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Water and Heat – The Priority for the Newborn Infant

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ABSTRACT

Maintaining fluid and heat balance is of vital importance to the newborn infant. At birth, the infant is exposed to a cold and dry environment, and preterm neonates in particular, are then at risk of dehydration and hypothermia. These conditions may have serious consequences and significantly influence mortality and morbidity. Preterm neonates have a high rate of water and heat loss mainly as a consequence of their immature skin. The care environment influences the magnitude of water and heat exchange and needs to be individually tailored on the basis of the infant's clinical status, maturity at birth and postnatal age. This paper reviews data obtained from series of studies on neonatal water and heat exchange using non-invasive measurements of insensible water loss and calculations of different modes of heat exchange. These studies have influenced the way in which newborn infants are being nursed today.

INTRODUCTION

Long before the emergence of the field of perinatal medicine, humans kept their newborns warm by nursing them close to their own skin covered with clothing or blankets, just as animals in a litter huddle together to keep warm. At the time of Nils Rosén von Rosenstein (1706-1773), promotion of breastfeeding was in focus, and this included keeping both the breasts and the infant warm (1, 2). From the time of Rosén, the infant mortality decreased gradually in Sweden (3). More than 100 years later (1880), the first known couveuse or incubator to keep an infant warm was constructed by Tarnier and used by his co-workers Pierre Budin and Alfred Auvard at The Paris Maternity Hospital. This couveuse was heated by letting a stream of air

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pass over a number of containers of warm water and pass through a wet sponge, which might have served as a humidifier, but Pierre Budin never mentioned anything about humidification in his original text (4).

During a long period of great improvements in health care in the 1900s (3), with a gradual decline in infant mortality, also in infants born preterm, new challenges concerning neonatal fluid balance and treatment of neonatal lung disorders appeared. Increased knowledge of newly recognised aspects of lung physiology (5, 6) formed the basis of improvements in assisted ventilation of the newborn infant, resulting in fewer severe complications. During 1971, the introduction of intermittent mandatory ventilation (7), continuous positive airway pressure (8) and high frequency positive pressure ventilation (9) contributed to better respiratory support for both the immature and mature newborn infant.

To investigate differences in water exchange between the infant and the environment, Hey and Katz (10) studied insensible water loss (IWL) both in fullterm infants and infants with a low birth weight, but their technique did not allow studies of the most preterm infants. In another investigation of insensible weight loss, Fanaroff et al (11) showed that this loss was very high in infants with a birth weight less than 1250 gram. There was no explanation, however, for the marked weight loss in the low birth weight infants.

Studies published in 1956 by Bent Friis-Hansen (12) on body water compartments during growth showed that the newborn term infant has a water content of 77%. The relative total body water at birth is even higher in preterm infants than in term infants, being 82% at 32 weeks of gestation, 84% at 28 weeks and 86% at 24 weeks. This fact, together with the observation of the shiny, wet skin of a very preterm infant nursed in an incubator, gave us the idea to study the transepidermal water loss (TEWL) in infants of different degrees of maturity (13-15). A series of studies was undertaken to delineate the relation between TEWL and gestational age at birth, postnatal age and environmental conditions, and to clarify the importance of this water loss for neonatal water and heat balance. To achieve more accurate estimates of water and heat exchange, studies of respiratory water loss were also included in the project.

These studies were made possible by the development of a novel technique. With the gradient method (13-15), transepidermal water loss ($g/m^2/h$) could then be estimated by measuring the evaporation rate (ER $g/m^2/h$) from the chest, an interscapular skin area and a buttock.

TEWL AT BIRTH AND AT DIFFERENT POSTNATAL AGES

There is an exponential relationship between gestational age and TEWL at the first day after birth. Infants born at 25 weeks of gestation have TEWL values up to 15 times higher than those in term infants (16) (Fig. 1). The relationship between TEWL and gestational age at different postnatal ages during the first four weeks

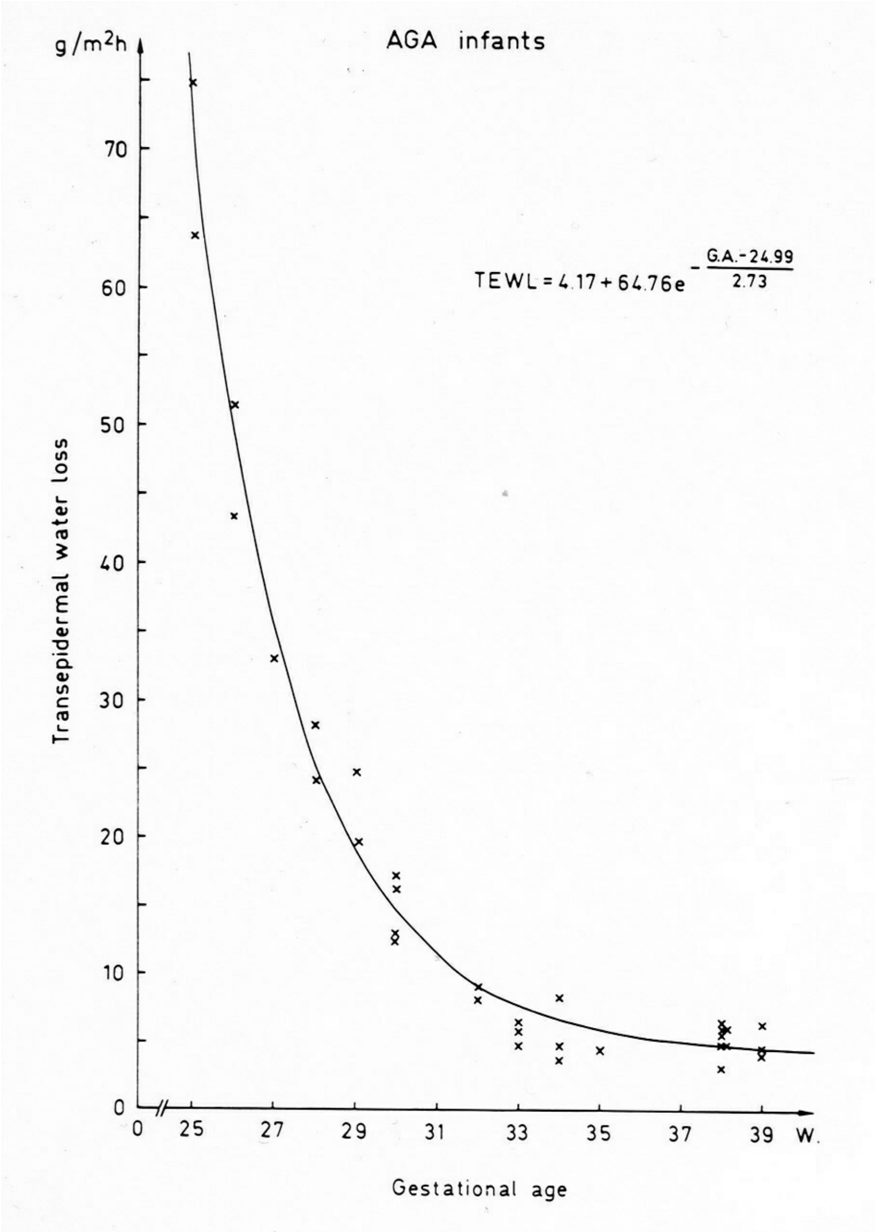

Figure 1. Transepidermal water loss (TEWL) in relation to gestational age (G.A.). AGA = appropriate for gestational age. w = completed weeks of gestation. (From ref 16)

after birth can be described with exponential equations (17, 18) (Fig. 2). In the most preterm infants TEWL gradually decreases and the difference in TEWL between the most preterm and the term appropriate for gestational age (AGA) infant diminishes with age, but four weeks after birth TEWL is still twice as high in the former as in the latter (18) (Fig. 2).

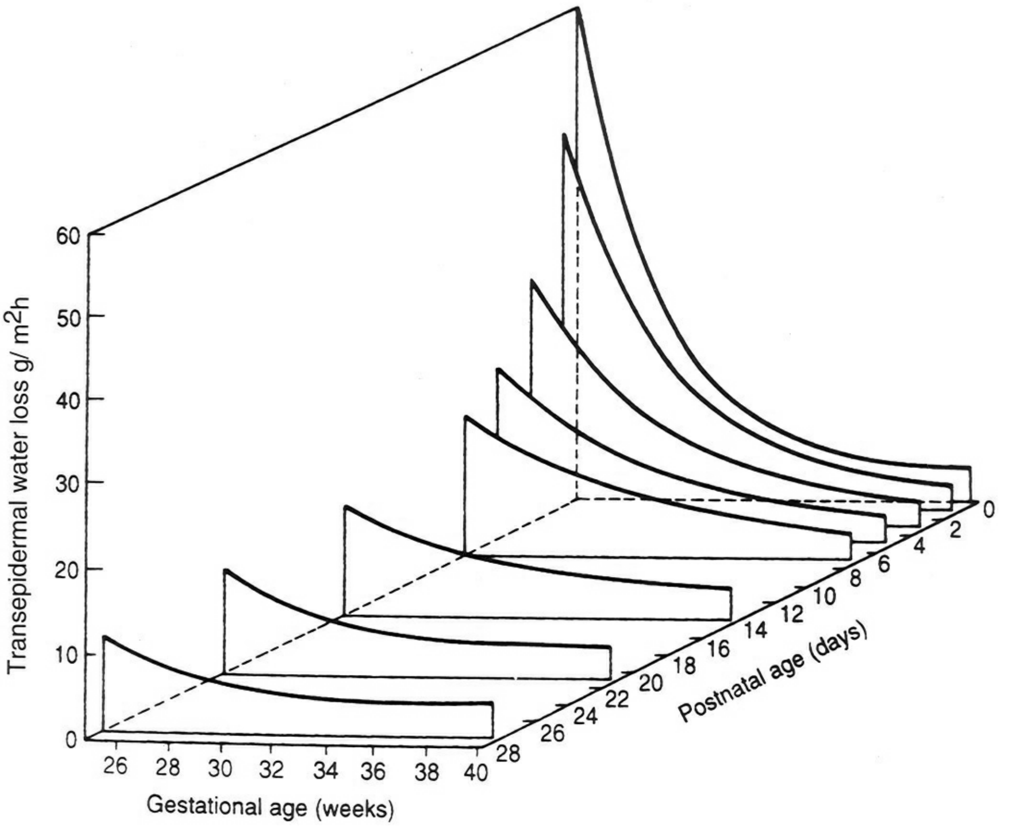

Figure 2. Transepidermal water loss in relation to gestational age at birth at different postnatal ages in appropriate-for-gestational-age infants. (From ref 18)

Among small for gestational age infants, TEWL is again highest in the most preterm infants, but their water loss from the skin is lower than that in AGA infants (19).

Evaporative water loss in relation to humidity

There is an inverse linear relationship between evaporation rate (ER) from the skin surface and ambient humidity in both term and preterm infants at different postnatal ages. The evaporation rate is much higher at a low than at a high relative humidity (15, 16, 19) (Fig. 3).

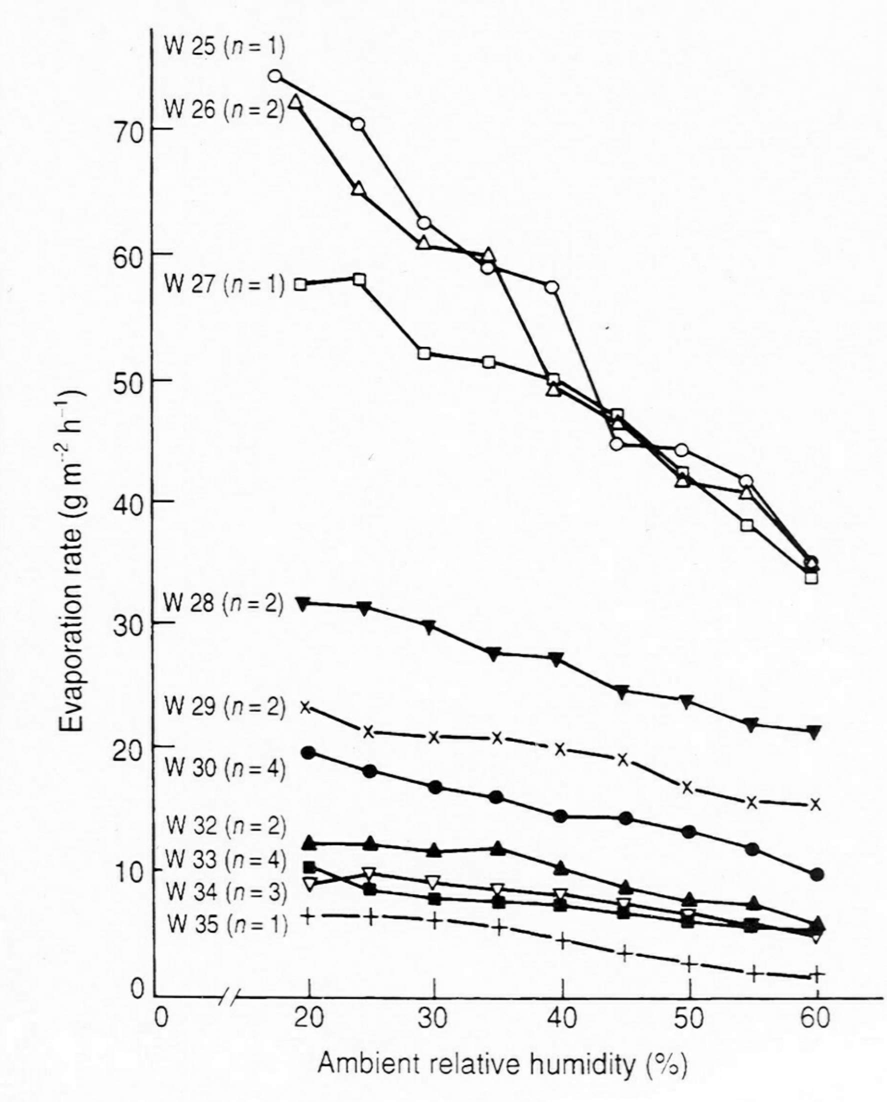

Figure 3. The relation between evaporation rate and ambient relative humidity in preterm newborn infants of different gestational age groups. (From ref 16)

Insensible water loss from the skin (IWL_S)

IWL_s in g/kg/day in infants can be calculated from TEWL, body surface area and weight (Fig. 4). Since TEWL is strongly related to postnatal age and since the ratio of body surface area to body weight is higher in the most preterm infants, it is obvious that IWL_s is considerably higher in preterm than in term infants. Accordingly, the environmental conditions (i.e. ambient humidity) have an even greater impact on the IWL_S in the tiniest infants, particularly during the first week after birth (19).

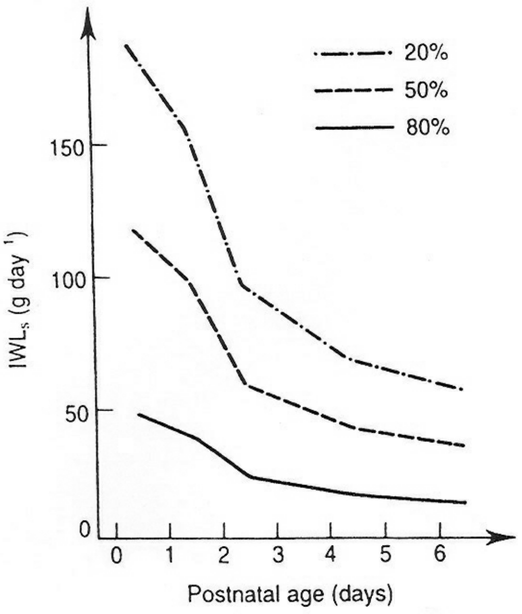

Figure 4. Insensible water loss from the skin (IWLs) in relation to postnatal age in infants born at a gestational age of 25-27 weeks. Data are given for three different ambient humidities. (From ref 28)

TEWL during activity and phototherapy

There is a pronounced increase in TEWL when infants born at term increase their motor activity, but no sweating is observed. If infants are nursed in a warm environment, the body temperature rises and TEWL increases markedly when they begin to sweat (20). In infants in thermal balance there is no indication that phototherapy increases the transepidermal water loss (21), respiratory loss or oxygen consumption (22). Previous observations of higher losses during phototherapy (23) might have been due to heat stress and not to the radiation from the phototherapy equipment (21, 22).

TEWL and radiant heaters

When very preterm infants are nursed first in an incubator at RH_{amb} of 50%, the evaporation rate from the skin is significantly lower than when the same infants are nursed at a lower humidity under a radiant heater. Still, the evaporation rate is lower under the radiant heater than what can be expected from the environmental vapour pressure. As can be seen in Figure 5, the measured water loss is lower than the expected water loss at the vapour pressure in the environment (24). Thus there is no indication that radiant heat increases water loss from the skin under conditions with a low air velocity close to the infant. However, losses of water and heat from the

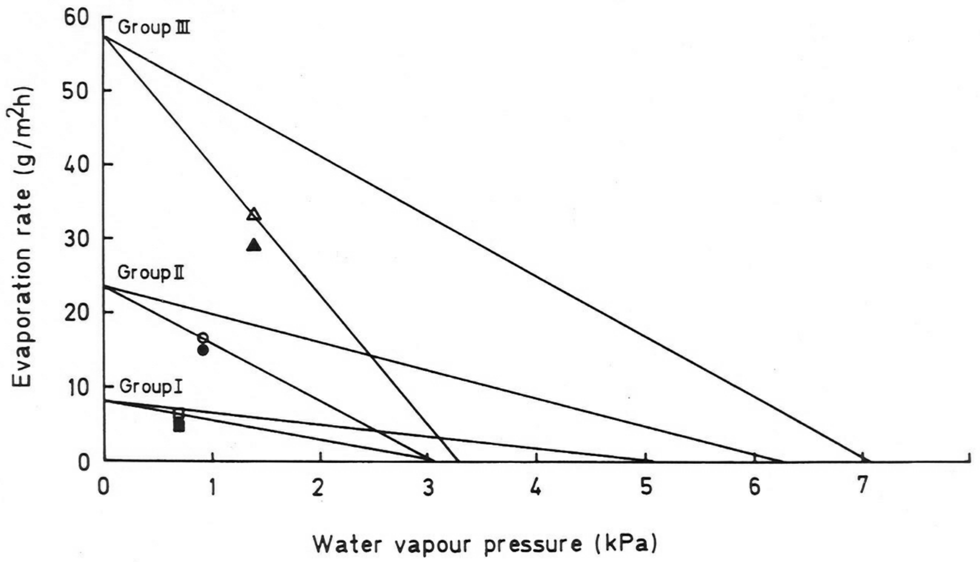

Figure 5. The calculated (*open symbols*) and measured (*filled symbols*) values for ER (g/m^2/h) during care under a radiant heater, together with the corresponding regression lines for ER on PH_2O at the air temperatures of the incubator and the radiant heater, in three infants (From ref 24)

skin surface can be increased if the normal gradient close to the skin surface is disturbed by movements of air in the nursery created by air condition systems and staff movements, for example.

RESPIRATORY WATER LOSS

A flow-through system for measurement of respiratory water loss (RWL), providing data on oxygen consumption and carbon dioxide production, was developed. The system uses a mass spectrometer, specially equipped with a water channel for analyses of gas concentrations (25). The studies showed that RWL in newborn term infants at rest is 4.9 mg/kg/min, i.e. about 50% of the total insensible water loss at an ambient air temperature of 32.5°C and an ambient humidity of 50% (26). RWL depends on the temperature and humidity of the inspired air and on the respiratory rate, tidal volume, dead space ventilation and the ability of the nose to dehumidify and cool expired air (25, 26). It was also found that there was an inverse relationship between RWL and ambient humidity, with higher losses at a low than at a high humidity (26) and that the insensible water loss from the respiratory tract (IWL_R) and the IWL_S were of the same magnitude at an ambient humidity of 20 %, whereas IWL_S was much lower than IWL_R at a high ambient humidity.

RWL increases with increasing activity in term infants. At rest both IWL_S and IWLR were 6 g/kg/day and IWLs increased very little, whereas IWL_R could theoretically increase to 16 g/kg/day if the infant was able to have the highest level of activity for 24 hours. VO2 and VCO2 also increased during activity (27) (Fig. 6).

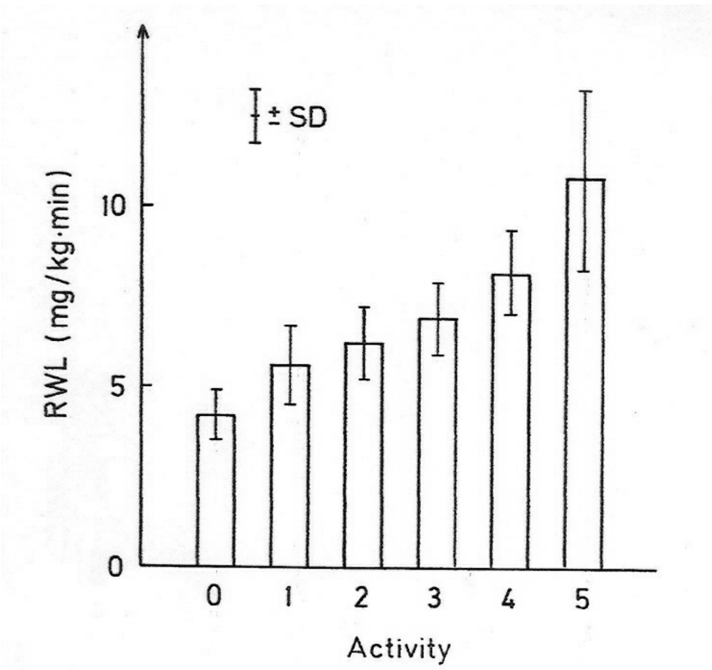

Figure 6. Respiratory water loss (RWL) at different levels of activity. Activity scale: 0 = asleep, no motor activity. 1 = asleep, minor motor activity. 2 = awake, quiet, no motor actitivy. 3 = awake, quiet, active. 4 = awake, crying, active. 5 = awake, furiously crying. (From ref 27)

WATER SUPPLY AND WATER BALANCE

Nutrition and/or water supplementation should be provided soon after birth. In term infants, water balance can be adjusted by increasing or decreasing the daily prescribed supply. In preterm infants, especially in those who are extremely preterm, who have very high insensible water losses, sometimes leading to hyperosmolality, high levels of water loss have to be avoided. The supply of fluid depends on the insensible water loss and can be kept low in a humid environment. The local guidelines for neonatal water balance are then:

Day 1: 65 ml/kg
Day 2: 75 ml/kg
Day 3: 90 ml/kg
Days 4-7: Increase gradually up to 150 ml/kg.
The volume of all fluid given or collected should be noted.

The basic prescription of fluid volumes may be changed if the serum osmolality exceeds 300 mosm/l and when weight loss exceeds 10-15%. Even in very preterm infants nursed at a high ambient humidity, there is usually an increase in serum osmolality during the first 3 days after birth, accompanied by an increase in sodium concentration (28) (Fig. 7) and in such cases the body weight is carefully monitored so that it does not drop more than 15%.

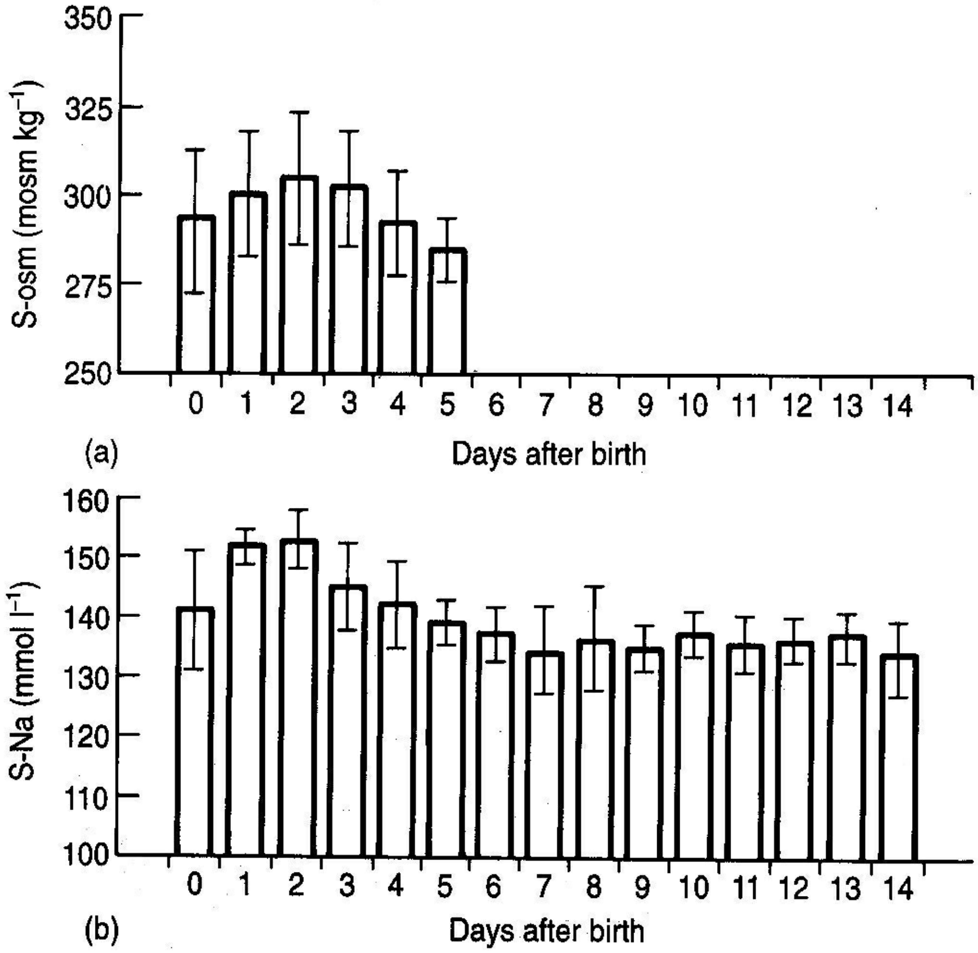

Figure 7. (a) Mean serum osmolality (S-osm ±SD) and (b) mean serum sodium concentration (S-Na ±SD) in 11 infants born at a gestional age of 24 weeks, in relation to postnatal age. (From ref 28)

In preterm infants born at 24 and 25 weeks of gestation, TEWL during the first week after birth was slightly higher than that found previously in the group of infants born at 25-27 weeks (29). Importantly, in infants born at 24-25 weeks and nursed at a high ambient RH, TEWL at a postnatal age of 4 weeks was twice as high as had previously been reported for slightly more mature infants. These findings led to a speculation as to whether maintaining infants at a high humidity for a long time might influence the development of their skin barrier. Recently, we studied a cohort of very preterm infants born at a mean gestational age of 25 (range 23-27) weeks and nursed at a high humidity (85%) during the first week after birth. At a postnatal age of one week the infants were randomized to continued care at either 75% or 50% RH for the following three weeks, but studied at the same humidity. Preliminary results from this study indicate that infants nursed at the lower level of humidity during the second, third, and fourth postnatal week have a lower TEWL than those exposed to the higher humidity. The results imply that the environmental humidity can significantly alter the process of postnatal skin barrier formation (30). These data need further assessment before publication but may lead to changes in the way preterm infants are nursed at our institution.

Mechanisms for transepidermal water transport

The high loss of water from the skin surface reflects one aspect of immature organ function in preterm infants. The epidermis is not fully developed in these infants and its outermost layer, the stratum corneum, is thin and lacks the structure and composition needed to provide its barrier function properties. In addition, recent studies on perinatal rat skin have shown that aquaporins (AQP), a group of integral membrane proteins with high water permeability, are abundantly expressed in the immature skin (31, 32). In this experimental model, higher expression of AQP3 in the basal parts of the epidermis was observed in immature than in more mature rat pups, and TEWL was much higher in the preterm pups. If these results are valid for the human preterm neonate, further studies on epidermal aquaporins might be of importance for human perinatal physiology, and interventions aimed at AQP inhibition might prove of clinical value.

Heat and water balance in extremely preterm infants early after birth

When extremely immature newborn infants are exposed to a cold, dry environment after birth, they are at risk of having a rapid drop in body temperature unless measures are taken to prevent heat loss (33, 34). Furthermore, the extremely preterm infants have only a limited capacity to produce heat. It is therefore of great importance to create a care environment that favours thermal balance in this situation (35).

At birth the exchange of heat depends very much on the maturity of the infant, the environmental temperature and relative humidity and the postnatal age, as displayed in figures 8, 9, and 10. Different methods to maintain heat have been proposed such as the use of semipermeable membranes to lower the water and heat loss in infants nursed under a radiant heater (36-38).

In a short time early after birth a semipermeable membrane, covering the infant,

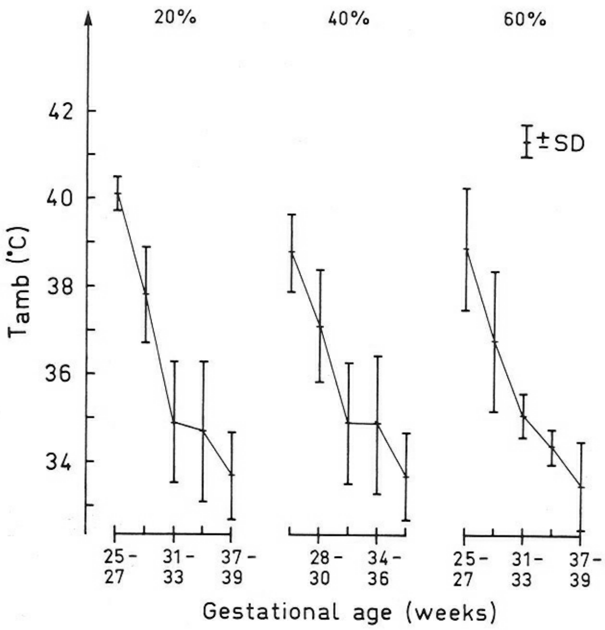

Figure 8. Ambient temperature (Tamb) in relation to gestational age at ambient relative humidity of 20%, 40%, and 60%. (From ref 33, 34)

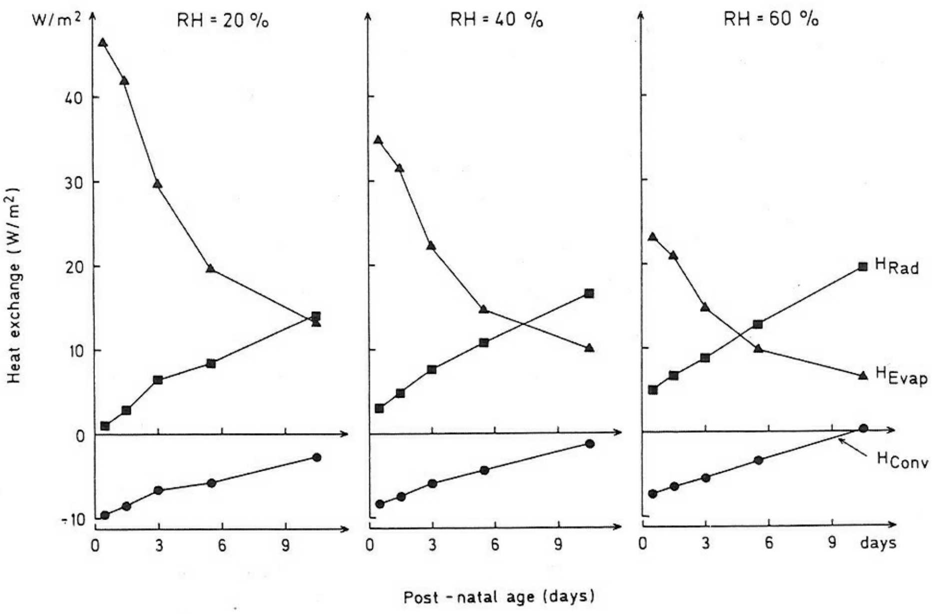

Figure 9. Heat exchange through evaporation, radiation, and convection in relation to gestational age at relative ambient humidities of 20%, 40%, and 60%. (From ref 35)

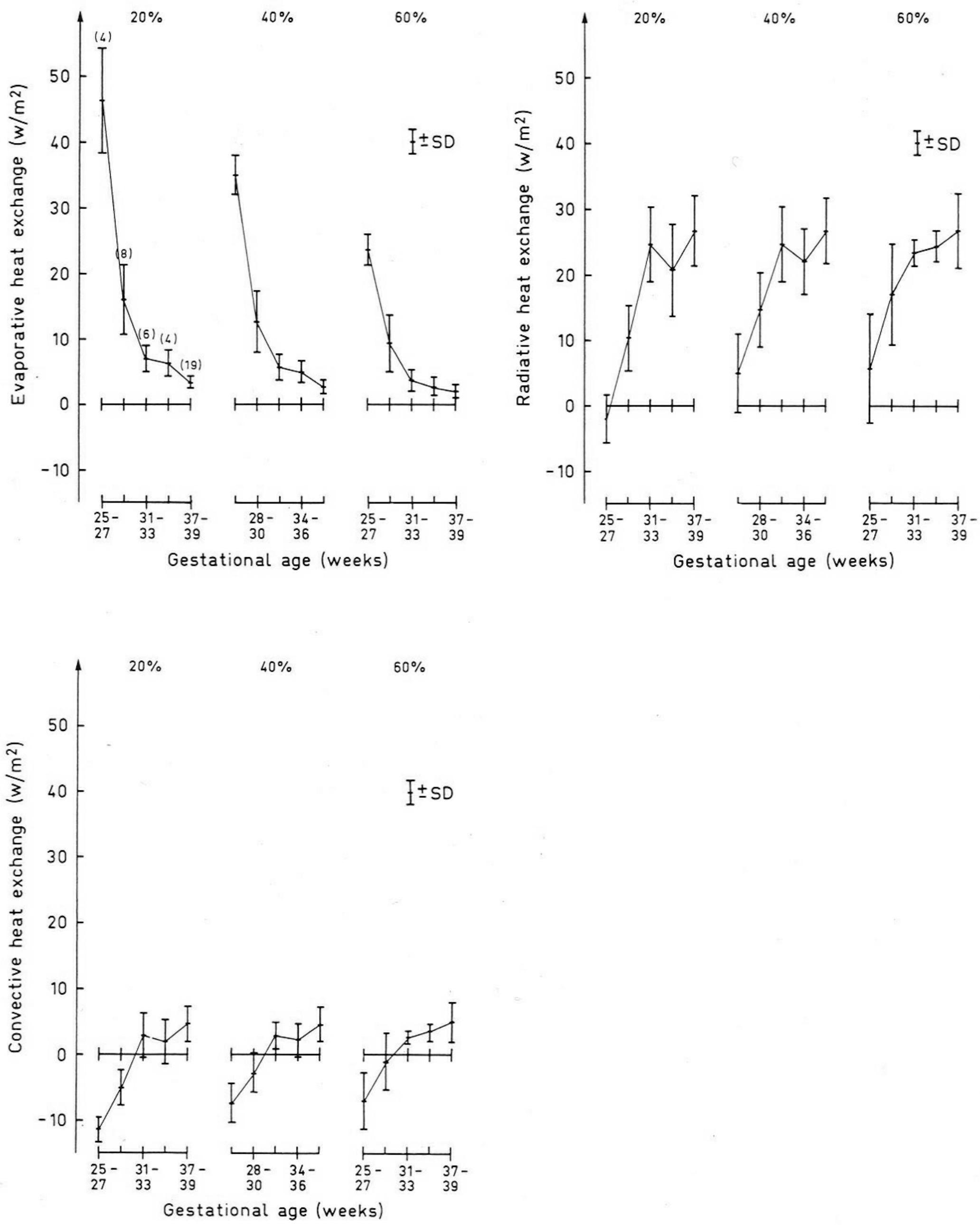

Figure 10. Heat exchange between the infant and the environment in relation to postnatal age at relative ambient humidity (RH) of 20%, 40%, and 60% in infants born at 25 to 27 weeks of gestation. (From ref 34, 35)

can create a humid environment close to the infant's skin and may lower the evaporative water and heat exchange during this period. An evaporative water loss from the skin will take place and contribute to a high humidity in the air between a membrane and the skin, which can lower evaporative heat loss temporarily (16). This type of care has not been evaluated concerning the fractional contribution of different modes of heat exchange. If the membrane is in direct contact with the skin, a component of heat conduction between the membrane and the skin may take place. All areas of the infant's skin that are not covered by a membrane will be exposed to room air temperature, air movements, evaporation and the colder walls of the neonatal intensive care unit. This will substantially alter the conditions for the heat exchange. Losses through convection can be considerably increased by air movements at low temperature in the vicinity of the very preterm infant (16, 34). These circumstances have further been discussed in a recent publication (39).

Very preterm infants who are held skin-to-skin by the mother early after birth and are covered with a blanket, can often maintain a normal body temperature in the first week after life if the gestational age at birth is 28-30 weeks (40). It has also been shown that very preterm infants nursed on a heated water-filled mattress and covered with a blanket can maintain their body heat (41). Use of a cap on the infant's head was proposed many years ago by Stothers (42) and may still be a way to save heat for the very preterm newborn infant.

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