Assessment of energy expenditure

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Medical interest in assessing energy expenditure has varied considerably during this century. The increase in recent years has been largely due to the recognition, by surgeons, of the catabolic state present in many of their patients, particularly those recovering from severe injuries and those with septic complications of accidental or surgical trauma. Examples of the last group are patients with subphrenic or pelvic abscesses, peritonitis, leaking bowel anastomoses, fistulae, etc. The interest of the surgeons is generated by the need to feed these patients in order to prevent disastrous weight loss and to keep them alive while the direct treatment of the lesions takes its effect. The object of the surgeon, therefore, is to determine the patient's energy expenditure and the fuels being used in order to prescribe the level and type of intake.

Although direct calorimetry must be considered the absolute method for measuring energy expenditure even the modern form of gradient layer direct calorimeter (Benzinger & Kitzinger, 1949) is not a very practical technique for use with ill patients. The assessment in ill surgical patients must depend on indirect calorimetry. The apparatus for this is simpler to use, gives more immediate results and can be adapted to give additional information about ventilatory equivalents and respiratory patterns which is needed for the care of these patients. Furthermore, if one wishes to know the fuels being used one has to depend on indirect calorimetry.

The apparatus for indirect calorimetry is designed to collect, measure and analyse the patient's expired air. This is most simply done with a mouthpiece and nose-clip, a system of valves and the well-known Douglas Bag (Douglas & Priestley, 1937). However, the crude valves previously used together with the difficulties in handling the collected gas and its analysis by the Haldane technique were all factors in the decline of interest in indirect calorimetry for clinical purposes. The introduction of better mouthpieces and masks with light-weight valves has been a major advance. Using these the Douglas Bag technique has been shown to give the same results as other methods (Wilmore *et al.* 1977) and should be kept in mind when there is a need to study patients in hospital away from the home institution (Henàne *et al.* 1981). The present tendency is to measure the volume of the expired air and the concentrations of O_2 and CO_2 with on-line apparatus which feeds the data into some form of computer to calculate and print out the results. Examples of commercial instruments of this type are the Beckman Metabolic Measurement Cart, the Siemens–Elema apparatus and the Mijnhardt Oxycon apparatus. These instruments have usually been designed for use in sports physiology, i.e. for exercising subjects with large minute volumes, therefore they may require some adaptation for patients with low tidal volumes. In these instruments CO_2 is measured by an infra-red analyser and O_2 by either a polarographic or paramagnetic technique. While the latter is more stable the polarographic technique has a fast response time suitable for breath-by-breath analysis which makes it possible to determine end-tidal values for pO_2 and pCO_2. These instruments also have the advantage that they are mobile and can be used on patients who are intubated and being ventilated. Such patients are often given O_2-enriched inspired air and this can present difficulties when the O_2 in the air is 40% or more. Our experience in this field is based on the Beckman Metabolic Measurement Cart using the manufacturer's Advanced Bedside Program which we have found to be satisfactory.

In the alternative method the patient's head is placed in some sort of canopy through which air is drawn. The changes in the composition of this air produced by the patient's respiration are measured with on-line instruments. An early version of this type of machine was the Noyons diaferometer (Noyons, 1937) used by Tweedle & Johnston (1971). Since then there has been a number of variants, the best known being the one devised by Kinney and his associates (Kinney *et al.* 1964). The disadvantage of this type of instrument is that most of them are static, the advantage is that the patient can be studied for a much longer period than when masks or mouthpieces are used. The canopy used by Kinney can be modified to give certain ventilatory data and has been used successfully to study the production of $^{14}CO_2$ from ^{14}C-labelled substrates (Long *et al.* 1971, 1979).

Several authors have compared these different methods with each other and with direct calorimetry and shown that with care and proper attention to detail, such as frequent calibration, they will all give closely similar results (Wilmore *et al.* 1977; Dauncey, 1980; Damask *et al.* 1981; Shetty *et al.* 1981).

The rate of energy expenditure is the product of the rate of O_2 consumption and the calorific value of the O_2 consumed. Changes in heat storage will have little effect under most circumstances. The caloric equivalent of O_2 varies with the respiratory quotient (RQ) (respiratory exchange ratio) which reflects the fuels being used by the body. Strictly, one should correct for the effect of protein metabolism and use the non-protein RQ. This depends on knowing the urinary nitrogen excretion during the relevant period and this may not always be possible for short observation periods and under clinical conditions. The error introduced by ignoring it and using the total RQ is usually less than 2% according to Wilmore (1977). It is important to obtain as accurate a value as possible for the RQ. This parameter is affected by inaccuracies in the measurements of the gases and by changes in the patient such as forced breathing. It is necessary to know the rate of urinary nitrogen excretion when using the gas exchange data to calculate the amounts of the different fuels being used by the formulae of Consolazio *et al.* (1963).

Having obtained a value for the patient's energy expenditure the next question is whether it is 'normal' or not. It must first be recognized that what has been measured will usually be a 'resting energy expenditure' rather than a basal metabolic rate. The latter is the minimal energy expenditure of the subject lying down at rest in a thermoneutral environment having fasted for the previous 12 h. Such conditions will rarely be appropriate for critically ill patients and certainly not for those on total parenteral nutrition. It is questionable that one should even aim at basal conditions. How, then, should the value of the resting energy expenditure be expressed? In the normal subject the metabolic rate is usually given in terms of the surface area of the body calculated from measurements of height and weight (see, for example Dubois & Dubois, 1916). This obviously works well for normal healthy subjects but hospital patients can present some problems. When a patient loses weight rapidly does the surface area fall *parri passu*? What is the relevant height of elderly patients with vertebral deformities? What value should be given to the weight in patients with oedema, water retention or gross obesity? To some extent such factors are minimized by the presence of both height and weight in the Dubois formula. Orthopaedic patients with limbs on traction or encased in plaster of Paris also cause problems since it is not often possible to weigh the accident victim before treatment begins and the taring of the bed, etc. for continuous measurements over a long period would be difficult. In practice, where an estimate of the daily energy expenditure is being used simply as a guide to the caloric intake required these matters are not important. However, the existence of these difficulties suggests that we still need a reference base suitable for a wide range of patients, particularly those who are critically ill. The arm muscle circumference is an accessible measurement which has been widely used for nutritional assessment. We are exploring its use for this additional purpose. Krebs (1950) has shown the important contribution of striated muscle to the oxygen consumption of the whole body.

However, until an ideal method has evolved we are still left with the problem of how to compare the behaviour of patients in different clinical states with some standard normal value. At present this is done by comparing the resting energy expenditure of the patient expressed as a function of body-surface area against the values for men or women of the same age in standard tables or against a value for the metabolic rate calculated by the Harris & Benedict equation (Harris & Benedict, 1919). There are a number of standard tables in the literature and, according to Wilmore (1977) the best are due to Fleisch (1951). The values in those tables are lower than in some of the others but should still not be regarded as basal metabolic rates. Fleisch used data from a number of sources and while these values could be described as standard they were not always basal, e.g. those of Vogelius (1945) were obtained shortly after the subjects had arrived at work in the morning having recently eaten breakfast. It is not surprising, therefore, that the values for the resting energy expenditure in our own control subjects only average 90% of the Fleisch values. In patients with pyrexia the values should be corrected to a body temperature of 37° (Wilmore, 1977) before making the comparison.

It had become customary, before widespread measurements of energy expenditure had been made, to speak of patients recovering from multiple injuries, with serious sepsis or large burns as being hypercatabolic. Measurements of energy expenditure have confirmed the underlying truth of this view but at the same time have shown that the prefix hyper- is probably only justified for patients with large burns. In other patients, even those with severe sepsis, the energy expenditure may be above that predicted for them but rarely exceeds 8372 kJ (2000 kcal)/d (Askanazi *et al.* 1980*a,b*; Stoner *et al.* 1981, 1982). This is now becoming generally appreciated.

Finally, how can these measurements of energy expenditure be used for the benefit of the patient. Firstly, they can give a guide to the number of calories which should be provided in the diet, be it enteral or parenteral. It is now thought that amounts of 1·25 to 1·5 times the energy expenditure should be adequate for most patients. Such amounts are certainly easier to give than the large amounts previously advised.

Indirect calorimetry can also help in deciding the form in which the calories should be offered to the patient. From the measurement of gaseous exchange and the urinary nitrogen excretion one can calculate the contributions of the fuels which are being burnt to provide the energy expenditure from the formulae of Consolazio *et al.* (1963). Using this technique one finds that in post-operative patients with sepsis and in patients shortly after serious injuries and for some time afterwards, fat is the preferred fuel for oxidation, even when glucose is present in excess (Askanazi *et al.* 1980*a,b*; Little *et al.* 1981; Stoner *et al.* 1982). In the septic patients an excess of glucose does not inhibit fat oxidation or promote lipogenesis from glucose to give an RQ greater than 1·0. This is only seen when the patient is recovering; before that glucose oxidation is inhibited, the more severe the sepsis the greater the inhibition (Stoner *et al.* 1982). These patients oxidize fat well and fat can form a useful part of the diet for patients on total parenteral nutrition, particularly if there are associated pulmonary problems (Askanazi *et al.* 1980*a,b*; Stoner *et al.* 1981).

These metabolic features of the critically ill patient were revealed because the indirect calorimetry measurements were made at times when an excess of glucose was apparently available to the cells. This raises a final question. When is the best time to assess the patient's energy expenditure? If it is done when the patient is fasting the rate of energy expenditure will be less than when feeding, but, more importantly, all that will be learnt about his metabolism will be that fat is the main fuel. The same would be true for a fasting healthy subject. Much more can be learnt if the measurements are made while the patient is performing some metabolic task. For the patient on total parenteral nutrition the end of a period of a 20% glucose infusion, e.g. after 8–16 h, is a particularly suitable time for indirect calorimetry as the patient has received an excess of glucose which should inhibit fat oxidation. In patients taking food by mouth the measurements could be made before and after an oral glucose load. It has already been suggested that indirect calorimetry measurements may be made after a light breakfast (Durnin & Passmore, 1967; Garrow, 1978) and test meals have been used by some workers (Shetty *et al.* 1981). These suggestions could usefully be formalized so as to provide a test which would yield the maximum information about a patient's energy expenditure and the fuels being used to provide it.

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