Insensible Water Loss and Metabolic Rate in Low Birthweight Newborn Infants

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Summary

Insensible water loss (IWL) and metabolic rate (MR) were measured simultaneously in three groups of low birthweight (LBW) infants in a special incubator with air and wall temperature separately controlled as to keep the infants in their neutral thermal environment. Group I infants ($n = 7$) had a birthweight of 1.125 ± 0.192 kg and a gestational age of 20.0 ± 0.6 wk; group II infants ($n = 8$) had a birthweight of 1.730 ± 0.440 kg and a gestational age of 33.0 ± 1.6 wk, and group III infants ($n = 7$) had a birthweight of 1.960 ± 0.230 kg and a gestational age of 38.3 ± 1.9 wk (small for dates).

In group I infants, IWL decreased significantly ($P < 0.05$) between the 1st and the 2nd wk of life from 54.1 ± 11.2 to 42.7 ± 12.7 ml $\cdot$ kg $\cdot$ d $^{-1}$, whereas MR increased significantly ($P < 0.01$) from 48.8 ± 6.7 to 57.5 ± 8.0 kcal $\cdot$ kg $\cdot$ d $^{-1}$. In group II infants, IWL in the 2nd wk of life was not significantly different from IWL in the 1st wk of life which was 26.3 ± 5.6 ml $\cdot$ kg $\cdot$ d $^{-1}$, MR increased significantly ($P < 0.001$) from 45.7 ± 6.2 kcal $\cdot$ kg $\cdot$ d $^{-1}$ in the 1st wk of life to 55.1 ± 6.3 kcal $\cdot$ kg $\cdot$ d $^{-1}$ in the 2nd wk of life. In group III infants, IWL increased significantly ($P < 0.05$) between the 1st and 2nd wk of life from 23.7 ± 7.5 to 31.9 ± 9.4 ml $\cdot$ kg $\cdot$ d $^{-1}$ with a concomitant increase in MR ($P < 0.01$) from 48.8 ± 7.1 to 61.0 ± 8.4 kcal $\cdot$ kg $\cdot$ d $^{-1}$.

It is concluded that very LBW preterm infants in a neutral thermal environment have an increased evaporation through the skin resulting in an IWL that is much higher than expected from their MR, and that minimization of heat loss by radiation and convection is necessary to keep the infants in thermal equilibrium without a fall in body temperature and an increase in heat production.

Speculation

Separate air and wall heating and extremely low air velocity may be important features of incubators to be designed for very LBW preterm infants.

Several investigators have shown that LBW infants have large insensible water losses when in conventional incubators (2, 11), under radiant heaters (11), and under phototherapy (8, 11). Fanaroff *et al.* (2) demonstrated that in conventional incubators IWL is strongly affected by the environmental conditions close to the infant. This was demonstrated by the remarkable reduction of the large IWL of very LBW infants in a single-walled convention incubator which was obtained by covering the infant with an open-ended plastic shield (heat shield) (5, 6). However, even under the heat shield, IWL still exceeded the basal values as reported by Hey and Katz (3). This was an unexpected finding, because the infants under the heat shield were in their neutral thermal environment (5, 6). Assuming that MR in their infants was not increased, Fanaroff *et al.* (2) suggested that very LBW premature infants may have an increased evaporation through the skin.

Increased evaporation through the skin in very LBW premature infants in their neutral thermal environment will not only affect

total water loss, but consequently evaporative heat loss. This may have consequences as to the design and adjustment of the incubator necessary to keep the infants in their optimum environment.

In the present investigation, MR and IWL were simultaneously measured in LBW and very LBW premature infants. The infants were at their neutral thermal environment in an incubator with separate air and wall heating and extremely low air velocity.

MATERIALS AND METHODS

IWL and MR were measured simultaneously in three groups of LBW infants in the 1st and 2nd wk of life. Birthweight and gestational age ranged from 0.88–1.35 kg and from 28–30 wk in group I infants, from 1.35–2.45 kg and from 31–35 wk in group II infants, and from 1.53–2.13 kg and from 36–41 wk in group III infants. Mean birthweight and gestational age are presented in Table 1. According to Dutch standards, group I and group II infants had birthweights appropriate for gestational age, group III infants had birthweights below the 2.3 percentile (small for dates).

At the time of the study, all infants were in good health except for their low birthweight. During the measurements they were asleep with only occasional body movements. A milk formula (Nutricia, Almiron A) was supplied by continuous gastric drip. Additionally, glucose was administered iv in the majority of the infants. No drugs were used apart from antibiotics in four infants.

All infants were studied naked in a specially constructed incubator in which the temperature of the air and the walls could be regulated independently (Fig. 1). Temperature of the incubator wall was measured at five sites using thermocouples let into the perspex wall. Mean wall temperature was calculated from these measurements assuming that the reading from each thermocouple represented the temperature of a certain area. The temperature of the air was measured with thermocouples in the inflow and outflow tubes of the incubator; the average of the two readings was taken. Rectal temperature and skin temperature (abdomen) were also measured with thermocouples. All thermocouples were connected to a switch box and could be read one at a time on a galvanometer scale (Ellab TE3). Temperatures were read at 5 min intervals. Air and wall temperature were adjusted for birthweight and postnatal age according to Hey and Katz (4). This resulted in the infant being at its neutral temperature. Air velocity was measured by means of a thermoelectric anemometer (Instituut voor Gezondheidstechniek T.N.O., Delft, The Netherlands) at 1–2 cm above the abdomen of the infant in the incubator. The air velocity never exceeded 0.05 m $\cdot$ s $^{-1}$. Humidity in the incubator was read at 5 min intervals from a hygrometer (Thies); during the measurement of O_2 consumption ($\dot{V}O_2$) and CO_2 production ($\dot{V}CO_2$) water vapor pressure (PH_2O) was determined in a sample of incubator air using a psychrometer (Haenni).

IWL was obtained from the continuous recording of weight loss (Δm_b) measured by means of a specially constructed balance (Fig. 2). This balance is composed of a heavy underframe (O), on which two supporting beams (D) are mounted. The supporting beams carry on the one side a weighing platform (P) and on the other side a counter weight (C). The connections between underframe

Table 1. Birthweight, gestational age, age at the time of study, air temperature (T_A), wall temperature (T_W) and water vapor pressure (P_{H_2O}) in the incubator and rectal (T_R) and skin temperature (T_S) of the infants¹

Group	Birthweight (kg)	Gestational age (wk)	Age (days)	T_A (°C)	T_W (°C)	P_{H_2O} (mm Hg)	T_R (°C)	T_S (°C)
I (n = 7)	1.125 ± 0.192	29.0 ± 0.6	3.6 ± 2.1	34.7 ± 0.3	34.7 ± 0.3	13.1 ± 1.9	36.1 ± 0.3	35.7 ± 0.3
			11.7 ± 2.5	34.4 ± 0.7	34.5 ± 0.7	13.1 ± 2.4	36.8 ± 0.2	36.4 ± 0.2
II (n = 8)	1.730 ± 0.440	33.0 ± 1.6	4.0 ± 2.2	34.2 ± 0.6	34.1 ± 0.6	15.0 ± 2.3	36.8 ± 0.3	36.5 ± 0.4
			10.7 ± 2.4	33.3 ± 0.7	33.0 ± 0.7	14.5 ± 2.6	37.0 ± 0.2	36.5 ± 0.2
III (n = 7)	1.960 ± 0.230	38.3 ± 1.9	3.7 ± 2.2	34.1 ± 0.8	33.7 ± 0.5	14.3 ± 1.2	36.9 ± 0.4	36.6 ± 0.2
			11.2 ± 2.4	33.4 ± 0.5	33.1 ± 0.6	13.5 ± 0.9	37.0 ± 0.2	36.6 ± 0.1

¹ All data are expressed as mean ± SD.

Fig. 1. Schematic drawing of the experimental design. The rectangles at the right represent the heating systems for incubator air (A) and incubator wall (W). The electrical thermometer is connected to thermocouples at various sites. A balance is used for the continuous recording of weight loss. O₂ consumption and CO₂ production are determined by means of a diaferometer.

Fig. 2. Special balance used for the determination of insensible water loss. C, counter weight; D, supporting beams; O, underframe; P, weighing platform; S₁ and S₂, spring-mounted hinges; V, displacement transducer; Z, piston in oil bath.

and supporting beams and between supporting beams and weighing platform are made by spring-mounted hinges (S₁ and S₂). The weighing platform can move upwards and downwards in horizontal position, with a maximum deflection of a few cm. The movements of the weighing platform are damped by means of a piston in an oil-bath (Z). The infant lies on a nylon net in the incubator, which is connected to the weighing platform by means of gas-tight, nearly frictionless connectors through the incubator wall. The load on the weighing platform is independent of the weight of the infant, because the balance is brought into equilibrium by adding weights to the platform. The deflection of the weighing platform is measured by means of a displacement transducer (V) and a potentiometric recorder (Philips PM8010). During each measuring period the calibration of the system is checked by removing and adding a weight of 1 g (Fig. 3).

Diapers or clothes, which can absorb or release an appreciable amount of water were not used. Absorption or release of water by the nylon net underneath the infant was negligible. To prevent urine and stool from influencing the measurements, a watertight plastic bag was carefully attached to the infant, enclosing both the

Fig. 3. Recording of weight loss (Δm_b) of a 2.2 kg infant. For calibration of the weighing system, a weight of 1 g is taken from the balance and subsequently added again.

anal and the genital area. Feeding by intragastric catheter and iv administration of fluid was continued during the measurements. This had no influence on the recorded decrease in weight, because food and infusion fluids were with the infant on the balance. The infant was continuously observed and the measurement terminated when any leakage of food, infusion fluid, urine or stool occurred, or when sweating was observed. A typical record of the decrease in weight of an infant is shown in Figure 3.

The continuous decrease in weight is, apart from the IWL, determined by the difference in weight between the O₂ consumed and the CO₂ produced. A correction for this factor could be carried out, because $\dot{V}O_2$ and $\dot{V}CO_2$ of the infant were measured simultaneously with the recording of the change in weight. For calculating IWL the following equation was used (9):

$$IWL = \Delta \dot{m}_b - 1.977 \dot{V}CO_2 + 1.429 \dot{V}O_2 \quad (1)$$

where IWL and $\dot{m}_b$ are in $mg \cdot min^{-1}$ and $\dot{V}O_2$ and $\dot{V}CO_2$ in $ml \cdot min^{-1}$.

MR was obtained from the simultaneous recording of the infant's $\dot{V}O_2$ and $\dot{V}CO_2$ measured by means of a thermal conductivity method carried out with a Kipp diaferometer which was calibrated with human expiratory gas (10). A mixture of the infant's expiratory gas and incubator air was drawn with an exactly known flow rate from a hood around the infant's head (open method) (Fig. 1). Reference gas was taken from the air inlet of the incubator. The deflections of the independent O₂ and CO₂ channels of the diaferometer were recorded continuously (Kipp BD5/BE5). For calculating MR the following equation was used (9):

$$MR = 3.797 \dot{V}O_2 + 1.204 \dot{V}CO_2 \quad (2)$$

where MR is expressed in $cal \cdot min^{-1}$ and $\dot{V}O_2$ and $\dot{V}CO_2$ in $ml \cdot min^{-1}$ (STPD).

For statistical evaluation of the data a two-tailed paired *t*-test and rank sum test (Wilcoxon) were used. Informed consent from the parents was obtained.

ACCURACY OF THE METHODS

IWL was determined by continuous weighing. The overall accuracy of the weighing system was estimated to be 0.4%. In calculating IWL from $\dot{m}_b$, a correction has to be made for the difference in weight between O_2 consumed and CO_2 produced. Omission of this correction may result in a considerable overestimation of IWL. If evaporation is low and the respiratory quotient high, an error > 20% may easily occur. Taking the accuracy of measuring $\dot{V}O_2$ and $\dot{V}CO_2$ into account, we found that the accuracy with which IWL has been determined, varies from 3–9%, depending on the value of $\dot{m}_b$ (9).

To increase the accuracy of the measurement of $\dot{V}O_2$ and $\dot{V}CO_2$, the diaferometer used in this study was calibrated several times using human expiratory gas (10). This resulted in an accuracy for the determination of both $\dot{V}O_2$ and $\dot{V}CO_2$ of 4%. The methods for calculating MR from $\dot{V}O_2$ and $\dot{V}CO_2$ were critically reviewed (9). As a consequence, equation 2 was formed, allowing the calculation of MR with an overall accuracy of about 4%.

RESULTS

A total of 83 measurements were obtained in 22 infants. Mean birthweight, gestational age, age at the time of the study, incubator air, and wall temperature, and PH_2O in the incubator, and rectal and skin temperature of the infants are represented in Table 1. Birthweight and gestational age in group I infant are significantly less than in group II infants ($P < 0.001$). Birthweights of group II and group III infants are not significantly different, although mean birthweight is lower in group II than in group III. At the time of the first study, the mean age in each group was between 3.6 and 4.0 days and at the time of the second study between 10.7 and 11.7 days ($P < 0.001$). There is no significant difference between age at the time of the first study in group I, II, and III infants. The same holds for the second study.

Incubator air and wall temperature were adjusted for birthweight and age according to Hey and Katz (4). This does account for the differences in incubator temperature between the three groups as well as between the infants within each group. PH_2O was slightly less in group I infants when compared to PH_2O in group II infants. This difference is significant ($P < 0.01$) for the first study, but not for the second one. In group III infants, PH_2O during the second study was slightly but significantly ($P < 0.05$) less than PH_2O . At the time of the first study, rectal and skin temperature in group I infants were significantly lower than in group II and III infants ($P < 0.001$). At the time of the second study, this difference had disappeared.

Data on IWL and MR are presented in Table 2. Both during the first and the second study, IWL in group I infants was significantly larger than in group II and III infants ($P < 0.01$). In group I infants, IWL at the time of the first study was significantly larger ($P < 0.001$) than at the time of the second study. In contrast, in group III infants, IWL at the time of the first study was significantly less than at the time of the second study ($P < 0.001$). In group II infants, there was no significant difference.

Both during the first and the second study there were no significant differences in MR between the three groups of infants. However, in all three groups, MR at the time of the second study was significantly higher than at the time of the first study ($P < 0.01$).

DISCUSSION

In this investigation, infants were studied in their neutral thermal environment as defined by Hey and Katz (4) in an incubator with separately controlled air and wall temperature, low air velocity, and moderate humidity. This incubator was of similar design as that of Hey and Katz (3). Analogous to their results, IWL in our infants was lower than that in infants in conventional convection incubators and under radiant heaters (2, 8, 11). However, in contrast to Hey and Katz (3) who reported no difference in IWL/ m^2 body surface area in infants from 1.0–4.5 kg of bodyweight, we found a considerably higher IWL in very LBW infants (group I) as compared with infants with higher birthweight (groups II and III).

The evaporation of water from the skin and airways is depen-

Fig. 4. Heat production (white columns) and evaporative heat loss (hatched columns) in group I (birthweight 1.125 ± 0.192 kg and gestational age of 29.0 ± 0.6 wk), group II (birthweight 1.730 ± 0.440 kg and gestational age of 33.0 ± 1.6 wk) and group III (birthweight 1.960 ± 0.230 kg and gestational age of 38.3 ± 1.9 wk) infants during the 1st (A) and the 2nd (B) wk of life. Heat production and heat loss on the vertical axis are in KJ/kg bodyweight/day and in kcal/kg bodyweight/day.

Table 2. IWL and MR in LBW infants¹

Group	Age (days)	IWL			MR		
		(ml·kg ⁻¹ ·d ⁻¹)	(ml·m ⁻² ·d ⁻¹)		(kcal·kg ⁻¹ ·d ⁻¹)	(kcal·m ⁻² ·d ⁻¹)	
I	3.6 ± 2.1	54.1 ± 11.2	568 ± 127.0	$P < 0.05$	48.8 ± 6.7	509.8 ± 66.2	$P < 0.01$
	11.7 ± 2.5	42.7 ± 12.7	449.0 ± 135.1		57.5 ± 8.0	603.4 ± 73.4	
II	4.0 ± 2.2	26.3 ± 5.6	307.9 ± 60.0	NS	45.7 ± 6.2	537.8 ± 83.0	$P < 0.001$
	10.7 ± 2.4	26.7 ± 6.5	324.0 ± 62.9		55.1 ± 6.3	678.0 ± 94.1	
III	3.7 ± 2.2	23.7 ± 7.5	302.2 ± 101.8	$P < 0.05$	48.8 ± 7.1	621.6 ± 103.2	$P < 0.01$
	11.2 ± 2.4	31.9 ± 9.4	398.2 ± 106.8		61.0 ± 8.4	765.1 ± 114.0	

¹ All data are expressed as mean ± SD.

dent on environmental factors (air and wall temperature, humidity, air velocity) and infant factors (body temperature, posture, metabolic rate). During our measurements, air and wall temperature were kept at the level advised by Hey and Katz (3). Humidity in our incubator, however, was slightly lower than in their metabolic chamber ($\text{PH}_2\text{O} = 13$ and 18 mm Hg, respectively). This slight difference may have caused the somewhat larger IWL in all our infants, but cannot explain the larger insensible water losses in the infants of our group I.

Another difference between our set-up and that of other investigators (2, 3, 11) was that in our incubator the infant was lying on a Nylon net, whereas in the other studies, it was placed on a mattress or a Perspex plate. In our opinion, however, the ensuing difference in body surface area available for evaporation, can hardly explain the considerably increased IWL in our group I infants, although it might explain the slightly increased IWL in group II and III infants.

Mature infants sweat in a hot environment when rectal temperature rises above 37.2°C , but their ability to sweat is limited (3). In LBW infants the ability to sweat is even less. In our infants mean rectal temperature during the measurements did not exceed 37.0°C . Consequently, sweating may be excluded as a contributing factor causing the higher IWL in our infants.

The influence of posture and activity on IWL has been studied by Zweymüller and Preining (12) in a group of newborn infants with birthweights of 2.4–4.6 kg. In actively moving infants IWL was shown to be increased as much as 65% in comparison with the sleeping condition. During our measurements the infants were usually asleep, but some moved quietly during part of the observation period. This may have increased IWL to some extent, but the functional state of our babies does not seem to have been appreciably different from that of the infants studied by others.

Hey and Katz (3) studied the relationship between IWL and MR. Using their equation (3) we calculated a smaller IWL from our MR measurements than we found experimentally. This especially holds for our group I infants where we found that the experimentally determined IWL values were 100–155% higher than the calculated ones. In our group II and III infants, the differences were much less (29–52% and 30–41%, respectively). Our study thus shows that IWL in very LBW preterm infants is out of proportion to MR. This also follows from the observation that in very LBW infants (group I, Table 2) IWL at the age of 3.6 days is significantly larger than at 11.7 days, whereas MR at 3.6 days is significantly less than 11.7 days.

Although the cause of the discrepancy between our findings and those of Hey and Katz (3) cannot be traced on the ground of the data reported in the literature, we have found an increased IWL in very premature infants in their neutral thermal environment. The supposition of Fanaroff *et al.* (2) that below a critical level of maturity, IWL through the skin is out of proportion to MR, seems quite reasonable. Additional evidence for this hypothesis can be found in the difference in IWL between group I, group II, and group III infants at comparable ages and similar MR. In the group I infants, the skin will be in an early stage of maturation with corresponding high permeability. In all infants of groups II and III, maturation of the skin will have proceeded resulting in much less permeability. The decrease in IWL of the group I infants between the 1st and 2nd wk of life despite an increase in MR indicates that the permeability of the skin has decreased. This observation is of particular clinical significance. It indicates that the water requirement of very LBW infants decreases rapidly. The amount of water supplied to these infants should not be based on a standard prescription, but adjusted to individual needs.

Evaporative heat loss, as calculated from IWL in comparison with total heat loss is shown in Figure 4. Assuming that T_R and T_S adequately represent overall body temperature MR equals total heat loss when T_R and T_S are stable. This allows to express evaporative heat loss as a fraction of total heat loss. Thus, in group III infants evaporative heat loss accounts for 28 and 30% of total heat loss for the first and second study, respectively. In group II

infants this is 35%, and 29% in the first and second study. These data are in accordance with those generally accepted in the literature where evaporative heat loss is given as 20–30% of total heat loss. In group I infants, however, this is much higher: 65% in the first study and 43% in the second one. In these infants evaporative heat loss, thus, is a much higher fraction of total heat loss. Heat loss by radiation and convection was correspondingly lower. As heat loss by radiation and convection depends on incubator wall and air temperature, the low radiative and conductive heat loss could only be accomplished by adjusting air and wall temperature. Minimization of heat loss by radiation and convection is absolutely necessary in order to keep very LBW preterm infants with their high evaporative heat loss in thermal equilibrium without a fall in body temperature and a rise in heat production. In a conventional convection incubator with a relatively cold incubator wall this would not have been possible.

Controlling heat loss by radiation and convection is most effectively done by separately heating incubator air and incubator wall. This makes incubator wall temperature independent of room temperature. Moreover, it obviates the demand for a higher air velocity to improve heating of the incubator walls. A higher air velocity increases evaporative heat loss, which again leads to the necessity of humidifying the inflowing air. This is demonstrated by the observation of Belgaumkar and Scott (1) that the rectal temperature of newborn infants nursed in a servo-controlled convection incubator, could be kept from falling only when the inflowing air was humidified. The results of this study suggest that separate air and wall heating and extremely low air velocity may be important features of future incubator designs for very LBW premature infants.

The results of our study do not explain why very LBW preterm infants in convection incubators and under radiant heaters have such very large insensible water losses. We suggest, however, that the increased evaporation through the skin will make the very premature infant more susceptible for the physical properties of its environment. Not only does their relatively large body surface area increase their susceptibility for the environmental factors that affect radiant and convective heat losses, in addition, will their increased evaporation through the skin increase their susceptibility for the environmental factors that affect evaporative heat losses. In other words, in incubators and other heat-supplying devices used for very LBW premature infants not only controlled air and wall (radiant) heating, but also controlled air velocity and humidity are important features.

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