A Workshop of the Macronutrient Metabolism Group of the Nutrition Society was held at The Moller Centre, Churchill College, Cambridge on 7 November 1995

Workshop on 'Measurement of energy expenditure'

Report of Macronutrient Metabolism Group Workshop

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INDIRECT CALORIMETRY

Professor Ian Macdonald (Nottingham) described the indirect calorimetry techniques used to measure energy expenditure, the assumptions which underlie them and the potential errors which may be incurred.

Indirect calorimetry can only be used to estimate energy expenditure accurately if the organism is dependent on aerobic metabolism for the release of energy. If the organism's metabolism is aerobic then energy expenditure can be estimated from measurement of respiratory gas exchange and preferably, also, urinary N loss based on the following relationship: fuel and O_2 combine and break down to produce CO_2, water, protein products and energy.

The main complication in using this relationship to estimate energy expenditure is that the amounts of O_2, CO_2 and energy involved are different for the various fuels which can be used. For accuracy, one can determine the actual quantities of different fuels being oxidized or instead use a predictive equation based on the mathematical relationship between O_2 consumption, CO_2 production and the energy equivalents appropriate for the fuels being used. In most situations the fuels being used are carbohydrate, fat and protein; however, if other fuels are also being used (e.g. alcohol) then errors can arise unless the rate of utilization of the other fuel is determined.

Different equations were described to calculate energy expenditure from O_2 and CO_2 concentrations (Weir, 1949; Consolazio *et al.* 1963; Ferrannini, 1988; Simonson & DeFronzo, 1990), but it was emphasized that the latest equations published by Elia & Livesey (1992) use more appropriate values for the energy content and RQ of protein than previous equations and, therefore, are likely to be more accurate. The use of the Haldane (1935) correction which allows for errors involving differences in volumes of inspired and expired air, was strongly recommended.

Indirect calorimetry will only provide a valid measure of energy expenditure if the rates of O_2 uptake and CO_2 output which occur through respiratory gas exchange, are equated to the rates of O_2 consumption and CO_2 production occurring in tissue metabolism. Errors may occur with acid–base disturbances or if the pattern of respiration is disturbed by the apparatus used to collect the expired air, e.g. ventilated hood, face mask, mouthpiece Douglas bag (Askanasi *et al.* 1980).

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Errors can also arise in the use of indirect calorimetry if the rates of gluconeogenesis, lipogenesis and ketogenesis are not equalled by rates of utilization of the products (Elia & Livesey, 1988). For example, producing glucose from amino acid and then oxidizing glucose is not different from simple deamination, and will only produce errors if there is net accumulation of glucose.

In summary, Professor Macdonald emphasized that anyone carrying out indirect-calorimetry energy-expenditure measurements should fully understand the equations being used and should also perform regular calibrations and checks on the accuracy and reproducibility of the measurement of gas exchange.

During the discussions Professor Stock (London) enquired about the composition of Kleiber's (1961) standard protein. Professor Macdonald described it as the composition of the protein which reflects the typical dietary protein composition. The energy equivalent of protein will only be different if people eat protein of markedly different composition, but this is rarely a problem except in cases such as artificial nutritional support with novel substrates. Dr Ruxton (London) questioned the need to know the composition of the diet around the time of the measurement, but it was agreed that this was only necessary if the individual was consuming unusual substrates.

Dr Norgan (Loughborough) enquired about the error caused by anaerobic metabolism. Professor Macdonald explained that the relationship between O_2 consumption and energy expenditure was essentially linear up to V_{O_2max}, but stressed that during a brief period of anaerobic exercise, the lactate produced is not oxidized at the same rate as it is being produced, which will affect the overall result.

Dr Harraldsdottir (Denmark) asked about the practical difficulties in measuring energy expenditure of people at 70–80% V_{O_2max}. Mr Murgatroyd (Cambridge) suggested using a mouthpiece which is ventilated directly to reduce resistance to high flow rates, which can be a major problem at high workloads. Currently, commercial indirect calorimeters have a maximum flow rate of 80 l/min, which is probably too low for exercising subjects.

THE DOUBLY-LABELLED-WATER ($^2H_2{}^{18}O$; DLW) TECHNIQUE FOR MEASURING FREE-LIVING ENERGY EXPENDITURE

Dr Andrew Prentice (Cambridge) outlined the principles of the DLW technique for measuring free-living total energy expenditure (TEE). This non-invasive, non-intrusive method simply requires free-living subjects to collect urine samples for a 7–20 d period, preceded by an oral loading dose of $^2H_2{}^{18}O$. It is safe for use in infants, pre-pregnant and pregnant women (Coward, 1988). It is important to stress that it should be seen as an adjunct and not an alternative to indirect calorimetry. In association with measurement of BMR, by indirect calorimetry, a measure of the energy cost of physical activity (TEE–BMR) can be derived.

The technique was described in detail, in which the HCO_3^- turnover (subjects' CO_2 production rate) can be calculated as the difference between the rate of disappearance of ^2H which labels the body's water pool and of ^{18}O which labels both the water and HCO_3^- pools. Hence, CO_2 production can be converted into energy expenditure using classical indirect calorimetric calculations. The rate of disappearance of the isotope can be measured either in serial urine samples (multi-point method) as described by Coward (1988) or by two single urine samples taken at the beginning and end of the measurement period (two-point method) as described by Schoeller (1988).

Although the DLW method has proved to be accurate, the technique is dependent on a number of assumptions. Under most circumstances, and assuming judicious selection of each assumption, these have a relatively minor effect on accuracy. For example, the proportion of water turnover subjected to isotopic fractionation must be estimated. Dr Prentice discussed the use of the technique in the tropics where the disappearance rates of water are greater (Singh *et al.* 1989); the larger the water turnover the less accurate the results will be. Further assumptions are necessary relating to possible changes in background enrichment levels and subjects' average RQ over the measurement period (International Dietary Energy Consultancy Group, 1990).

Furthermore, it is possible to make detailed estimates of the precision of the measurement. The multi-point method incorporates its own estimate of precision of every individual estimate of TEE, based on the goodness-of-fit of the isotope-disappearance curves (Coward *et al.* 1988). This includes both biological and methodological noise. Estimates of error are usually in the range of 3–7%. Most importantly, the validation studies, mainly against indirect calorimetry, resulted in close agreement (±2–3%) with no significant bias between the methods.

A full description of the technique with details of the method, mass spectrometric analysis, calculations, assumptions and limits of error has been published by a consensus group of experts (International Dietary Energy Consultancy Group, 1990).

The limitations of this technique include its technical complexity, the lack of short-term resolution, and the high capital and running costs. However, these are far outweighed by the advantages; it is an accurate, safe, non-invasive and non-intrusive technique which is resistant to observer effects and is one of the few methods providing a reliable estimate of habitual, free-living energy expenditure.

In the discussion, Professor Stock (London) pointed out that an additional benefit to the DLW method is that it gives a measure of body water which can be used in the determination of body composition. A number of practical issues also arose. The measurement time was shown to vary depending on the water turnover of the subject. Ideally, the measurement should take place over one to two biological half lives of the isotope. For example, it will be longer in the elderly and shorter in the tropics. Dr Henry (Oxford) asked about the consequences of dehydration. In the short term this is not a problem as long as subjects are in a similar state of hydration at the beginning and end of the measurement period. Interim fluctuations will increase the precision error but should not harm the absolute accuracy of the results. Further discussion took place between Dr Elia (Cambridge) and Dr Prentice about the accuracy of the assumptions in the method; for example, whether it is reasonable to assume an RQ of 0·85. For most Western diets this is the best approximation, although modification may be needed in subjects consuming ethnic diets, or deriving a large percentage of their energy from alcohol.

Finally Dr Harroldsdottir (Denmark) asked whether there was any significant difference between measurements of energy expenditure in lean *v.* obese subjects. Dr Prentice commented that a small study by Harper *et al.* (1991) suggested DLW may underestimate TEE in obese subjects by about 3–4%, but in the context of the validation of dietary records this would only serve to increase the extent of apparent under-reporting.

THE BICARBONATE–UREA METHOD FOR MEASURING ENERGY EXPENDITURE

Dr Marinos Elia (Cambridge) spoke of the novel HCO_3^-–urea method for measuring energy expenditure (Elia, 1991). This method depends on the principles of isotopic dilution. Infused labelled CO_2 is diluted with CO_2 produced in the tissues of the body, i.e. when CO_2 production is high, isotopic dilution is high, and when CO_2 production is low, isotopic dilution is low.

In theory, the integrated mean specific activity, i.e. the isotopic dilution of CO_2, can be estimated by making measurements of urinary urea, into which CO_2 is incorporated in the liver. However, two corrections must be taken into consideration: (a) percentage recovery of the label (consistently 95%) and (b) a factor (0·85) taking into account additional isotopic dilution due to splanchnic CO_2 production and formation of urea from unlabelled arginine (estimated to be about 0·85).

In practice, $H^{14}CO_3^-$ is given as a continuous subcutaneous infusion using a portable minipump. After an initial equilibration period of approximately 12 h, urine is collected over 24 h periods. The specific activity of urinary urea can then be measured. First, CO_2 in urine is removed by acidification or vacuum extraction, urease is then added to form CO_2 from urea. This CO_2 liberated is then trapped in a known amount of hyamine. The labelled CO_2 is then quantified using a radioactive scintillation counter. As in the DLW method, energy expenditure is calculated using an appropriate value for the energy equivalent of CO_2.

Dr Elia presented data from indirect whole-body calorimetry studies that were performed in order to validate this tracer method over a period of 1–4 d. The results are extremely promising (Elia *et al.* 1995). Further validation studies involving a small number of patients suffering from malignancy are in progress, and the preliminary results are as encouraging as those obtained in normal subjects.

Dr Elia described the method as an alternative to DLW in measuring free-living energy expenditure. It is not only unobtrusive but also inexpensive. The technique is simple, does not require sophisticated equipment and can yield results rapidly. It can also measure CO_2 production over periods as short as 1 d.

During the discussions, Chairman Professor Stock (London) asked about the specific requirements for urine collection. Dr Elia described the methodology used in the studies previously mentioned, in which a plasma sample (to measure urea concentration) and a 2 h urine sample (to measure urea specific activity) are collected at the beginning and end of the study to correct for changes in the size and specific activity of the urea pool. Corrections are usually <1–2% in normal individuals, but may be very significant in individuals with renal failure.

Dr Webber (Birmingham) queried whether the method could be modified to use ^{13}C. Dr Elia believes that in theory this would be possible, but that to infuse sufficient quantities subcutaneously would not only increase the cost but also increase the osmolarity and the volume that has to be infused by the minipump. Dr Elia suggested the possibility of using ^{13}C in oral tablet osmotic minipumps.

Mr Murgatroyd (Cambridge) questioned the theoretical and practical limits to the shortness of measurements which could be made. Dr Elia described an increase in imprecision due to diurnal changes in size and specific activity of the HCO_3^- and urea pools. In short periods it is possible to get different results due to loss or accumulation of label in the body pools. In previous studies, measurements started and finished at the same time of day, when size and specific activity of urea and HCO_3^- pools are relatively constant. Dr Elia suggested it should be possible to derive a theoretical model that takes these effects into account, but currently measurements are made over 24 h or more.

HEART-RATE (HR) MONITORING: PRINCIPLES, USES AND LIMITATIONS IN MEASURING ENERGY EXPENDITURE

Dr Barbara Livingstone (University of Ulster) described the technique of using HR monitoring in the measurement of energy expenditure. The method is based on the principle that HR increases with physical activity and that this increase is associated with a proportional linear rise in O_2 consumption (V_{O_2}). Thus, measurements of HR allow the estimation of O_2 consumption and, hence, TEE using standard indirect calorimetric equations.

In the medium-to-long term, the variation in the relationship between TEE and HR may be affected by physiological factors such as changes in body weight or body composition, state of fitness, illness or ageing. In the short term, a major shortcoming is the poor correlation between HR and V_{O_2} at low levels of energy expenditure when factors such as shifts in body position, ambient temperature and humidity, emotional state, prandial status and smoking can modify HR with no discernible influence on V_{O_2}. Consequently, over the entire range of energy expenditure, the relationship between HR and V_{O_2} has two components. The first is curvilinear and applies to sedentary activities such as lying, sitting and standing at rest. The second, linear component, relates to submaximal muscular work during which the factors that influence the HR at rest do not affect the HR:V_{O_2} relationship. It is in the range where resting and exercise HR converge and overlap that the prediction of TEE is most uncertain. This is where the HR of most people engaged in light activity is encountered.

In practice, the technique involves three distinct components; first the HR:V_{O_2} regression equation for each individual must be derived. This is obtained by measuring energy expenditure whilst simultaneously monitoring HR under standardized conditions, during selected activities at various levels of intensity of activity.

Second, the continuous recording of HR under free-living conditions is measured using a HR monitor such as the Sport Tester. This consists of a small lightweight transmitter attached to the chest which transmits HR to a micro-computer receiver in the form of a wrist-watch. The latest version of the equipment has a 34 h memory capacity and data can be retrieved by an IBM or Apple Mac compatible interface. The disadvantage of the equipment is that no more than one transmitter at any time should be inside the range of the receiver, and electromagnetic interference may also affect its operation. The final stage is the calculation of TEE from HR.

Older studies which used a mean HR to determine TEE have justly been criticized for the lack of accuracy because mean HR over an entire day is not discernibly related to energy expenditure, as described by Christensen (1983). Minute-by-minute profiles of HR now negate the need to rely on HR as an index of energy expenditure below a pre-determined critical FLEX HR (mean of highest HR for resting (supine, sitting, standing) and the lowest HR for exercise activities). This individually pre-determined HR is used to discriminate between resting and active states, and values for resting energy expenditure (REE) are substituted for periods of the daytime when HR falls below the FLEX HR. Energy expenditure (activity energy expenditure; AEE) above FLEX HR is determined by application of the regression equation for individually calibrated subjects. Finally sleeping energy expenditure (SEE) is assumed to be equal to BMR. TEE is thus: SEE+REE+AEE.

The estimation of TEE by the FLEX HR method has been validated against whole-body calorimetry (Spurr *et al.* 1988; Ceesay *et al.* 1989) and under free-living conditions using DLW as the reference method (Livingstone *et al.* 1990, 1992; Lovelady *et al.* 1993). The validity and precision of the FLEX HR method depends primarily on the accuracy of the measurements of BMR and TEE, the definition of a reproducible FLEX HR and the representative nature of the derived HR:V_{O_2} regression equation. While the group averages in HR-derived TEE were not significantly different from the reference methods, individual estimates still lacked precision. The range of errors for individual subjects was most pronounced when HR-derived TEE was measured under free-living conditions. Clearly the method is not suitable for application in a single measurement of TEE in individuals. However, the validity increases for even small groups of people (n >10).

In conclusion, the limitations of the method were discussed and it was agreed that the individual calibration and potential recalibration of HR:V_{O_2} relationship for each subject over a range of activities is time-consuming. But this method requires no direct supervision and is a socially acceptable, non-intrusive technique to assess patterns of physical activity as well as calculating TEE.

In the discussion Dr Campbell (Manchester) expressed some concern that the calibration procedure using a treadmill did not involve arm movements, but Dr Prentice (Cambridge) commented that it was important to use activities representative of everyday movements during the calibration; for example, repeatedly moving a brick from A to B to simulate the sowing and weeding activities of women in The Gambia. Dr Cruickshank (Manchester) suggested looking into the possibilities of generic calibrations, particularly to derive group estimates of activity. Dr Jebb (Cambridge) questioned the measurement time necessary for a valid estimate of habitual activity. This depends on the CV which may be subject dependent.

There was some interest in the use of HR monitoring to determine patterns of physical activity. Dr Livingstone said that in such studies it was helpful also to have an activity diary to define the type and intensity of activity associated with a particular HR. However, this will of course reduce the non-invasiveness of the method. Professor Macdonald (Nottingham) queried whether the variation between individuals can be explained by various physical activity levels and questioned whether agreement is better in those with a higher physical activity level. Theoretically, this would be so, in practice, but no practical evidence exists as yet.

OBSERVATIONAL-, DIARY- AND PEDOMETER-BASED METHODS OF MEASURING ENERGY EXPENDITURE

Dr Nick Norgan (Loughborough) described the observational-diary-based and pedometer-based methods for estimation of energy expenditure. Attempts to determine energy expenditure by such simple techniques without actually measuring it are usually based on descriptions, reports of activity or the observation and measurement of the duration of activity.

At the simplest level probability statements can be made. For example, most UK adults are inactive city dwellers whose energy expenditure is 1·5 × BMR. If more details of

https://doi.org/10.1079/PNS19960068 Published online by Cambridge University Press

leisure-time activities are obtained the estimate can be refined further. Such information can be obtained retrospectively by self-report or by using activity questionnaires or interviews (Backe *et al.* 1982; Cox, 1987; Allied Dunbar National Fitness Survey, 1994). Such techniques are often used to determine health relative to fitness rather than for calculating TEE.

With observation and measurement, a recording of time allocation to each activity is made by an observer or the subjects themselves, thus a more accurate account is obtained. In the discussion Dr Webber (Birmingham) queried the accuracy of this technique as it tends to be subjective, and people classify work differently. Dr Norgan agreed that observer bias can occur and that giving full descriptions can eliminate such bias. He went on to suggest the technique is better able to measure intra-individual variation rather than inter-individual variations.

Expenditure can also be measured by objectively quantifying motion using such instruments as pedometers. Unfortunately, such motion sensors usually only work in one plane and, thus, seem to under-report energy expenditure. Such techniques are good at separating rest from walking and other such activities, but offer a poor estimate of actual energy expenditure (Avons *et al.* 1989; Robinson *et al.* 1995).

Finally, Dr Norgan discussed the estimation of energy intake as an indicator of energy expenditure, although he expressed concerns about the validity of this approach due to errors in intake measurement.

During the discussion Dr Henry (Oxford) pointed out that Ravussin (1986) had suggested activities such as fidgeting are important factors in energy expenditure of some individuals, and questioned how such activities would be measured in these ways. Dr Norgan agreed it was probably important but very difficult to measure effectively.

Dr Campbell (Manchester) queried the positioning of the motion sensor and to what extent this would affect the results. Dr Norgan pointed out that positioning is extremely important. He highlighted that such places like the wrist would be extremely bad as driving would be measured at high activity because of movement of wrist.

Dr Wareham (Cambridge) questioned whether a combination of methods would yield a more accurate measurement since the errors of each technique are likely to be uncorrelated.

CLINICAL APPLICATIONS OF MEASURING ENERGY EXPENDITURE

Dr Ian Campbell (Manchester) outlined the need to measure energy expenditure in the clinical situation in order to determine the required energy intake during periods of artificial nutritional support. He discussed the problems resulting from a nutritional overload and also those caused by undernutrition.

The DLW technique seems the obvious way to measure energy expenditure, but this expensive method simply takes too long to yield a result (10–14 d) and is impractical in the clinical setting. The $H^{13}CO_3^-$ method only gives an instantaneous 'snapshot' of what is actually happening in energy expenditure terms and the mean recovery of ^{13}C over short periods can be as low as 60%.

The reverse Fick/cardiac output method can be used if the patient has a pulmonary artery catheter in place. This calculates V_{O_2} from cardiac output measured by thermodilution and mixed venous and arterial O_2 content. However, this method only provides an instantaneous snapshot measurement, is relatively unstable and consistently gives lower readings than V_{O_2} by gaseous exchange.

Indirect calorimetry is, therefore, the most usual method to measure energy expenditure. Dr Campbell provided a history of indirect calorimetry at the bedside from the Beckman Metabolic Cart to the present day. An absorption technique such as the Benedict Roth Spirometer (McLean & Tobin, 1987) is the simplest way of measuring O_2 consumption, but in spontaneously breathing patients this entails using a mouthpiece and nose clip and the system has to be driven by the patient. However, sick patients do not tolerate mouthpieces, and the use of a face mask presents problems in ensuring an airtight seal. Systems which draw air past the patient's face (ventilated hood) are more acceptable, the Beckman Horizon was such a system introduced in the mid 1980s, but was expensive and complicated to use (Takala *et al.* 1989; Regan *et al.* 1990).

Indirect calorimetry performed on ventilated patients allows true 24 h energy expenditure to be measured. The problems are that such patients require high concentrations of inspired O_2 and if the Haldane (1935) transformation is to be used, it ceases to work at a fraction of O_2 in expired air of 0·6–0·7. Apparatus that allows 24 h energy expenditure to be measured continuously on ventilated patients are the Engstrom Metabolic Computer (Regan *et al.* 1990), the Engstrom Elvira Ventilator (Engstrom, Gambro, Brummer, Sweden) and the recently introduced Puritan-Bennett Metabolic Monitor (Weissman *et al.* 1994).

The Datex Deltatrac Metabolic Monitor seems to be the definitive machine in clinical use today, although the Europa Scientific 'Gem' is becoming increasingly common. This method uses a differential O_2 analyser and can be used with any ventilator. It is reasonably mobile and non-invasive, but can take up precious space at the bedside (Weissman *et al.* 1994; Vohra *et al.* 1995).

In the presence of an ongoing inflammatory process, positive energy balance does not lead to maintenance of lean body mass which tends to decline in proportion to the magnitude of the inflammatory stimulus. The ability to change energy expenditure in response to treatment and/or resuscitation indicates an increased chance of a favourable outcome.

During the discussion Dr Jebb (Cambridge) raised the problem of extrapolating from measurements of REE by indirect calorimetry to TEE. However, it was considered that in many hospitalized patients levels of physical activity are very low indeed and REE accounts for the bulk of the energy requirements. At a practical level, Dr Elia (Cambridge) asked how to check for any leaks in the calorimetry system when used in ventilator mode. A number of suggestions were made, the most practical of which was to look for breath vapour on a strategically positioned mirror.

EQUATIONS TO PREDICT BMR: A NEED FOR RE-APPRAISAL

Dr Jeya Henry (Oxford) critically reviewed the various equations used to predict BMR. BMR is commonly used as a basis for predicting energy requirements. Conventionally, BMR is measured using direct or indirect calorimetry. Although ideally BMR should be measured, in practice the use of predictive equations is common.

A wide variety of equations have been proposed (e.g. Dubois & Dubois, 1916; Harris & Benedict, 1919). Most recently, Schofield *et al.* (1985) reviewed the available literature and presented predictive equations for both sexes in various age-groups. Their analysis forms the basis of the equations used in the Food and Agriculture Organization/World Health Organization/United Nations University (1985) report on energy and protein requirements.

However, Dr Henry questioned the validity of the Schofield *et al.* (1985) equations, suggesting that they tended to more accurately predict BMR of individuals living in temperate climates and are less accurate for other groups, such as tropical populations (Henry & Rees, 1988, 1991; Piers & Shetty, 1993) or North Americans (Clark & Hoffer, 1991).

Dr Henry then proceeded to present preliminary data (the Oxford Database) currently being reviewed by his group. He explained the addition of over 3000 individuals to the database, especially children, and the removal of a similar number from the Schofield *et al.* (1985) equations pertaining to Italian military recruits. The Oxford Database will be the largest BMR database available, and due to its ethnic diversity it will be universally applicable. So far, the equations from this database have been significantly different from the Schofield *et al.* (1985) equations (3–20% difference), decreases are seen in the 18–30 years and 31–60 years age-groups. Dr Henry also described modifications to the age-groups in the Oxford Database. Unlike Schofield *et al.* (1985), the Oxford Database has split the ages into different physiological limits (years; 0–1 , 2–5, 6–10, 11–15, 16–20, 21–40, 41–60 etc.), although these limits need further validation.

In the disscussion, Dr Cruickshank (Manchester) questioned the representivity of the sample used in the Oxford Database. Dr Henry agreed that appropriate representation is, and always will be, a problem, but investigators had a responsibility to be aware of this in any interpretation of the data. Dr Norgan (Loughborough) expressed concern about the 'editing' process, but was reassured that the exclusion criteria extend only to those who did not give a full description of the conditions of the BMR measurement or if weight or height was not correctly stated. Professor Macdonald (Nottingham) emphasized the importance of this work, particularly if the apparent reduction in predicted BMR relative to Schofield *et al.* (1985) is confirmed, since this will have huge implications for food policy and provision. Professor Stock (London) queried whether it might be more appropriate to express BMR in relation to fat-free mass (FFM) rather than weight, since interpretation may be confused by secular changes in body composition. Unfortunately measuring FFM creates even further problems.

Miss Black (Cambridge) expressed concern about the use of the phrase 'BMR' when often the conditions under which the measurement was performed were not correctly standardized. Dr Elia (Cambridge) commented that the situation is likely to be even worse in clinical practice than in healthy volunteers, since many patients were measured whilst receiving feeds, so the measurement also incorporates the effects of diet-induced thermogenesis.

CLOSING DISCUSSION

The Chairman, Professor Stock (London) began the final discussion by reminding the audience that in animal studies energy expenditure can be calculated from energy balance as the difference between metabolizable energy intake and carcass analysis. Dr Jebb (Cambridge) cautioned that a similar approach in human subjects is limited by the imprecision of *in vivo* measurements of changes in body composition. Professor Macdonald (Nottingham) added that in man, metabolizable energy intake is also more difficult to assess than in animals. However, this approach has been used in critically ill patients by Dr Hill's group in New Zealand.

There was an important discussion about the accurate calibration of indirect calorimetry systems. Mr Murgatroyd (Cambridge) warned of the potential errors when using alcohol burns because of incomplete combustion and encouraged the use of a N_2 and CO_2 infusion. These comments were widely supported. Those embarking on the energy-expenditure measurements described at the workshop were encouraged to seek the advice and support of others experienced in the techniques.

Additional further reading includes some general reviews (Acheson *et al.* 1980; Murgatroyd *et al.* 1993; Norgan, 1996).

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Printed in Great Britain