Cold stress is a life and death challenge for many newborns, especially premature infants and babies who are small for their gestational age. The dissipation of body heat and the physiology of heat production must be well understood if the pathophysiology of cold stress is to be recognized and treated.

Physical methods of heat loss

Heat loss can occur in four different ways: (1) radiation, (2) convection, (3) conduction, and (4) evaporation.

Radiation is the transfer of heat energy from one surface to another in the form of electromagnetic waves. Heat loss by radiation occurs when the relatively large surface area of the infant is exposed to surrounding objects with a lower than body temperature. The greater the temperature gradient between the surface of the infant and the surrounding environment, the greater is the degree of heat loss (radiant heat loss). Peripheral vasoconstriction facilitates heat loss.

Approximately 45-60% of heat loss from the body occurs by radiation. Since air currents or direct body contact with a cold object is not necessary for the heat transfer in this form, radiant heat loss can also take place in a vacuum. For instance, an infant two feet away from a dark wall will lose more heat to the wall than the infant two feet from a white wall.

Convection is the transfer of heat from the body to the surrounding air. Convection is a process by which the air temperature can deliver or take heat away from the body. For example, if the infant’s temperature is 36° C and the ambient temperature of the operating room is 34° C, the infant will be losing heat to the air in the room even though he is lying on a warm water mattress. Approximately 35% of the infant’s heat loss is through convection.

Conduction is the transfer of heat directly from molecule to molecule. Heat loss via conduction only occurs when there is direct physical contact of the skin to a solid surface. Again, the temperature of the object in relation to the infant’s own body temperature will determine if heat will be lost or gained by conduction. An infant placed on a warm (higher than body temperature) water mattress will not lose heat by conduction to the mattress.

Evaporation is a change of state from a liquid to a gas or vapor. Molecules in liquid are drawn to the center of this liquid. Some of the more energetic molecules overcome this force, escape from the liquid and change to a vaporous state. When this happens, the energy remaining in the
liquid will fall, as is reflected by a reduction in the temperature of this liquid. Evaporative losses are dependent upon the surface area, the velocity of air movements over this surface, and the relative humidity of the surrounding environment. For example, evaporative loss in the lungs depends upon the difference in absolute humidity of the inspired and expired air and upon the amount of air breathed. In infants, evaporative loss from the skin is minimal due to immature sweating mechanisms.

**Physiology of heat production in the newborn**

*Adult and newborn differences.* There are several differences in methods of heat production between newborns and adults. All humans must increase heat production on exposure to cold in order to maintain body temperature. Adults shiver when exposed to cold. Shivering is the rhythmic contraction of muscle fibers which produces a rise in body heat. Newborns have an inadequate shivering mechanism, however. In the absence of this muscular activity, infants must rely upon a chemical method of producing heat called non-shivering thermogenesis.

Other newborn differences include: (1) a lack of subcutaneous fat; (2) a larger surface area to body weight ratio; and, (3) the maximal tissue insulation resulting from vasoconstriction is considerably less than adults (due to their small size).

*Mechanisms of heat production.* Heat production in the newborn occurs in strategic areas of the body. These areas contain brown fat. Brown fat has a rich nerve and blood supply along with a high content of mitochondria accounting for its dark color, and thus, its name.

Brown fat has two main functions: (1) storage and supply of fatty acids; and, (2) extra heat production during cold exposure.

Brown fat has been found in five sites: (1) between the scapulae; (2) around the blood vessels of the neck; (3) in the axilla; (4) in the mediastinum, between the esophagus and trachea, also around the mammary vessels; and (5) around the kidney and adrenals.

Heat is produced in the following way. Upon exposure to cold, the sympathetic response releases norepinephrine. Norepinephrine activates tissue lipase which stimulates the increase of triglyceride hydrolysis to fatty acids and glycerol; the fatty acids are oxidized, re-esterified to triglycerides or released in the circulation. The production of heat occurs during oxidation.

An increased production of heat in the newborn involves an elevated metabolic rate with resultant rise in oxygen consumption. The resting metabolic rate is 4.5-8.2 mg/O_2/kg/min in a healthy newborn.

The premature baby has the ability to release norepinephrine under nonstress situations, but is unable to increase its output quantitatively in the presence of cold. The findings of Stern (1978) suggest that the major mechanism in the newborn's defense against cold stress is its ability to release norepinephrine and that the maturity of the infant parallels thermal stability. Thus, the larger the infant, the greater is the thermal stability.

**Neutral thermal environment**

It is apparent from the preceding discussion that the newborn must be maintained in an environment which is neither too cold nor too hot, a so-called neutral thermal environment. This state allows control of body temperature by vasomotor adjustments, with minimal changes in metabolic rate and oxygen consumption.

What is a safe zone? Thermal neutrality can be measured by three different approaches:

1. **Body temperature.** A rectal temperature between 36.5 and 37.5° C appears to be associated with minimal thermal stress (infants 1500-2500 gm).

2. **Temperature gradients.** These may be measured between the infant's skin temperature and the environment. A rectal/environment gradient (difference) of 1.5° C for a 1 kg infant who is vasodilated, premature and one day old appears to be associated with minimal stress. For a three-week-old who is vasoconstricted, a rectal/environment temperature gradient of 4.8° C is still considered in the neutral thermal zone.

Adams and colleagues (1965) suggest that once the skin/environmental gradient exceeds 1.5° C, oxygen consumption will begin to rise at a rate of 0.6 ml/kg/min. These figures indicate that the environmental temperature is just as important in the maintenance of a neutral thermal state as is the temperature of the body. In other words, although the infant may arrive in the operating room with a temperature of 36° C, dangerous increases in thermal stress may occur if the environmental temperature has not been properly adjusted.

3. **Environmental temperature.** Determination of the neutral thermal state by measuring environmental temperature is very complex. There are many contributing factors, such as a single or
double wall incubator, relative humidity in the room, the presence or absence of clothing, and whether the infant is vasoconstricted or vasodilated.

Studies done by Hey (1965) show a minimal oxygen consumption when the environmental temperature is between 35° and 38° C. When the temperature falls below 35° C, oxygen consumption rises. A vigorous healthy infant unclothed and in an ambient room temperature of 25° C cannot accommodate this cold stress for even a short time.7

Hey and Katz (1970) have shown that in spite of a significant drop in the environmental temperature below the neutral thermal range, often only a moderate fall is observed in the rectal temperature. They found this to be primarily due to the compensatory mechanisms of heat production and increased oxygen consumption. A 2° C fall in the environmental temperature can produce an increase in heat production of more than 25%.8

In order to achieve a neutral thermal state, the infant must be above the critical temperature for cold inducing metabolic stress, but below a temperature associated with evaporative heat loss and increased metabolic rate. The older the infant, the greater is the resting rate of heat production relative to surface area. A 1 kg infant will need a neutral environment warmer than that of a 2 kg baby and a one-day-old will need a warmer environment than a 15-day-old baby.

Pathophysiology of cold stress

The infant challenged by cold stress undergoes a number of physiologic changes which may be life threatening. The changes3 consist of the following:

1. Peripheral vasoconstriction resulting in maximal tissue insulation; 2. an obligatory rise in metabolic rate; 3. sympathetic response in which norepinephrine release will increase the metabolic rate leading to increased oxygen consumption; 4. metabolic acidosis, which is the result of two functions, (a) increased metabolic rate, and (b) persistent vasoconstriction, causing a reduction in tissue perfusion and oxygenation; and, 5. pulmonary vasoconstriction which decreases pulmonary perfusion.

Clinical implications/surgery

A neutral thermal environment for newborns is optimal. Heat loss can be minimized by the following:

1. Convection—radiant heat lamps; warm operating rooms; wrapped extremities.

Pathophysiology of cold stress

The infant challenged by cold stress undergoes a number of physiologic changes which may be life threatening. The changes3 consist of the following:

1. Peripheral vasoconstriction resulting in maximal tissue insulation; 2. an obligatory rise in metabolic rate; 3. sympathetic response in which norepinephrine release will increase the metabolic rate leading to increased oxygen consumption; 4. metabolic acidosis, which is the result of two functions, (a) increased metabolic rate, and (b) persistent vasoconstriction, causing a reduction in tissue perfusion and oxygenation; and, 5. pulmonary vasoconstriction which decreases pulmonary perfusion.

Clinical implications/surgery

A neutral thermal environment for newborns is optimal. Heat loss can be minimized by the following:

1. Convection—radiant heat lamps; warm operating rooms; wrapped extremities.

2. Radiation—light-colored nursery and operating room walls; double-wall incubator design.

3. Conduction—warm water blanket; warm blankets, scales, irrigation solutions and preparatory solutions.

4. Evaporation—heated humidifier; covering of exposed bowel with warm laps.

The procedure described below should be followed routinely on all newborns, premature infants, and infants who are small for their gestational age. The pathophysiology of cold stress previously described is a common occurrence. However, if the basic equipment is not available, the procedure should not be attempted.

The temperature of the operating room is warmed in advance of the infant's arrival. Two radiant heat lamps are placed on both sides of the operating table and turned on at least 15 minutes before the infant's arrival. The thermal mattress is turned on and is circulating warm water. Irrigation and prep solutions are warmed.

The infant is not brought to the room until the anesthetist, operating room nurses, and surgeons are available in the operating suite. The infant is never allowed to lie unattended and exposed in a cold corridor. Doors to the operating room are kept closed to minimize heat loss from the room. The infant is brought from the unit in the incubator and transfer is made in the room where the surgery is to take place. No transfer should be made in the hallway of the operating room.

During the procedure, the room temperature remains warm, the heat lights are on, and the temperature of the baby is maintained at 36° C. All infused blood and fluids are warmed. The entire staff must understand the meaning of thermal stability and the consequences if appropriate measures are not carried through.

Despite these attempts, the baby may not be able to maintain a satisfactory thermal state. Since apnea and lethargy (associated with hypothermia), combined with hypoxia and acidosis, could prove to be disastrous, the infant is not extubated at the termination of surgery, until he is awake and his rectal temperature reaches at least 36° C. At times this rewarming period may take 10 to 15 minutes or longer, and the infant is returned to the unit with the endotracheal tube in place.

Conclusion

The importance of temperature monitoring must be stressed, both in and out of the operating room. Recognizing methods of heat loss and knowing ways to prevent it can improve the morbidity
and mortality of these infants. They are different from adults and this fact must be appreciated. Emphasis must be placed on minimizing total heat loss, using the various methods described in this article to achieve this.

REFERENCES

AUTHORS
Mary Ellen Farney, CRNA, BA, is a 1967 graduate of St. Bernard's Hospital School of Nursing in Chicago, Illinois, and a 1973 graduate of Rush-Presbyterian St. Lukes Hospital School of Anesthesia in Chicago. Miss Farney received a Bachelors Degree in management from Mundelein College in 1979, and is currently Chief Nurse Anesthetist at Children's Memorial Hospital in Chicago, Illinois.
Frank L. Seleny, MD, is Chairman of the Department of Anesthesia and an active attending staff anesthesiologist at Children's Memorial Hospital in Chicago. He is Associate Professor of Clinical Anesthesia at Northwestern University Medical School in Chicago, Illinois.