30 Neonatal Energy Metabolism

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It is a characteristic of all living individuals that they continuously consume energy and produce heat. Chemical energy is converted into a form of energy that can be used by the individual. Subsequently this energy is used for maintenance of the body: contraction of heart muscle, excretion of products by liver and kidney, and so on. The energy used for these processes is finally given off as heat. Energy can be used for activity and external work. All energy used for activity is given off as heat, and during the process of external work, part of the energy consumed is given off as heat. When the individual is nursed outside the thermoneutral environment (vide infra), energy is used especially for heat production.

In the fetus and neonate energy is needed for growth. This energy can be divided into that present in the components of new tissue: amino acids, fatty acids, single carbohydrates, and the energy needed to store components and to form the more complex molecules of the new tissue (e.g., DNA, lipoproteins). One of the most important laws of thermodynamics is the law of conservation of energy: Energy can be transformed from one form of energy into another form of energy, but energy can never be lost. The energy balance of a fetus or neonate can be written as:

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\text{Energy intake} = \text{energy maintenance} + \text{energy activity} + \text{energy thermoregulation} + \text{energy growth} + \text{energy urine + feces}
\]

Direct Calorimetry

All energy consumed within the body for maintenance, activity, and thermoregulation is finally converted into heat. This energy, the heat production of the body, is equal to the heat loss plus the heat stored within the body. The heat production can be measured by measuring total heat loss plus heat storage within the body. This method is called direct calorimetry and was performed for the first time in 1780 when Lavoisier and Laplace measured the amount of ice melted by a guinea pig.\(^1\) Since that time many direct calorimeters have been built for use mainly for adults.\(^2\)\(^-\)\(^4\) A few studies using direct calorimetry in neonates have been published.\(^5\)\(^-\)\(^8\) Direct calorimeters are complicated to build and because heat loss of the preterm and term neonate is rather low, it is difficult to quantify. The direct calorimeters currently in use measure the heat flux by gradient layers, a series of thermocouples covering the wall of the calorimeter. The heat lost by radiation, convection, and conduction can be measured in this way. The difference in temperature between the air coming into and leaving the incubator must be added. The heat lost by evaporation is measured separately, usually by measuring the difference in humidity of the air entering and leaving the calorimeter. Another problem regarding direct calorimetry is the heat storage within the body, usually calculated by the following formula:\(^9\):

\[
\text{Heat storage} = \text{body weight} \times C_b \frac{0.6 \text{T}\text{int} + 0.4 \text{T}\text{skin}}{t}
\]

\(C_b =\) specific heat of body mass (0.84 kcal·kg·C\(^\circ\))

\(\text{T}\text{int} =\) change in deep body temperature over time

\(\text{T}\text{skin} =\) change in skin temperature over time

\(t =\) duration of study
Calculation of heat storage is only an approximation and should be small compared with heat loss. The neonate should have almost no change in body temperature during an evaluation, and a study should be conducted at least over a 4- to 6-hour period. Measurements of direct calorimetry completed over a period of less than 4–6 hours should be regarded with extreme caution.

An interesting direct calorimeter for adults has been designed by Webb et al. They designed a suit filled with water that covers the body completely. The heat production is calculated from the increase in water temperature, corrected for the change in body temperature. This technique has not been used in the neonate.

### Indirect Calorimetry

Because of the problems related to direct calorimetry, other methods to measure heat production and heat loss have been developed. The most widely used method is indirect calorimetry. This method is based on the assumption that foodstuffs are oxidized in order to produce energy—using oxygen and producing carbon dioxide. By measuring the oxygen consumption and carbon dioxide production, with the nitrogen excretion as a product of protein oxidation, heat production can be calculated. This method has been reviewed extensively.

Indirect calorimetry has been used to calculate the amount of the substrates—glucose and fat—that are oxidized. Lusk published a table in 1924 from which the carbohydrate and fat oxidation could be calculated for a given oxygen consumption and respiratory quotient (RQ) (carbon dioxide production divided by oxygen consumption). These tables were designed for the fasting adult. When glucose is the only source of energy, the RQ is 1 compared with an RQ of 0.70–0.72 when all energy is derived from fat. This method has been used extensively in the fed state. When these tables are used in the fed state, the possible conversion of one substrate into another is ignored, as only the end-products, oxygen consumption, carbon dioxide production, and nitrogen excretion are measured. Energy is stored within the body in the fed state as fat, carbohydrate, and protein. During a high carbohydrate feeding, carbohydrates may be converted into fat for storage, and at the same time fat oxidation can take place. With indirect calorimetry, this process cannot be differentiated from direct carbohydrate oxidation. The results of measurement of substrate utilization based on indirect calorimetry in the fed state have to be regarded with some caution.

The carbohydrate utilization calculated from indirect calorimetry, at an RQ of less than 1, includes carbohydrate oxidation and the possible conversion of carbohydrate into fat when at the same time fat is being oxidized. An RQ of more than 1 indicates that there is net accretion of fat from glucose; expressed differently, the lipogenesis from glucose is higher than any ongoing fat oxidation.

Another potentially complicating factor in the calculation of substrate utilization is the estimation of protein oxidation from urinary nitrogen excretion. Protein consists of various amino acids that have different RQs when oxidized. Usually an RQ of 0.81 is used as mean value for protein oxidation, but this figure is clearly an approximation. Errors in the collection of urinary nitrogen hardly affect the estimation of energy expenditure but can have a significant influence on the calculation of substrate utilization.

Another factor that must be taken into account in relation to the results of indirect calorimetry is the duration of the study. Oxygen consumption can fluctuate considerably with time as well as when all external factors are constant. Various investigators have studied the pattern of oxygen consumption over periods of hours to several days in preterm neonates. It can be concluded from these studies that a reliable estimate of the 24-hour energy expenditure needs continuous measurement over at least 6-hour periods. The variations found between short-term and long-term measurements are probably due to differences in activity and increased metabolic rate after a feeding. In adults the basal metabolic rate, defined as “the lowest observed resting metabolic rate, measured in a healthy adult after a overnight fast of 12 hours at an environmental temperature of 22–27°C,” has been introduced to decrease the variability in the estimate of oxygen consumption. In the neonate it is impossible to use this definition, as it is unrealistic to starve a neonate for 12 hours. In the neonate the term resting metabolic rate has been considered to be the metabolic rate during sleep, or the lowest metabolic rate observed in each neonate. This rate may show quite some variation, depending on the period the oxygen consumption is measured. Not only activity can influence oxygen consumption, but oxygen consumption is different at different sleep states in preterm neonates.

As direct and indirect calorimetry have their limitations and are difficult to use in ventilated neonates, other methods of measuring heat production have been sought. Chessex et al. indicated a correlation between heart rate and oxygen consumption, suggesting that the heart rate might be used to estimate heat production. They showed that oxygen consumption increases when heart rate increases above 160 beats per minute (bpm). No correlation between heart rate