the calves rewarmed in warm water, with and without ethanol, quickly settled when the cool water was replaced with warm water and they remained calm and relaxed throughout rewarming process.

<table>
<thead>
<tr>
<th>Item</th>
<th>Added insulation</th>
<th>Heat lamp</th>
<th>Warm water</th>
<th>Warm water plus ethanol</th>
<th>± SEMb</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of calves</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Birth weight kg</td>
<td>40.2</td>
<td>42.8</td>
<td>41.2</td>
<td>43.3</td>
<td>3.7</td>
</tr>
<tr>
<td>Minimum rectal temperature °C</td>
<td>28.8c</td>
<td>28.1c</td>
<td>29.4d</td>
<td>29.2d</td>
<td>.29</td>
</tr>
<tr>
<td>Duration of transition min</td>
<td>44.4c</td>
<td>49.6c</td>
<td>18.0d</td>
<td>22.8d</td>
<td>6.67</td>
</tr>
<tr>
<td>Heat production during transition kJ/kg</td>
<td>14.0c</td>
<td>14.1c</td>
<td>5.0d</td>
<td>5.8d</td>
<td>1.46</td>
</tr>
</tbody>
</table>

aTime from end of cooling in 18°C water until calves regained a rectal temperature of 30°C, see text.
bSEM are approximate because of unequal number of observations within treatment.
c,d Means within rows with different subscript letters differ (P < .05).
Figure 1 illustrates the changes in Tr and metabolic heat production of the calves during rewarming. The Tr of the calves in the warm water and warm water plus ethanol treatments increased to 37°C faster than did the calves in the added insulation and the heat lamps treatments (Table 2). After the transition phase, the metabolic heat production of all the calves increased, then declined, and the maximum metabolic heat production during rewarming tended to be inversely related to the level of supplementary heat that was provided (Figure 1). However, the Tr at which this maximum metabolism occurred was not treatment-dependent (Table 2). The total amount of heat produced during rewarming (metabolic effort) was calculated by multiplying the average metabolic rate during rewarming by the time required for recovery. The calves immersed in warm water required 50% less metabolic effort than the calves

Figure 1. Metabolic heat production and rectal temperature of hypothermic neonatal calves rewarmed with assistance provided as added thermal insulation or supplementary heat from infrared heat lamps or immersion in 38°C water with or without an oral drench of 8 ml of ethanol. The standard error for metabolic heat production and rectal temperature values ranged from .26 to .37 W/kg and .13 to .58°C, respectively.
TABLE 2. RECOVERY OF HYPOTHERMIC (RECTAL TEMPERATURE [Tr] OF 30°C) NEONATAL CALVES WHEN REWARmed WITH ADDED THERMAL INSULATION, SUPPLEMENTAL HEAT FROM INFRARED LAMPS, WARM (38°C) WATER OR WARM WATER PLUS AN 8-ML ORAL DRENCH OF ETHANOL

<table>
<thead>
<tr>
<th>Item</th>
<th>Added insulation</th>
<th>Heat lamp</th>
<th>Warm water</th>
<th>Warm water plus ethanol</th>
<th>± SEM^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to regain Tr of 37°C, min</td>
<td>90^b</td>
<td>92^b</td>
<td>59^c</td>
<td>63^c</td>
<td>6.4</td>
</tr>
<tr>
<td>Maximum metabolic rate during rewarming, W/kg</td>
<td>7.5^b</td>
<td>6.8bc</td>
<td>6.0^c</td>
<td>5.6^c</td>
<td>.50</td>
</tr>
<tr>
<td>Tr at maximum metabolic rate, °C</td>
<td>33.0</td>
<td>32.8</td>
<td>33.0</td>
<td>33.3</td>
<td>.53</td>
</tr>
<tr>
<td>Metabolic effort during rewarming, kJ/kg</td>
<td>34.1^b</td>
<td>31.1^b</td>
<td>18.3^c</td>
<td>16.9^c</td>
<td>1.07</td>
</tr>
</tbody>
</table>

^aSEM are approximate because of unequal number of observations within treatment.
^b,cMeans within rows with different subscript letters differ (P < .05).

in the added insulation and the heat lamp treatments (Table 2). All calves used in the tests were successfully rewarmed. No ill health was apparent during the tests or after the calves were returned to the herd.

**Discussion**

The physiological state and potential for recovery of hypothermic animals depends on the duration as well as the severity of hypothermia (Burton and Edholm, 1955). Chronic hypothermia has been associated with physical exhaustion, dystocia (Vermorel et al., 1983; Eales and Small, 1985), depletion of metabolic substrates (Eales et al. 1982) and a shift in body fluids (Burton and Edholm, 1955). In our study hypothermia was acutely induced and was of relatively short duration; therefore, some of the complications evident in chronic cases of hypothermia, as sometime observed in the field, may not be comparable with our results.

*Resting and Summit Metabolism.* The metabolic values for the neonatal calves in the present study were similar to previously reported values for dairy calves (Okamoto et al., 1986; Carstens et al., 1987). However, higher values of resting metabolism were reported by Thompson and Clough (1970) and Vermorel et al. (1983, 1987). Those higher values possibly were a consequence of the methods and environments used to confine the calves during the metabolic measurements. Muscular activity, recent ingestion of food and even a mildly cold environment can increase metabolic heat production (Young et al. 1988).

*Temperature-Limited Metabolism.* During the induction of hypothermia, the maximum rate of metabolic heat production (summit metabolism) was 8.2 W/kg and occurred at a Tr of 36.2°C. In contrast, the maximum rate of metabolic heat production during the rewarming phase was 5.6 to 7.5 W/kg and occurred at a Tr of about 33°C (Table 2). Furthermore, during body cooling, the metabolic heat production of the calves declined at the rate of .65 W/kg per C° decline in Tr. Similar rectilinear decreases in the maximum metabolic rate with the development of hypothermia has been reported in newborn lambs (Alexander, 1962; Robinson and Young, 1988) and adult sheep (Bennett, 1972). From these rates of decline in metabolic heat production, the temperature of zero metabolism can be estimated. For the newborn calves in the present trial, zero metabolism would occur when Tr reached 23°C; similar estimates for newborn lambs are 19 to 26°C (Alexander, 1962) and 21°C (Robinson and Young, 1988).

As indicated above, the apparent constraining effect of temperature on metabolism was different between the cooling and rewarming phases. Figure 1 illustrates that during rewarming, the apparent constraining effect of temperature on maximum metabolic heat production decreased as Tr increased to about 33°C. Following this, the metabolic heat production of the calves declined as Tr continued to increase. It is not clear why the maximum rate of metabolic heat production occurred at a lower Tr
during rewarming than during the cooling phase. Olson et al. (1983) reported regional differences in tissue temperatures in hypothermic calves and during rewarming. Such differences in temperature may influence metabolic capacities of tissues and thus the maximal whole-body metabolic heat production.

The limiting effect of temperature on maximum metabolic heat production becomes an important factor in the recovery of hypothermic animals and clearly illustrated the need for supplemental heat during rewarming and recovery of animals from deep hypothermia. As body temperature approaches the temperature of zero metabolism (estimated in lambs and calves to be about 20°C), recovery becomes more difficult. With a Tr of about 30°C the maximum metabolic heat production was about half the summit metabolism of an euthermic animal but, as shown in our study and by Robinson and Young (1988), calves and lambs can recover from this level of hypothermia.

Recovery of Hypothermic Animals. The body heat content of the hypothermic animal must be increased. Primary factors in quickly regaining body heat are the rate of metabolic heat production and net rate of heat exchange between the animal and its surroundings. The potential for metabolic heat production can be seriously constrained during hypothermia and, if the animal is in an appropriate environment, heat can be lost from the body faster than it can be produced. However, environments can be established that result in a net influx of heat into the animal to effectively supplement heat produced metabolically.

The rate of rewarming was much more rapid in the calves immersed in 38°C water compared with those with added insulation or exposed to the infrared heat lamps. Furthermore, the metabolic effort was less for the calves in the warm water than in the air environments. The calves with added insulation and under the heat lamps struggled considerably; this activity may have increased the rate of return of cool blood from the periphery and contributed to the greater drop in Tr and longer transition phase. Hayward et al. (1973) reported that the rate of heat loss from humans immersed in cold water increases with movement of legs and arms. Struggling during rewarming may have increased the rate of heat loss and slowed the process of rewarming of the calves in the added insulation and heat lamp treatments.

The relative contribution of metabolic heat production to the increase in body heat content of calves during rewarming was estimated assuming a specific heat of tissue of 3.47 kJ/(kg • °C) (Minard, 1970) and Tr the same as mean body temperature. Rewarming from 30 to 37°C in the added insulation, heat lamp, the warm water and warm water plus ethanol treatments required heat production through metabolism of 198, 186, 94 and 95% of the heat needed simply to increase body heat content. These estimates, similar to results previously reported for neonatal lambs (Robinson et al., 1986; Robinson and Young, 1988), indicate a net influx of heat from immersion in 38°C water. The calves in the present study gained about 5% of the needed body heat from the warm water, whereas those in air environments with or without supplementary heat lost substantial amounts of heat to the environment during rewarming and thus required a greater metabolic effort to recover euthermia.

Oral drenching with alcohol has been recommended for recovery of hypothermic humans (Alexander, 1946), and alcohol is sometimes given to hypothermic animals to assist in their recovery. In the present study there was no apparent benefit of giving approximately 8 ml of ethanol to hypothermic calves.

The maximum metabolic capacity of hypothermic neonatal calves depended on their body temperature. Acutely cold-stressed calves with Tr of 30°C have their maximum metabolic heat production reduced by about 50%, but they recovered with minimal metabolic effort when immersed in 38°C water. Compared with immersion in 38°C water, the rewarming of calves in an air environment (20°C) with the addition of thermal insulation or with supplementary heat from infrared heat lamps can be achieved, but recovery was slower and required greater metabolic effort by the calves.

Literature Cited
Bennett, J. W. 1972. The maximum metabolic response of sheep to cold: effects of rectal temperature, shearing, feed consumption, body posture...
Carstens, G. E., D. E. Johnson, M. D. Holland and K.
nutrition and birth weight on basal metabolism in
hypoxia on heat production capacity in newborn
Eales, F. A., J. Small and J. S. Gilmour. 1982. Resuscita-
Gonzalez-Jimenez, E. and K. L. Blaxter. The metabo-
467
lism and thermal regulation of calves in the first
720
Thermographic evaluation of relative heat loss
areas of man during cold water immersion. Aero-
sp. Med. 44:708.
Dairy calf mortality rate: Influence of metro-
logic factors on calf mortality rate in Tulare
McLean, J. A. 1972. On the calculation of heat pro-
duction from open-circuit calorimetric measure-
Minard, D. 1970. Body heat content. In: J. D. Hardy,
A. P. Gagge and J.A.J. Stolwijk (Ed.). Physi-
ological and Behavioral Temperature Regulation.
pp 345–357. Charles C. Thomas, Springfield, IL.
Okamoto, M., J. B. Robinson, R. J. Christopherson
and B. A. Young. 1986. Summit metabolism of
newborn calves with and without colostrum. Can.
The effects of cold stress on neonatal calves. I. C1
Clinical condition and pathological lesions. Can.
J. Comp. Med. 44:11.
Olson, D. P., P. J. South and K. Hendrix. 1983. Re-
gional differences in body temperature in hypo-
thermic and rewarmed young calves. Am. J. Vet.
Med. 44:564.
Robinson, J. B., M. Okamoto, B. A. Young and R. J.
 Christopherson. 1986. Metabolic rate and rewar-
ming speed of hypothermic neonatal lambs given
thermal assistance or added insulation. Anim.
Prod. 43:115.
Robinson, J. B. and B. A. Young. 1988. Recovery of
neonatal lambs from hypothermia with thermal
Book Co., New York.
Thompson, G. E. and D. P. Clough. 1970. Temperature
regulation in the newborn calf (Bos taurus). Biol.
Neonate 15:19.
Vermorel, M., C. Dardillat, J. Vernet, Saido and C. De-
migne. 1983. Energy metabolism and thermoregu-
382.
Vermorel, M., J. Vernet, C. Dardillat, Saido, C. Demig-
me and M. J. Davicco. 1987. Influence of difficult
parturition on energy metabolism of newborn
calves. In: P. W. Moe, H. F. Tyrrell and P. J. Re-
nolds (Ed.) Energy Metabolism of Farm Animals.
pp 34–37. Rowman and Littlefield, Totowa, NJ.
Withers, F. W. 1952. Mortality rates and disease inci-
dence in calves in relation to feeding, manage-
ment and other environmental factors, Part II.
Calibration methods in respiratory calorimetry. J.
Appl. Physiol Respirat. Environ. Exercise Physiol.
56:1120.
Procedure for measurement of resting and summit
68:173.