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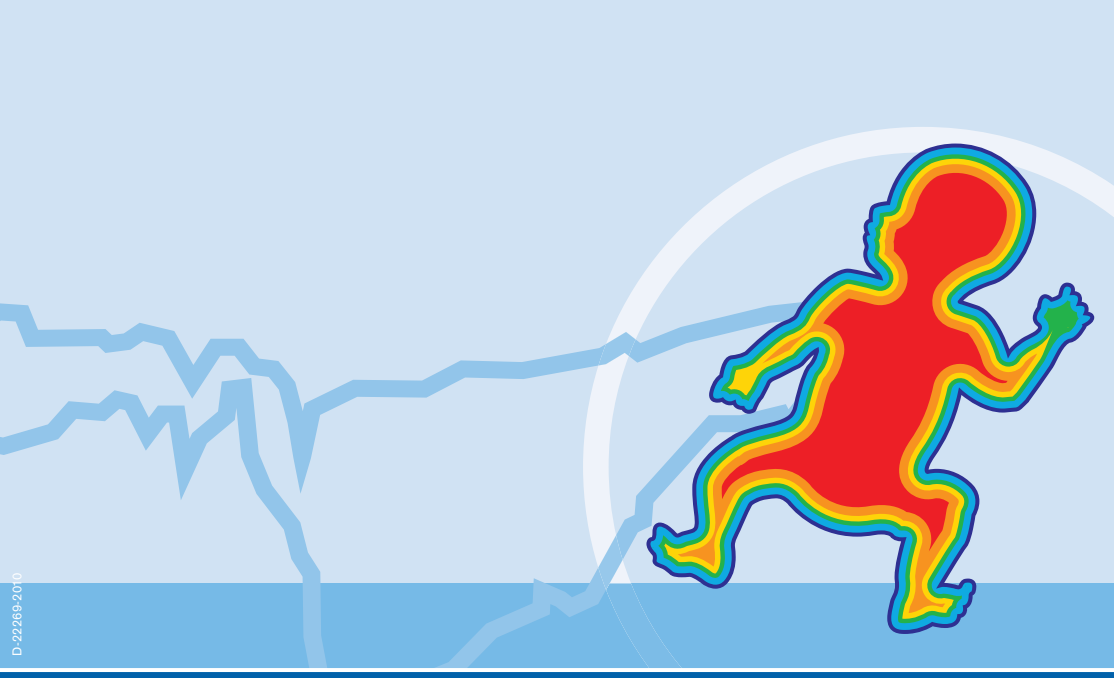

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ThermoMonitoring
A step forward in neonatal intensive care

Andrew Lyon, Peter Püschner

Dräger. Technology for Life®

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CONTENTS

This booklet has been created with the help of neonatal units who have experience in ThermoMonitoring. It aims to give a basic introduction to the problems of temperature control in the newborn and to the benefits of ThermoMonitoring.

Close collaboration with nurses and neonatologists helps us at Dräger to design equipment and devices to meet your clinical needs. We would like to take this opportunity to thank all involved for their suggestions and criticisms during the writing of this booklet. As always, we welcome further comments.

Introduction

Are babies comfortable in their environment?
The importance of maintaining the temperature of the newborn baby has been known for centuries, starting with the work of Soranus of Ephesus (98-131AD), followed by Tarnier and Budin in the 19th century and William Silverman in the 1950s [1,2].

FIGURE 1 is a thermograph of a preterm baby and it shows that there is a wide variation in temperature throughout the body. The so-called core temperature is not constant in all tissues and organs, with the brain probably having the highest temperature.

It is difficult to know which temperature to measure. Also, the measurement of a single temperature tells us how well a baby is able to maintain that temperature but will not give any information on the energy being used for thermoregulation.

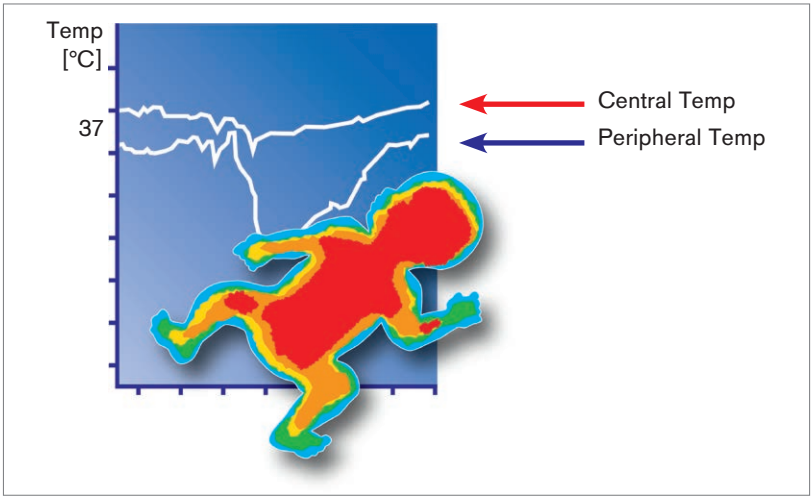

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FIGURE 1. Thermograph of a preterm baby with ThermoMonitoring

How can we tell if we have made the correct choice of environmental temperature?
ThermoMonitoring will give an answer... The body will attempt to maintain its temperature within narrow limits and, if exposed to thermal stresses, will utilize energy to achieve temperature stability. It is not possible in 'day to day' neonatal care to measure heat transfer or energy expenditure in the baby and we have to rely on information from temperature measurements. We can get a better picture of the thermal stresses experienced by a baby if we measure simultaneously more than one body temperature.

If a baby is exposed to cold stress, peripheral parts of the body will cool before more central temperatures drop. By measuring a central and a peripheral temperature, changes in the central-peripheral temperature difference give an early indication of thermal stress, long before any alteration is seen in the central temperature of the body.

Thermal stress has been associated with an increase in morbidity and mortality, making early detection of this problem an important part of monitoring of the sick baby.

ThermoMonitoring involves continuous display of a central and a peripheral temperature, as well as the air temperature and humidity that sourrounded the baby inside the incubator.

This booklet will introduce the concept of ThermoMonitoring based on both clinical practice and scientific studies.

Why prevent cold stress?

Although a baby may be exposed to excessive heat, the more common clinical problem, particularly in the preterm infant, is of cold stress due to heat loss.

Babies lose heat during birth, resuscitation and transportation to the nursery as well as during handling or other procedures. Cold stress has been associated with an increase in both mortality and morbidity [3].

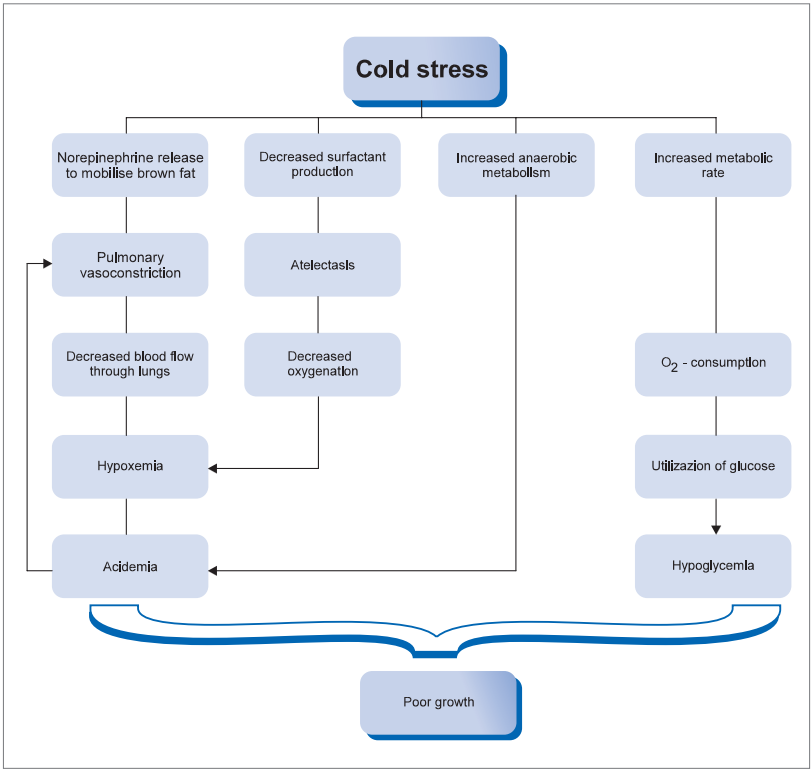

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FIGURE 2. Problems caused by cold stress.

In a series of randomized controlled trials in the 1950s, William Silverman showed that keeping babies warm resulted in a 25% absolute reduction in mortality in all birthweight groups, including those under 1000g[2]. Despite these studies, recent data show that newborn babies still get cold and hypothermia, especially in the preterm infant, which may result in increased mortality [4-6].

Cold stress results in an increase in pulmonary artery resistance which affects oxygenation. The increasing hypoxis results in a metabolic acidosis which is exacerbated by poor tissue perfusion caused by vasoconstriction. Acidosis inhibits surfactant synthesis, further affecting oxygenation and the 'cycle'.

Cold stress results in a raised metabolic rate of the baby. This increases the risk of hypoglycaemia and also reduces the energy available for growth of the baby.

What happens if a baby is too cold?

Cold Stress:

- exacerbates lung problems and increases the need for ventilation
- increases metabolic acidosis
- results in poor growth and increases length of time in hospital
- displaces bilirubin from albumin binding sites, raising the risk of kernicterus
- increases mortality and morbidity

Prevention of cold stress reduces mortality and morbidity in newborn babies.

ThermoMonitoring shows the thermal state of the baby

Cold Stress – early effects

Cold stress occurs when heat loss is such that the baby has to mobilize thermoregulatory mechanisms to increase heat production or prevent heat loss. These mechanisms will allow the baby to maintain central temperatures, but only at a large metabolic cost. If we do not act until we see the central temperature falling we will have exposed the baby to a critical period of metabolic stress which may have detrimental effects.

It is standard practice to measure the temperature of a baby undergoing intensive care. Usually only a single temperature is measured, often at infrequent intervals. This practice will not detect the early changes of cold stress as the baby will initially use energy to maintain its central temperature.

An early response to cold stress is vasoconstriction to reduce heat loss from the peripheries. As adults we know that our hands and feet are first to feel cold as the body reduces blood flow to the peripheries in response to cold exposure. By measuring both a central and a peripheral temperature it is possible, therefore, to obtain more detailed information on the thermal state of the baby.

FIGURE 3 shows the response of a baby to a procedure during which the incubator was opened for a brief period. The upper trace represents the central and the lower trace the peripheral temperature. Soon after the start of the procedure the baby's peripheral temperature drops but the central temperature remains stable.

Measurement of a central and a peripheral temperature, and continuous display of the difference between them, will give an early indication of developing cold stress. An increase in the central-peripheral temperature differential occurs before the fall in core temperature. This is the principle of **ThermoMonitoring**.

Cold stress starts long before we see a fall in core temperature.

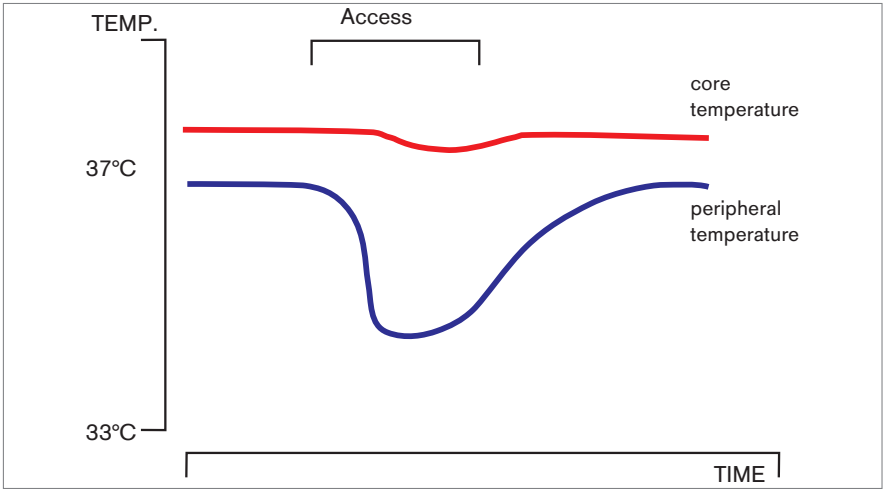

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FIGURE 3. A baby in response to early cold stress.

Without knowledge of the Peripheral Temperature the early changes of cold stress would not have been noticed.

Cold Stress – later effects

The effects of a prolonged handling episode are shown in FIGURE 4.

The central-peripheral temperature difference increases as the baby is exposed to a cold stress and the peripheries cool. Eventually the baby can no longer compensate by mobilising thermoregulatory mechanisms and the central temperature drops.

If only a single temperature had been measured at infrequent intervals, this cold stress would not have been detected until the central temperature decreased – some time after the start of the episode. The baby would have been exposed to a period of increased metabolic stress.

ThermoMonitoring gives us a better idea of when a baby is too cold.

Reacting to changes in the temperature difference could have prevented the drop in central temperature.

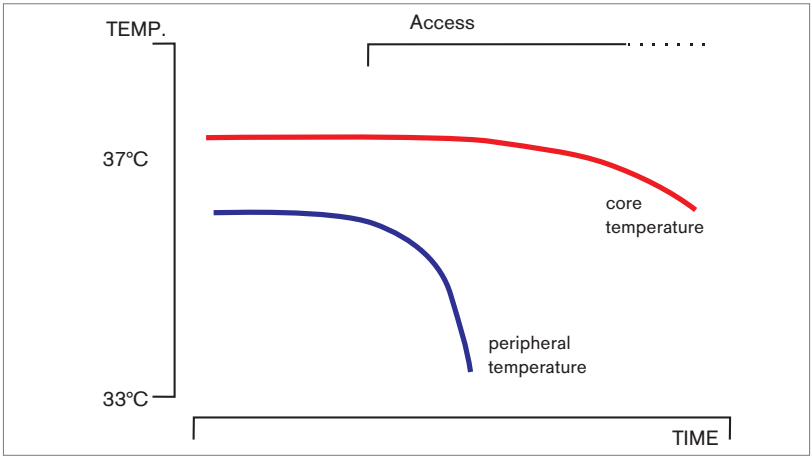

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FIGURE 4. A baby becomes too cold (hypothermia).

Heat Stress

A baby can also suffer heat stress if exposed to high environmental temperatures. FIGURE 5 shows what happens to the central and peripheral temperatures when a baby is too warm.

With overheating both the central and peripheral temperatures rise and the temperature difference decreases. As with cold stress, the peripheral temperature responds before any change is seen in the central temperature.

In heat stress there is often an associated increase in heart rate.

ThermoMonitoring gives us a better idea of when a baby is too warm.

By measuring the peripheral temperature, heat stress could have been detected earlier and the increase in central temperature prevented.

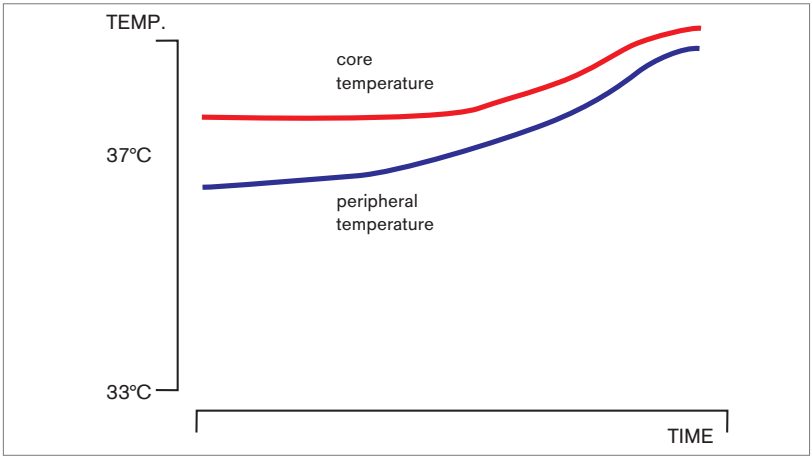

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FIGURE 5. A baby becomes too warm (hyperthermia)

The baby with an infection

A rise in central temperature may be due to fever secondary to infection and the typical pattern in this case is shown in FIGURE 6.

In the pyrexial baby there is often an increasing central-peripheral difference in association with the rising central temperature. This is due to peripheral vasoconstriction secondary to production of circulating cytokines, such as interleukin-1, as a response to the infection.

By measuring the peripheral temperature, a high central temperature due to overheating can be distinguished from that due to fever.

ThermoMonitoring can detect when a baby has a fever.
ThermoMonitoring can help in the diagnosis of infection in the newborn.

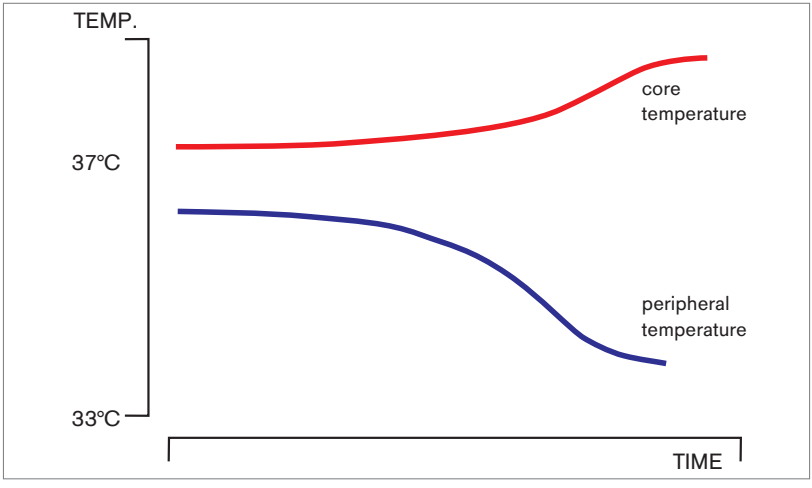

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FIGURE 6. A baby with fever

Thermoregulatory Problems

Many babies show an unstable temperature pattern, similar to that shown in FIGURE 7. This can occur just after birth, before the baby has fully developed its thermoregulatory mechanisms, and when the baby is sick, particularly when septicaemic [7].

Just after birth the baby often cannot mobilise thermoregulatory mechanisms and the body temperature is dependent on that of the environment. If the air temperature around the baby varies, for example during handling, the baby's temperature becomes unstable. This is discussed in more detail in a later section of this booklet.

Many babies with infection do not respond with a pyrexia, as seen in older children and adults, but develop an unstable temperature pattern as shown in FIGURE 8.

ThermoMonitoring can show when a baby has thermo-regulatory problems.

Temperature instability can be an important indicator of infection in the newborn baby.

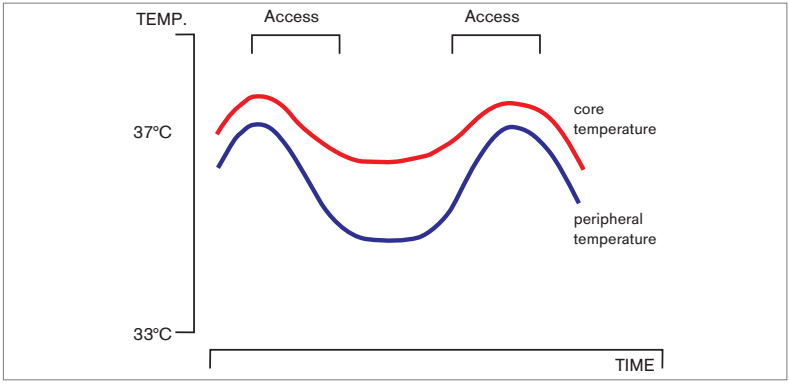

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FIGURE 7. Baby with temperature instability and thermoregulatory problems.

Conclusion

The monitoring of peripheral and central temperatures, and the continuous display of the central-peripheral difference as a trend graph.

- gives more information than can be obtained from the periodic measurement of a single temperature alone
- allows early detection of both cold and heat stress before changes are seen in central temperatures
- distinguishes overheating from fever as a cause of pyrexia
- gives an overall more complete picture of the thermal balance of the baby

Where can temperature be measured?

If there is no single core temperature in the body, what can we measure to give us some idea of the central temperature. What we need to monitor is a temperature which is close to an “average” core temperature and which will show changes in the central temperature. FIGURE 8 shows possible sites for the measurement of such a central temperature.

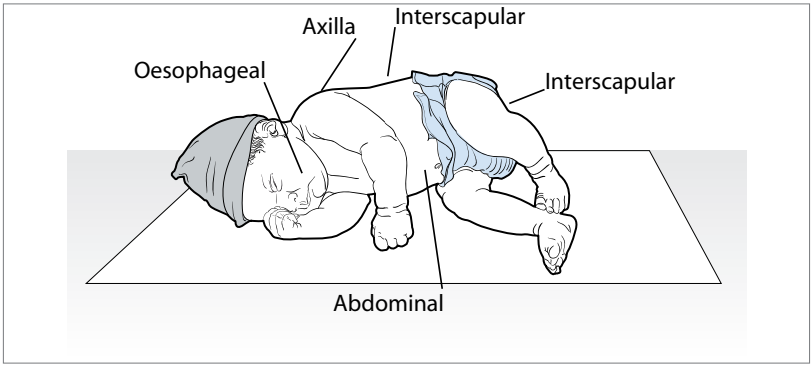

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FIGURE 8. Sites used for temperature measurement.

Rectal temperature:

Traditionally the rectum has been used as a measure of the core temperature. However taking a rectal temperature is an invasive procedure and the measurement is not always reliable.

- The rectal temperature depends on the depth to which the probe is inserted
  - FIGURE 9.

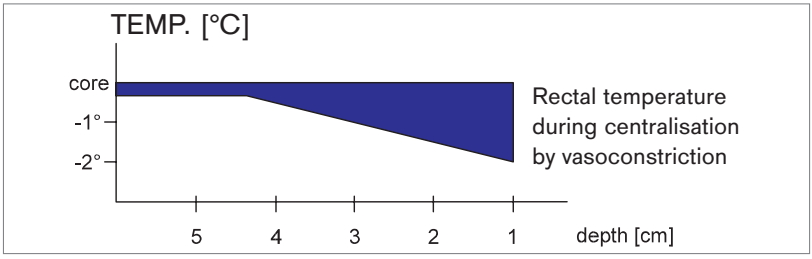

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FIGURE 9. Effect of depth of probe insertion on measured rectal temperature

– Rectal temperature is also affected by the temperature of the blood returning from the lower limbs. If there is peripheral vasoconstriction, and the baby is centralising its circulation, the cold blood returning from the legs will significantly lower the measured rectal temperature.

– From a practical point of view, it is impossible to keep a rectal probe in the same position for any length of time and so this is not a suitable site for continuous temperature monitoring.

Axilla and abdominal skin temperatures

The axilla and the abdomen (over the area of the liver) are alter-native sites commonly used to represent central temperature. In the newborn baby these sites, although on the skin, do not appear to react to lower temperatures with vasoconstriction[8]. This means that, although the temperature measurements in the axilla or on the abdomen are slightly lower than the true central temperature, they will change in the same way as the central temperature. Monitoring the trends in the axilla or abdominal skin measurements will therefore give information on the way the central temperature is changing. The axilla is a good site for a probe as it is not easily affected by changes in environmental temperature and the position of the probe does not interfere with X ray fields.

Zero heat flux temperature

If the baby is lying on a non-conducting mattress, the skin adjacent to the mattress will be unable to lose heat and will therefore warm up to the temperature of the body's core[9]. This is called the Zero Heat Flux Temperature. With the baby on its back on a non conducting mattress, this temperature can be measured by a probe placed in the interscapular region. It is important to use small, flat probes that will not cause pressure damage to the baby's skin.

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Peripheral temperature

In the newborn baby the foot has been shown to respond to lower temperatures with vasoconstriction. Peripheral temperature is usually measured by a probe attached to the foot.

With ThermoMonitoring it is recommended that:

- There is continuous monitoring of a central temperature and a peripheral temperature.
- Abdominal skin, axilla or interscapular probes are used to monitor central temperature.
- The sole of the foot is used to monitor peripheral temperature.
- Both temperatures and the central-peripheral temperature difference are displayed as a continuous trend graph.

What temperature values should we use?

The continuous measurement of both a central and a peripheral temperature is important in thermal monitoring of the newborn baby.

As there is no single central temperature it is difficult to give recommendations for this value. The figure will also depend on the site from which the temperature readings are taken. Most staff caring for babies feel that the central temperature measured from rectum, abdominal skin or axilla should be around 37°C. In a study of 150 babies under 1500g birthweight, the median abdominal skin temperature was found to be 36.9°C with an interquartile range of 36.8 to 37.2°C. Some babies however had an abdominal skin temperature significantly above 37.5°C [10]. In these babies any attempt to lower their temperature resulted in a widening of the central-peripheral temperature difference, suggesting increasing cold stress. It would seem that some babies, in the first few days after birth, set their own central temperature to above 37°C.

The mean central-peripheral temperature difference increases over the first 5 days of life[11]. In babies less than 1000g birthweight the temperature difference increased from 0.5°C on day 1 to 1.0°C by day 3. In heavier babies the temperature difference was between 1.0 and 1.3°C

At what central temperature does the baby feel comfortable ?

What value for the central-peripheral temperature difference should we aim for?

The data suggest that:

- A central-peripheral temperature difference of around 1.0°C is appropriate from day 3 of life.
- The environmental temperature should be altered to maintain this value at 1°C.
- If necessary, the central temperature should be allowed to rise above 37°C to maintain the central-peripheral difference at 1°C.

Temperature difference and hypovolaemia

The central-peripheral temperature difference increases when there is vasoconstriction of the peripheral circulation. Such vasoconstriction may be due to cold stress but also could represent an attempt by the baby to maintain venous return and hence protect its blood pressure in the face of hypovolaemia. In the latter situation there is often an accompanying rise in heart rate as the baby attempts to maintain cardiac output. Blood pressure will not fall until these compensatory mechanisms fail.

In a review of temperature data from 76 babies of birthweight <=1000 g in a single unit over a 2 year period, a central-peripheral temperature gap of 2.0°C or more was associated with other evidence of hypovolaemia for only 11% of the total time[12]. An increasing central-peripheral temperature gap is more likely to be due to cold stress than hypovolaemia, particularly if there is no associated increase in heart rate.

An increasing central-peripheral temperature difference:

- Is usually due to cold stress
- Maybe due to hypovolaemia if there is an associated rise in heart rate or fall in blood pressure

Thermoregulation and the Baby

In the adult there is a wide range of environmental temperatures over which the central temperature remains constant. This “normo-thermal” range is shown in upper part of FIGURE 10.

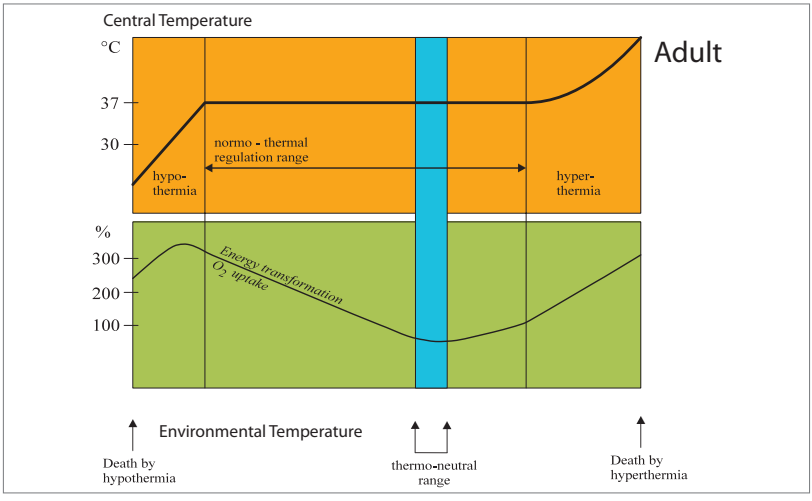

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FIGURE 10. Thermo-neutral range of an adult.

The graph shows what happens to the central temperature (vertical axis) as the environmental temperature (horizontal axis) changes. To maintain the central temperature the body has to use energy and the amount used can be assessed from measurements of oxygen consumption. This is shown in the lower graph with increasing oxygen consumption, and hence energy utilisation, as the environmental temperature is raised or lowered.

If an adult is too cold, his body responds with vasoconstriction to reduce heat loss from the peripheries. With further decreases in environmental temperature, shivering occurs to increase metabolism and heat production.

Within the “normo thermal” range the body is able to cope with the environmental temperature by increasing energy expenditure. Below a certain environmental temperature the central temperature drops; hypothermia then results (see FIGURE 4).

Likewise, an adult starts sweating to cool the body when the environmental temperature is too warm. At high environmental temperatures the body can initially compensate by using energy for heat loss but at a certain point these mechanisms fail resulting in hyperthermia (see FIGURE 5).

Within this “normo-thermal” range there is a point at which the body is using a minimum of energy for thermoregulation. This is the “thermo-neutral” range and corresponds to the most comfortable environmental temperature for the body. The mature baby at birth has a smaller “normo-thermal” range than the adult but this rapidly matures. In the preterm, low birthweight infant both the “normo-thermal” and “thermo-neutral” ranges are very narrow. This is shown in FIGURE 11.

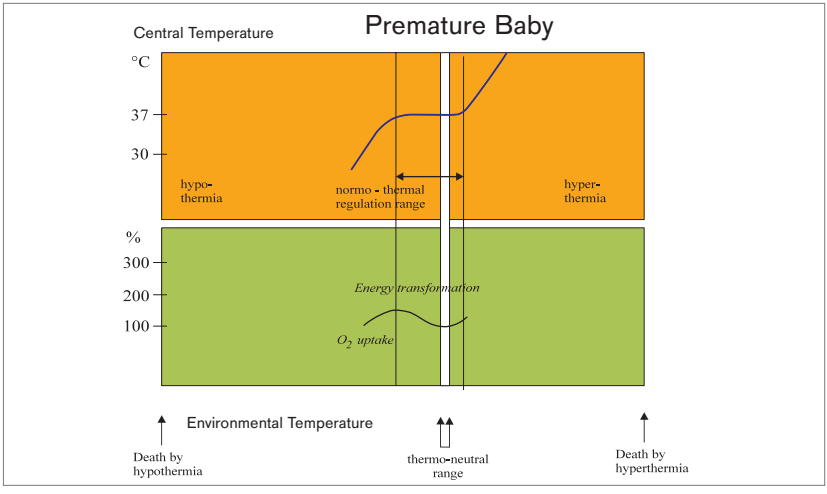

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FIGURE 11. “Thermal-neutral” range of a premature baby

In fact, the premature baby is not provided with mechanisms like sweating and shivering and its metabolism is limited as well. The only response to cold stress is vasoconstriction, which is seen with **ThermoMonitoring**.

Therefore, it should be the target of nursing care to keep the baby in its "thermo neutral" range to provide the best conditions for growth and maturity.

ThermoMonitoring gives us the information, whether babies are in their "thermo neutral" range.

Maintaining the optimum environmental conditions for the preterm baby is therefore a challenge.

The Preterm Baby after Birth

The fetus does not have a system for temperature regulation. Before birth the baby is poikilothermic which means that it adapts to the temperature of the mother. This means that the fetal central and peripheral temperatures are the same and have a value determined by the central temperature of the mother.

FIGURE 12 shows what happens in the preterm baby after delivery. Just after birth the central and peripheral temperatures depend directly on the environmental temperature but with time the baby activates its own system for the regulation of body temperature, changing from a poikilothermic (period A in FIGURE 12) to a homeothermic state (period C). As this occurs the "normo-thermal" and "thermo-neutral" ranges both increase.

The more mature the baby, the quicker this change occurs but in some preterm infants it can take several days. This period of increased thermal instability, with all its potential complications, adds to the baby's problems at a time when it is often already critically ill.

Once the baby has activated its own body temperature regulation systems it is more stable and able to cope better with changes in environmental conditions without any effect on central body temperature.

Resuscitation

All babies cool rapidly after birth because of heat loss from evaporation of amniotic fluid from the skin. Drying and wrapping the term baby prevents such heat loss. The preterm baby is at higher risk of significant cold stress, particularly if resuscitation is needed. In the preterm infant low temperature on admission to the neonatal unit has been associated with increased mortality[6] and morbidity. Evaporation, the major source of heat loss, can be significantly reduced using occlusive dressings[13]. Clean plastic bags are easier to use and prevent hypothermia immediately after delivery[14,15]. The baby can be slid into the bag, up to the neck, whilst still wet. The head is covered with a hat.

No blankets are used, allowing radiant heat to warm the infant through the bag. Clinical inspection and auscultation during resuscitation can be done through the bag and if vascular access is needed a small hole can be cut in the plastic.

It is important to prevent heat loss during transport to the neonatal unit. The infant can be transported while still in the bag, which is only removed once the baby is in a humidified environment.

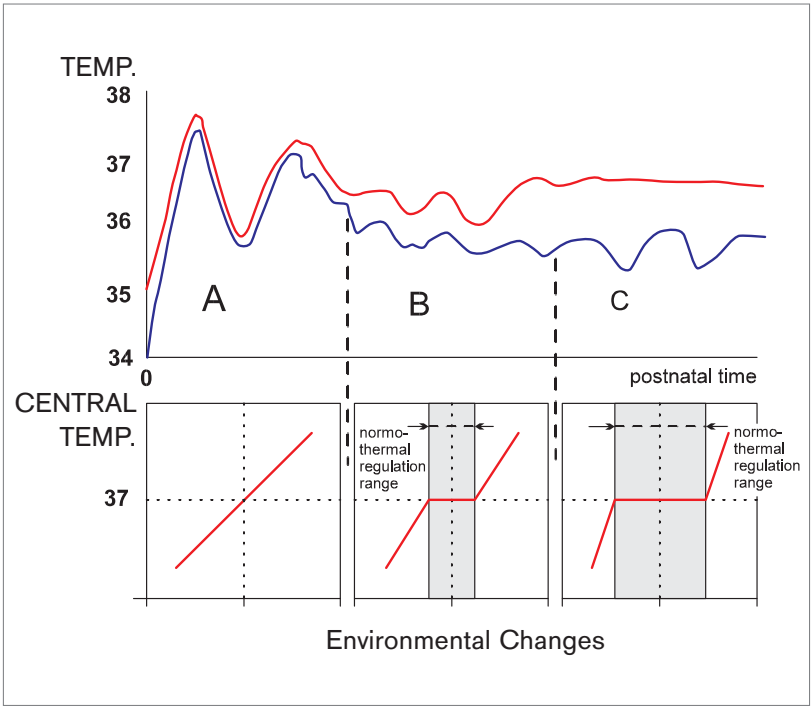

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FIGURE 12. Changes in central and peripheral temperature of a preterm baby after birth[6].

Examples

The influence of environmental changes on the baby
In FIGURE 13 the upper trace shows the central and peripheral temperatures with the ambient temperature and humidity shown in the lower traces. The peripheral temperature was measured on the foot and the central temperature behind the ear.

As the two probes were attached, a high skin temperature was observed. At the same time the heart rate was above 180 beats per minute (bpm). The baby was too warm and trying to lose heat. As the ambient temperature was reduced, the baby responded with a fall in central temperature to a “normal” value just below 37°C. The heart rate also fell to around 140.

During nursing procedures (marked with the vertical lines), the baby responded with a drop in peripheral temperature – an early effect of cold stress. The longer the nursing procedure the more significant the drop in peripheral temperature. These observations show the importance of minimal handling for these babies. Handling was also associated with a fall in humidity within the incubator and this was at least in part responsible for the increased heat loss and the subsequent cold stress.

FIGURE 13 shows a change in central temperature every 3 hours associated with handling. During the nursing procedures the baby’s head was turned. The central skin probe was placed behind one of the ears and whenever this was situated between the mattress and the baby’s head it was more insulated and gave a higher temperature reading.

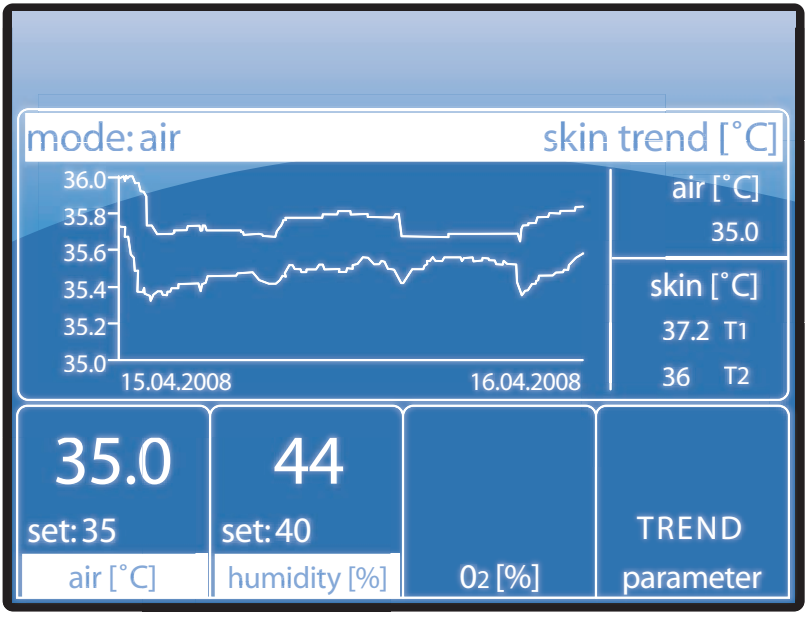

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FIGURE 13. A preterm baby monitored during nursing procedures.

Cold stress and reintubation

In FIGURE 14, the temperature trace shows the central and peripheral temperatures with the blue shaded area representing their difference. It shows how continuous monitoring and display of central and peripheral temperatures gives a clear visual picture of changes in the thermal state of the baby.

In this case the episode of handling was a reintubation and it can be seen that there was significant cold stress during this procedure, with a fall in both the central and the peripheral temperatures and an increase in the central-peripheral difference.

Following the procedure the central temperature returned to normal but the central-peripheral temperature gap remained high. The baby was subsequently found to be lying on a wet nappy. This had caused local cooling of the peripheries which was “cured” by changing the diaper.

All temperature probes can be affected directly by environmental conditions and give incorrect readings as shown in FIGURE 14. Other heat sources may also affect the probes, e.g. phototherapy lamps and overhead radiant heaters. Where possible, skin temperature probes should be shielded from the direct effects of external heating sources. This can be done by using better protected sites, such as the axilla or the baby’s back, or by covering the probe with a silver reflective pad.

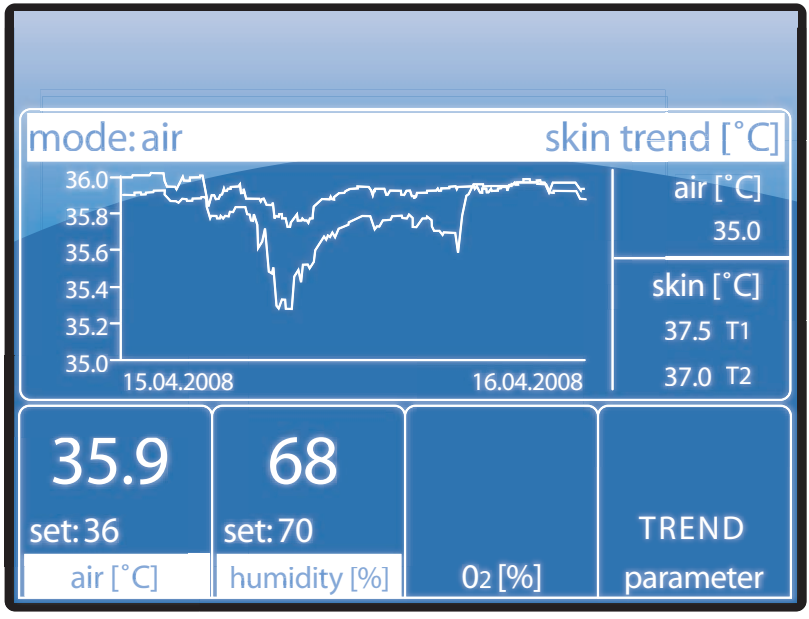

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FIGURE 14.

Excessive rewarming after cold stress

This trace shows the early effects of cold stress during handling with a fall in peripheral temperature and the central temperature remaining normal. The incubator temperature had been increased during the handling to compensate for any heat loss. This was not, however, reduced after the procedure resulting in overheating of the baby, with a rise in both temperatures, and a narrowing of the central-peripheral temperature gap.

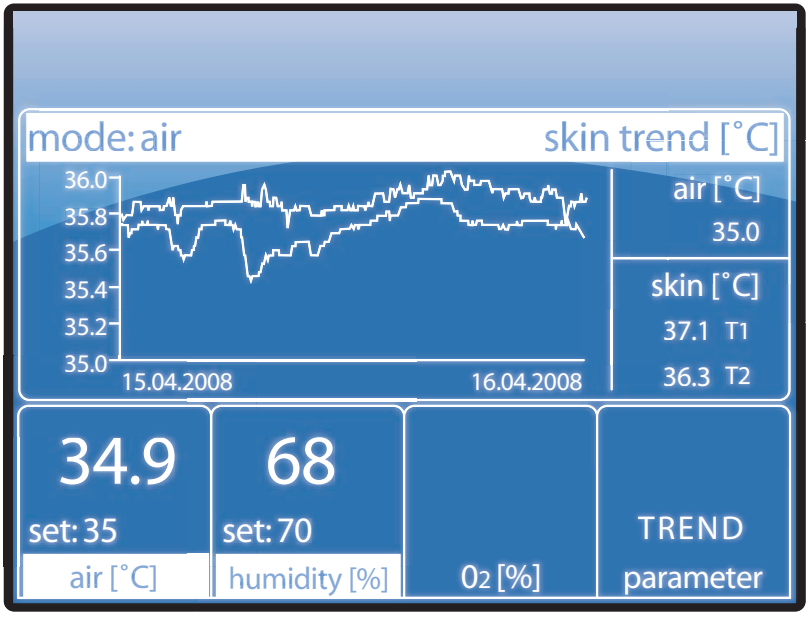

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FIGURE 15. Effects of excessive rewarming after cold stress.

Experiences with ThermoMonitoring

Kathy Brogan
Head Nurse — All Saints Hospital — Chatham, UK
"Measurement of the toe-central [peripheral-central] temperature difference is a regular practice for all babies requiring intensive care in the neonatal unit. Widening of the toe-central [peripheral-central] differential is an indication that all is not well with the baby, the nurse is quickly alerted and problems identified early. Environmental factors especially following handling may widen the toe-central [peripheral-central] differential but should improve with minimal handling and a suitable thermal environment. A persistent widening of the toe-central [peripheral-central] differential alerts staff to the possibilities of infection or poor circulatory volume. Continuous monitoring of toe-central [peripheral-central] temperature is a valuable aid to nurse observation and care of the sick and preterm baby."

"Continuous monitoring of toe-central [peripheral-central] temperature is a valuable aid to nurse observation . . ."

Barbara Schulz
Head Nurse — Heinrich Heine Universität, Zentrum für Kinderheilkunde Düsseldorf
"We have already been practising Thermo-Monitoring for 11 years. The main advantage from our point of view is that we are able to see a critical situation for the baby much earlier, than we would with only one temperature."

". . . we are able to see a critical situation for the baby much earlier."

Anne Mitchell
Neonatal Nurse Practitioner — Simpson Memorial University Hospital Edinburgh, Scotland
"Thermal perfusion and an awareness of peripheral perfusion is an integral part of neonatal intensive care. This non-invasive monitoring is easy to use and gives useful, early information about changes in the baby's condition."

". . .non-invasive monitoring is easy to use . . ."

Dräger ThermoMonitoring Solutions

Dräger's goal is to supply all equipment necessary for the care and monitoring of the newborn baby. **ThermoMonitoring** is a clinical approach which gives important information on the condition of the baby and this can be incorporated into the organised neonatal working place.

The Dräger incubators **Caleo and Isolette® C2000** can have two skin temperature channels. Both can display the central and peripheral temperatures, as well as the ambient air temperature and humidity continuously. **Caleo's** specific trend monitor, FIGURE 16, called ThermoView displays central and peripheral temperatures in parallel.

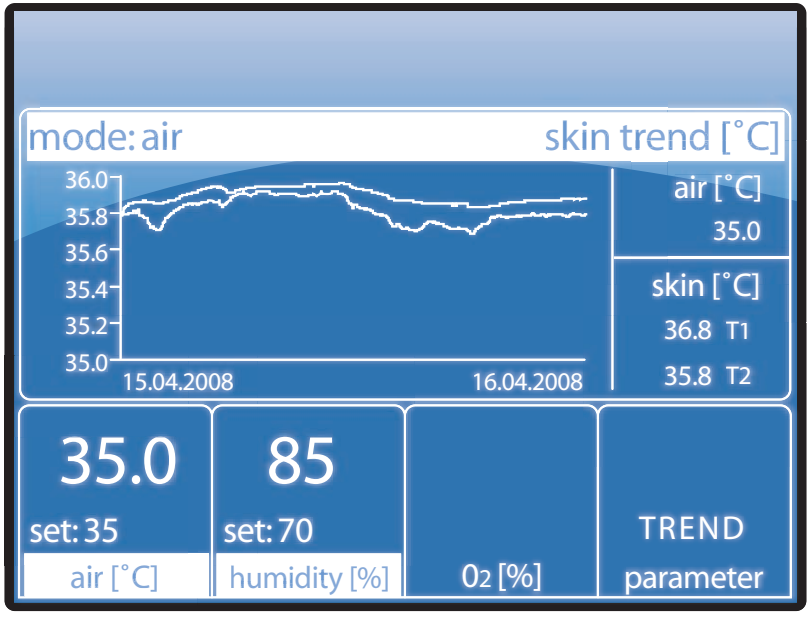

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FIGURE 16. Advanced ThermoMonitoring with ThermoView

Types of Heat Losses

Heat is lost by four different mechanisms:

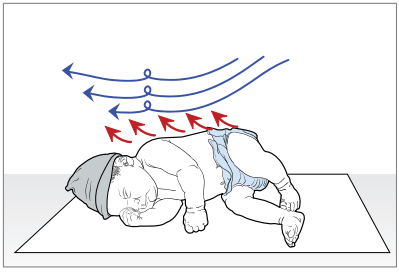
- **Convection**
- **Radiation**
- **Conduction**
- **Evaporation**

During the care of the baby all four types of heat loss have to be minimised. To understand better how this may be achieved, each of the methods of heat loss is described below:

Convection

Everyone knows that if you sit close to an open window the draught of air can cool you. In the same way movement of air around the baby will cause loss of heat if that air is below body temperature.

To reduce this heat loss when the ambient temperature is below 37°C, the air velocity of one of our Caleo is below 8cm/sec.



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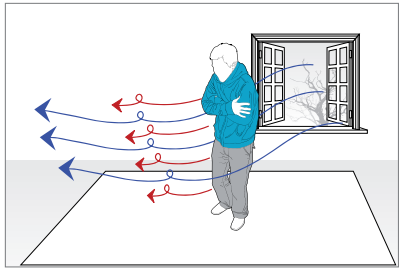

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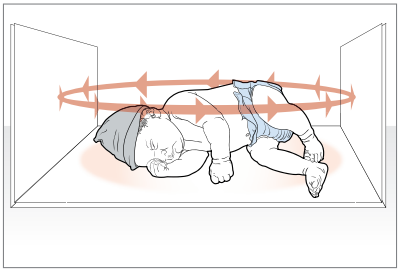
FIGURE 17. Heat loss by convection

Radiation

Radiation is the transfer of heat from a warm to a cooler surface. If you sit in front of a campfire the side of your body facing the fire becomes hot while your back becomes cold. If the baby is surrounded by cooler surfaces, there will be radiative heat loss.

To reduce radiative heat loss the Isolette® C2000 has double walls with a stream of warm air between the surfaces. This raises the temperature of the walls, thus reducing radiation.



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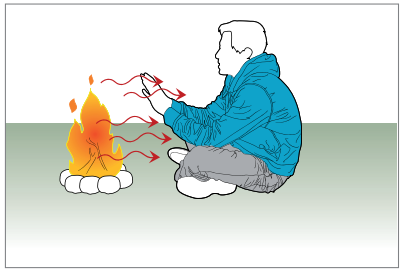

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FIGURE 18. Heat loss by radiation.

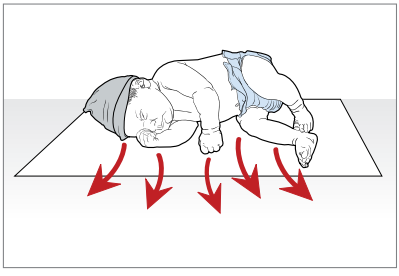
Conduction

Heat will be transferred from the baby to the mattress with which it is in contact. If the mattress is a good heat conductor then heat will be lost from the baby.

In everyday life, you are aware of the difference between heat gain from a warm foot bath compared with the heat loss from sitting on a cold stone.

To reduce conductive heat loss, the Isolette® C2000 has a well insulated, poorly conducting mattress.

Conduction is a very effective way of transferring heat to the baby. To take advantage of this Dräger has incorporated a gel mattress in our Open Care Warmer (Babytherm 8000 and Babytherm 8010).



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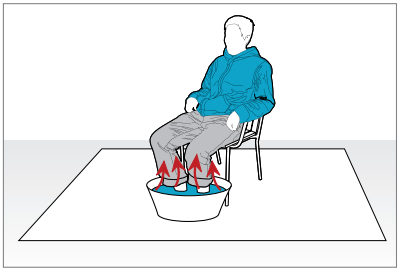

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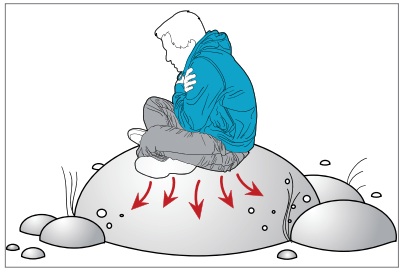

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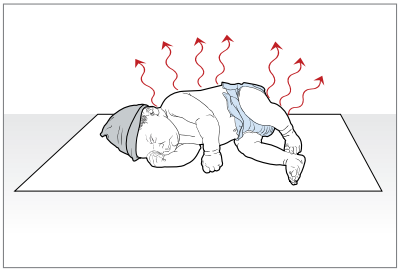
FIGURE 19. Heat loss by conduction.

Evaporation

Whenever liquid evaporates there will be heat loss because of the heat of evaporation. This is the reason why we feel cold when we open the door after taking a hot shower. The wet and thin skin of the preterm baby can result in significant fluid and heat loss if evaporation is not prevented.

The loss of heat by evaporation is reduced by using high ambient humidity in the incubator. For this purpose the Caleo is fitted with an integrated and powerful humidifier which is using the water boiling principle[10].



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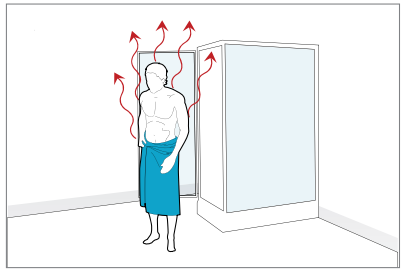

D-22277-2010

FIGURE 20. Heat loss by evaporation.

Heat Balance and the Baby

On a day to day basis, finding the ideal incubator settings can be difficult. To help in this task, Dräger has developed the computer program HeatBalance[1].

HeatBalance is ideal for teaching purposes and as a demon-stration tool. It gives staff suggested incubator settings based on gestation, weight and postnatal age of the baby. Using HeatBalance it is very easy to find the optimum incubator setting which should keep the baby in thermal balance. An example is shown in FIGURE 21.

This program is derived from basic physical principles and uses a very simple baby model. In reality babies are individuals and all have their own pattern of heat production and loss. Although HeatBalance can suggest initial incubator settings it is essential to have a method of continuously monitoring the baby's thermal state. ThermoMonitoring is important for the subsequent monitoring and assessment of the thermal state of the baby.

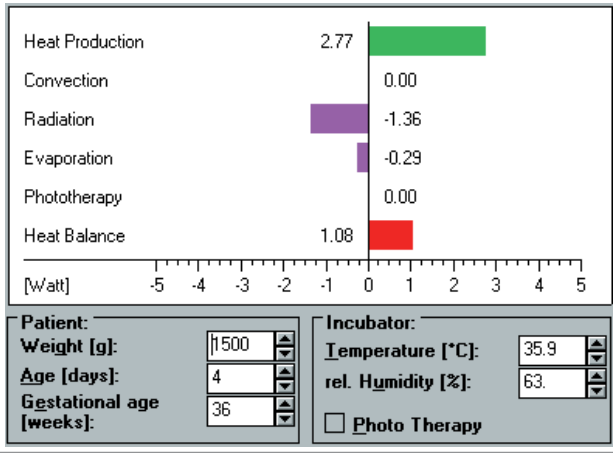

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FIGURE 21. WINDOWS1) PC Program HeatBalance

[1] Windows is registered trademark Microsoft Coorporation

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