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Does Non-ionizing Radiant Energy Affect Determination of the Evaporation Rate by the Gradient Method?

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ABSTRACT

A study was performed to investigate whether measurements of the evaporation rate from the skin of newborn infants by the gradient method are affected by the presence of non-ionizing radiation from phototherapy equipment or a radiant heater. The evaporation rate was measured experimentally with the measuring sensors either exposed to or protected from non-ionizing radiation. Either blue light (phototherapy) or infrared light (radiant heater) was used; in the former case the evaporation rate was measured from a beaker of water covered with a semipermeable membrane, and in the latter case from the hand of an adult subject, aluminium foil or with the measuring probe in the air. No adverse effect on the determinations of the evaporation rate was found in the presence of blue light. Infrared radiation caused an error of 0.8 g/m^2h when the radiant heater was set at its highest effect level or when the ambient humidity was high. At low and moderate levels the observed evaporation rate was not affected. It is concluded that when clinical measurements are made from the skin of newborn infants nursed under a radiant heater, the evaporation rate can appropriately be determined by the gradient method.

Key words: Newborn infants, evaporation rate, water balance, heat balance, phototherapy, radiant heater.

INTRODUCTION

Phototherapy and the use of radiant heaters have been reported to increase the insensible water loss from newborn infants by approximately 40-190% (1, 2, 6, 9, 10). These reports are based on gravimetric determination of the insensible water loss from the infants, i.e. by the weighing method.

Since the gradient method for direct measurement of transepidermal water loss was introduced (3, 4, 5) it has been used in many studies of insensible water loss in newborn infants (7). As the effect of non-ionizing radiant energy on the measuring sensors was not known, we have not used it together with phototherapy or with the infant under a radiant heater.

The aim of the present study was thus to investigate the influence of radiant energy within the blue and infrared spectra on determination of the evaporation rate by the gradient method, in order to resolve the question as to whether direct measurements of insensible water loss from the skin of newborn infants can be made during phototherapy and treatment with radiant heaters.

METHODS

The method for measurement of the evaporation rate (Evaporimeter EP 1, Servomed AB, Stockholm, Sweden; (5)) is based on determination of the water vapour pressure gradient in the air layer close to the evaporating surface. At a constant rate of evaporation there is a linear relationship between the water vapour pressure and the distance from the surface within 10-13 mm from the surface (8). The vapour pressure gradient and the evaporation rate are calculated from the vapour pressure at two separate points situated on a line perpendicular to the surface and within 10 mm from the surface. The water vapour pressure at each point is calculated from the relative humidity and the temperature. Relative humidity is measured with a capacitive sensor based on an organic-polymer dielectric, sensitive only to changes in relative humidity (Vaisala Humicap HMP11, Vaisala Oy, Helsinki, Finland). The temperature at each point is measured with a small, fast thermistor (M81, Siemens A G, West Germany).

Recordings of ER, relative humidity and water vapour pressure were made on a Watanabe recording system (Watanabe Instruments Corporation, Tokyo, Japan).

Blue-light radiation with a wavelength of mainly 440-470 nm was obtained from a light source that is intended for treatment of hyperbilirubinaemia in newborn infants (Bililite, Olympic Medical, Seattle, USA).

Infrared radiation was obtained from an overhead radiant heater, intended for the care of newborn infants (Ohio Medical Products, Wisconsin, USA). It has a peak wavelength of 3.8-8 um and gives a maximum output of approximately 850 watts. The power requirements of the radiant heater were determined by inserting a wattmeter between the radiant heater and the electric mains outlet. The radiant heater has an arbitrary power scale from 0-5. The corresponding power consumption is shown in Table 1.

Table 1. Power requirements at different radiant heater levels.

Level	1	2	3	4	5
Power (W)	627	935	1038	1063	1089

Temperatures were measured with a YSI telethermometer (43 TA, using probes 405 and 427, Yellow Springs, Ohio, USA).

Spectral irradiance was measured with a phototherapy radiometer (PR 3, Air Shields, Hatboro, PA, USA).

Air-flow velocities were measured with an air velocity meter (Omnisensor, model 1640, TSI Incorp, St Paul, MN, USA).

MEASUREMENT PROCEDURE

The evaporation rate (ER, g/m^2h) is measured by first establishing a stable baseline recording with the measuring probe exposed to the ambient conditions. The probe is then placed on the surface from which ER is to be measured. A stable reading is obtained after 1-3 minutes. The measurement is concluded by making a second baseline determination. ER is obtained by subtracting the mean baseline value from the steady state reading obtained during the measurement.

Blue-light radiation (phototherapy)

A beaker, nearly filled with water and covered with a semipermeable membrane (Lundia ultra flux, Gambro, Sweden.), was placed in an incubator (AGA MK 241, AGA medical, Lidingö, Sweden) and was allowed to equilibrate to the incubator temperature. The temperature of the incubator air was kept at $31^{o}C$, and the relative humidity at 50 %. The air velocity 3-5 cm above the membrane was less than 0.1 m/sec. The blue-light source was placed above the incubator so that the spectral irradiance at the level of the membrane was 12 uW/(cm^2nm). A specially constructed, removable shield was used to protect the measuring sensors in the Evaporimeter probe from direct radiation from the light source (Fig.1). To allow air movements through the shield, it was constructed from metal netting.

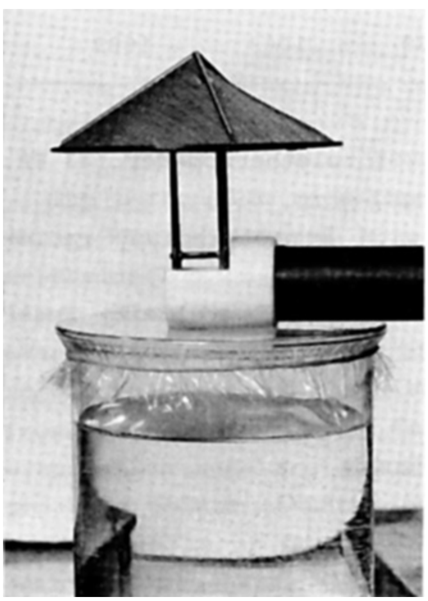

Fig 1.
Measurement of evaporation rate from a semipermeable membrane. The figure shows the probe with the protective shield mounted.

Fifteen intermittent measurements of ER were made under each of the four conditions shown in Table 2. The measurements were made on two separate occasions. On the first occasion ten measurements were made under each condition in the sequence given in Table 2. On the second occasion the remaining five sets of measurements were performed. The temperature of the water (T_{water}, ^oC) was measured in the middle of the beaker, 1 cm below the surface of the water. The temperature of the air in the incubator (T_{air}, ^oC) was measured in the centre of the incubator roughly 10 cm above and 10 cm to the side of the beaker. T_{water} and T_{air} were recorded before each measurement of ER.

Infrared radiation (radiant heater)

Four different series of measurements were made to test whether infrared radiation influenced the ER values obtained. The protective shield on the probe was not used.

In series I, II and III half of the platform under the radiant heater was protected from radiation by a plate covered with aluminium foil as shown in Fig.2.

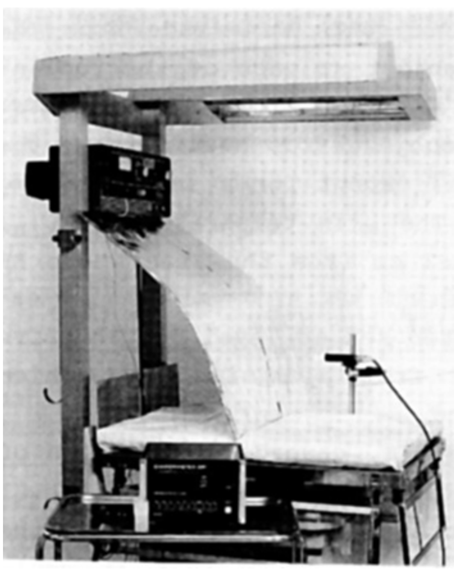

Fig 2.
Radiant heater with the protective plate in place. The probe is exposed to the radiation.

Measurements of ER were made from the hand of an adult subject. During the measurements the hand rested on the platform. Measurements were made with alternate protection from and exposure to the radiant energy by moving the hand between the two compartments under the radiant heater. Every second measurement was thus made with the probe and hand exposed to the radiant energy. The measurements were evaluated in consecutive pairs starting with a value from the protected compartment. In **series I** and **II** baseline determinations before and after each ER measurement were made with the probe protected from radiant energy. In **series III** baseline determinations were made with the probe exposed to radiant energy when measurements were made in the exposed compartment.

Before the start of each measurement series the temperature (T_{amb}, ^{o}C) and relative humidity (RH, %) of the ambient air in the room were recorded, but could not be regulated. The air velocity was less than 0.1 m/sec over the site of measurement. The radiant heater was preheated for at least 30 minutes prior to all measurements.

Series I. Five to eight pairs of ER measurements (protected-/exposed) were made from the thenar region of the hand of six adults. The radiant heater was set at level 1. In all, 42 pairs of measurements were made.

Series II. Ten pairs of ER measurements were made from the thenar region of the hand of one subject at each of the radiant heater levels 1, 3 and 5 (**series II:1**, **II:2** and **II:3** respectively). In an attempt to protect the subject from heat stress, the hand was covered with aluminium foil except for a small opening which allowed measurements of ER. The skin temperature (T_{skin}, ^{o}C) was measured under the foil, 2-3 cm from the area where ER was measured.

Series III. With the radiant heater set at level 5, ten pairs of measurements of ER were made from aluminium foil which completely covered the subject's hand.

Series IV. A possible baseline shift, caused by radiation of the sensors, was looked for. The radiant heater was set at level 2. The protective plate was interposed horizontally between the radiant source and the platform in such a way that it could easily be removed. The probe was placed 11 cm above the platform. The holder for the probe can be seen in Fig.2. Continuous baseline recordings of ER were made. The interposed plate was removed for 5-minute periods to allow exposure of the sensors to the radiant energy. This was alternated with 5-minute periods with the sensors protected. Recordings were made during eight pairs of periods at a relative humidity of 26 % and an air temperature of 21.8 °C (**series IV:1**). Recordings were made during five pairs of periods at a relative humidity of 57 % and an air temperature of 21.9 °C (**series IV:2**).

TREATMENT OF DATA

Data were obtained for ER, relative humidity, T_{water}, T_{amb}, T_{air} and T_{skin}. All statistical testing was done with Student's t test, either on grouped observations (evaluation of blue-light radiation) or on paired observations (evaluation of infrared radiation).

RESULTS

Blue-light radiation (phototherapy)

ER, T_{water} and T_{air} lay at the same level under all four measurement conditions (Table 2) and no statistically significant differences were found in these variables. Blue-light radiation did not influence the determination of ER.

Table 2. The mean values and standard deviations for ER (g/m^{2}h), T_{water} (°C) and T_{air} (°C) under the four measurement conditions with and without blue-light radiation.

Metal shield	Light source	ER	T_{water}	T_{air}
off	off	41.1±1.3	27.3±0.4	30.9±0.1
off	on	41.7±1.8	27.6±0.4	31.0±0.2
on	off	40.9±1.5	27.4±0.3	30.9±0.2
on	on	40.7±1.9	27.6±0.3	31.1±0.2

Infrared radiation (radiant heater)

The results are summarized in Tables 3-5. In **series I**, where measurements were made from the hands of six subjects, no statistically significant difference in ER was found between determinations made with the sensors protected from and exposed to radiant energy (Table 3).

Table 3. Mean values and standard deviations for ER (g/m^2h) in series I and II with the sensors protected from and exposed to infrared radiation, and relative humidity (RH,%) and ambient temperature (T_{amb},°C) at the start of the measurements. D_{ER}=difference in evaporation rate. Ral=radiant heater level.

	ER protected	ER exposed	D_{ER}	p	RH	T_{amb}	Ral
I	37.9±8.6	38.3±8.9	0.4±2.3	ns	26	23.4	1
II:1	32.1±1.3	33.2±0.9	1.1±1.5	<0.05	27	23.9	1
II:2	37.6±1.7	41.1±1.7	3.5±2.0	<0.001	19	24.2	3
II:3	43.3±1.8	45.8±1.2	2.5±1.1	<0.001	15	25.7	5

In **series II**, where ER was measured from the hand of one adult at three different radiation levels, ER was significantly higher when the sensors were exposed to than when they were protected from radiant energy, at all three levels (Table 3). T_{skin} was also significantly higher when the skin was exposed to radiant energy than when it was protected from it (Table 4).

Table 4. The mean skin temperature (T_{skin},°C) with standard deviations and the T_{skin} differences ($D_{T(skin)}$) in series II when the ER measurements were made during protection from (A) and exposure to (B) infrared radiation.

	T_{skin} A	T_{skin} B	$D_{T(skin)}$	p
II:1	34.7±0.4	34.8±0.4	0.1±0.1	<0.01
II:2	35.9±0.1	36.3±0.1	0.5±0.1	<0.001
II:3	36.3±0.2	36.5±0.1	0.3±0.1	<0.001

In **series III**, where measurements were made from aluminium foil at the highest level of radiation, ER was significantly higher when the sensors were exposed to radiant energy than when they were protected from it (Table 5).

In **series IV**, where the effect on the baseline was studied, the baseline value at a high ambient humidity (57%) was significantly higher when the sensors were exposed to than when they were protected from radiant energy. At a low ambient humidity (26%) there was no corresponding difference (Table 5).

Table 5 The mean change in recorded ER (D_{ER};g/m^{2}h) and its standard deviation with the sensors protected from and exposed to infrared radiation in series III and IV, and the relative humidity (RH,%) and ambient temperature (T_{amb},^{o}C) at the start of the measurements. Ral=radiant heater level.

	D_{ER}	p	RH	T_{amb}	Ral
III	0.8±0.3	<0.001	19	26.6	5
IV:1	0.0±0.3	ns	26	21.9	2
IV:2	0.8±0.3	<0.01	57	21.8	2

DISCUSSION

This study has shown that measurements of ER can be made during exposure to blue-light energy (phototherapy) without undue influence on the sensors.

The evaluation of the effect of infrared light energy (radiant heat) is much more difficult, as this energy also influences the surface being studied, making it difficult to distinguish between an adverse effect on the sensors and an appropriate increase in evaporation. This made it impossible to use the same set-up as when studying the effect of blue-light energy. The radiant heat quickly increased the temperature of the water in the beaker and also affected the semipermeable membrane. The thenar region of the hand, from which most measurements were made, has an abundance of sweat glands, which can be activated both by thermal and by emotional stimuli. The high ER values obtained in this study show that sweat glands were active. In series II higher ER values were obtained when the probe and the hand were exposed to radiant energy than when they were protected from it. The higher ER values were accompanied by higher skin temperatures under the foil protecting the hand. It is possible that both the higher ER and the higher temperature are signs of an increased heat load to the subject when the hand is placed in the exposed compartment under the radiant heater.

In series III the effect of heat stress on the subject was eliminated by covering the hand completely with aluminium foil, and any difference in ER between measurements made with the sensors exposed to infrared radiation and those made with the sensors protected should be due to an influence on the sensors. The ER value was found to be 0.8 g/m^2h higher with the sensors exposed and can, at least partly, be due to reflection from the aluminium foil. In this series the highest level of radiation was used, but this level is only applied for very short periods, if ever. In series IV, where the level of radiation was more moderate, the baseline ER value was 0.8 g/m^2h higher during exposure to infrared radiation at a humidity of 57 %. At the lower humidity used, 26 %, there was no difference in ER.

From a theoretical standpoint, the error in ER introduced by the direct influence of radiant energy on the sensors should be small if both pairs of sensors have the same characteristics and are subjected to the same amount of radiant energy. If the probe is held in such a manner that the lower pair of sensors is shaded from the radiant heat source while the upper pair is exposed, a greater error might possibly occur. The results in this study were all obtained with both pairs of sensors either exposed to or protected from the radiant energy.

Thus, this study shows that the radiant energy from a radiant heater does affect the measurements of ER, but only when the energy level or the ambient relative humidity is high. In the normal clinical situation the level of radiation will be fairly low, and in most places the ambient humidity will be low. It is concluded that the Evaporimeter can be used for measurements from infants during treatment under radiant heaters as well as during phototherapy. However, the observed error introduced by the direct influence of the radiant energy on the sensors must be kept in mind if measurements are ever made under the more extreme conditions of a very high radiation level or a high humidity. In these conditions it is of special importance that the sensors give a linear response and are precisely calibrated in the range of vapour pressure under study.

CONCLUSION

It can be concluded from this study that measurements of the evaporation rate with the Evaporimeter

* are not influenced by blue light-radiation (phototherapy)
* are influenced by infrared radiation (radiant heater) at high energy levels and at a high ambient humidity, and
* can be used at low radiant energy levels without the need for correction and at high levels if the error imposed by the effect on the sensors is taken into consideration.

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