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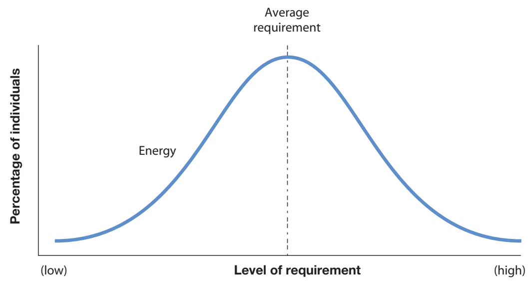
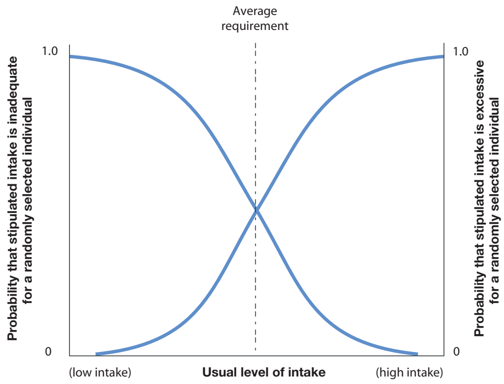
1

Human energy requirements

Report of a Joint FAO/WHO/UNU Expert Consultation

Rome, 17–24 October 2001





FOREWORD

Assessing the calorie and nutrient requirements of human beings, with the greatest possible degree of accuracy, is one of the most important and central mandates of the Food and Agriculture Organization of the United Nations (FAO). Since 1948, FAO has convened numerous expert groups in the field of nutrition to collate, evaluate and interpret current scientific knowledge in order to derive estimates of human energy requirements and use these estimates to provide recommendations to people and policy-makers. The World Health Organization (WHO) began its collaboration with FAO on this important work in the early 1950s, while the United Nations University (UNU) joined the initiative in 1981.

This important publication is the final report of the most recent expert group meeting, the Joint FAO/WHO/UNU Expert Consultation on Human Energy Requirements, convened in October 2001 at FAO headquarters in Rome, Italy. The primary purpose of the expert meetings on nutrient requirements has remained the same throughout the years: to give advice on scientific issues related to food energy and nutrient requirements and to formulate recommendations for action. Various expert groups have contributed principles for determining and applying general requirements, which have been adopted worldwide.

The global scientific community has continued to embrace the advice on requirements that was first published by FAO alone and later in collaboration with WHO. The FAO/WHO recommendations have reflected the state of knowledge at particular points in time, and have also influenced research agendas and methodologies over the years. In fact, the FAO/WHO recommendations are currently utilized in virtually all countries, and nutrient requirement reports are among the most frequently referenced and most sought-after publications in both organizations.

Estimates of human energy requirements are essential for assessing whether food supplies are adequate to meet a population’s nutritional needs. Such estimates are also essential in assessing the proportion and absolute number of undernourished people worldwide. The recommendations derived from these estimates assist governments to monitor nutrition programmes and plan development activities. The recommendations also help with the specific formulation of planning at the national level for agricultural production, food supplies and the mobilization and distribution of emergency food aid. FAO has an ongoing mandate to review these assessments periodically – particularly as new research findings emerge – and to produce estimates using the highest possible degree of accuracy based on recent scientific advances and developments in the field.

FAO publishes this report on behalf of the three United Nations (UN) agencies (FAO/WHO/UNU) that organized the consultation. We would like to express our gratitude to the members of the expert consultation for their contribution to this important report, as well as to the numerous participants of the working groups. The work of these groups preceded the expert consultation and served as the foundation for discussions and exchange during the meeting. Thanks are also due to Dr E. Kennedy, who very skilfully chaired the expert consultation, and to Dr B. Torun for his commitment to the role of rapporteur and for his contribution to early drafts of this report.

We thank all the participants, as well as the non-participating experts who drafted background papers as part of the preparatory process for the expert consultation. These background papers will be published in a special issue of *Public Health Nutrition* in 2005, thereby providing a more detailed peer-reviewed literature source for many of the ongoing debates on the various topics discussed during the consultation. We would also like to express our special gratitude to the FAO staff members who constituted the Secretariat and completed much of the follow-up work that culminated in this report, in particular the staff of the Nutrition Planning and Evaluation Service (ESNA), P. Shetty, R. Weisell, and B. Burlingame, as well as G. Kennedy, F. Martinez Nocito, T. Ballard and J. Shaw who assisted as consultants both during and after the expert consultation.

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PREFACE

The purpose of the expert consultations on human energy requirements convened by FAO, WHO and, more recently, UNU is to advise the Directors-General on scientific issues related to food energy, including requirements, so that appropriate recommendations for action can be formulated. It is hence important that during the process of determining energy requirements the question of "requirements for what?" be constantly borne in mind. While biological scientists are generally concerned with the physiological basis of estimating requirements, it is also necessary to be aware of the practical applications of these recommendations for estimating the energy requirements and food needs of populations worldwide.

The principal objective of expert consultations on human energy requirements is to provide international agencies and their member countries with the necessary tools for addressing practical questions, such as assessing the adequacy of food supplies and the numbers of people who do not attain energy adequacy, drawing up targets for food production and informing national food and nutrition policy and planning. The recommendations and guidelines that result from these consultations will serve to enable governments and organizations to plan, monitor and evaluate nutrition programmes and policies better. They will also help Member Nations to develop estimates of requirements appropriate for local conditions and for direct application in their countries. It is important to remember that while developed countries are able to constitute their own committees of experts who can make recommendations on energy and nutrient requirements for their populations, the majority of humanity in the developing world relies largely on UN agencies such as FAO. Hence, the development of pragmatic recommendations by expert committees convened by UN agencies, which are based on sound scientific evidence and have practical relevance to the conditions prevailing in the developing world, is paramount.

The entire process leading up to the convening of an expert group and the resulting consultation is highly formalized and follows a number of required protocols. For the first time, FAO adopted a two-stage process, which started with convening working groups in those areas where it believed that new scientific knowledge existed that might influence the current recommendations for energy needs. The second stage of the process was the expert consultation itself. The rationale behind convening the working groups was that many of the scientific questions could be dealt with by experts in the areas concerned, even though the participation of those experts at the consultation *per se* was uncertain owing to the need to provide a globally representative consultative panel. Working groups would also facilitate discussions, as any contentious issues could be debated and settled before the expert meeting, which would benefit from the results of such discussions. Accordingly, working groups met from 27 June to 5 July 2001 at FAO headquarters in Rome, several months before the expert meeting in October 2001. Three of the working groups focused primarily on energy requirements throughout the life cycle and related to two important sub-populations – infants and children, and pregnant and lactating women – for which substantial scientific advances had been made. These working groups were on: 1) energy (and protein) requirements of infants and preschool children; 2) energy (and protein) requirements of pregnancy and lactation; and 3) analytical issues in food energy and composition: energy in food labelling, including regulatory and trade issues, which looked at food energy values. An additional working group was constituted to provide documentation on methodologies for energy balance and energy requirements, but it was felt that – given the nature of the task – there was no need for this group to meet, although their background documents were available to the expert consultation. The chairpersons of all the working groups on energy were invited to the expert consultation to present a summary of the deliberations and recommendations of their groups and to advise the experts. Background papers were commissioned, peer-reviewed and made available to both the pre-consultation working groups and the experts who met for the consultation. The entire process of pre-consultation activities and the consultation itself went smoothly, despite a few hitches that were largely the result of the unhappy events of 11 September 2001, which prevented some of the invited experts from coming to Rome to join the consultative process. Lists of the participants in the various working group sessions, and those invited as experts to the consultation are included as Annex 1 of this report. Annex 2 provides details of the authors and reviewers of the background documents, which are expected to be published shortly as a supplement to the journal *Public Health Nutrition*. The wide availability of this publication as a peer-reviewed journal supplement is expected to provide the academic community with an opportunity to examine the collated evidence base that informed the expert panel and influenced their latest recommendations.

As part of the second stage of the process, the members of the expert consultation met in FAO headquarters in Rome from 17 to 21 October 2001. The meeting was chaired by Dr E. Kennedy, with Dr B. Torun serving as rapporteur. The following are the specific tasks outlined in the charge given to this expert consultation on human energy requirements:

1. To review the background documents on the state of the art of the scientific literature in this area of work, assembling the best evidence on the topic and using, where appropriate, the summary, advice and recommendations arising from the deliberations of the working groups that had met earlier in the year.
2. To deliberate on and arrive at recommendations for energy requirements throughout the life cycle, while clearly outlining the approaches used to estimate requirements that may be of benefit to users. This included taking into account physiological states such as growth, pregnancy and lactation and, where relevant, pathological conditions and the additional needs during infections. The recommendations were expected to be reached by consensus, and where differences persisted the reasons for those differences were to be clearly outlined, with all sides presented and appropriately reflected in the report of the expert consultation.
3. To examine the feasibility of arriving at minimum requirements that may be of use in estimating the numbers of individuals in populations who are unable to meet energy adequacy.
4. To comment on the consequences of deficit and excess of energy, and to recommend ways by which the health, social and economic consequences of these can be minimized or avoided.
5. To highlight the main changes to the recommendations of the 1985 report, with particular emphasis on those aspects of the new recommendations that have a significant impact on the way in which nutritional adequacy of population groups is assessed by those involved in policy, planning or analysis of the nutritional status of populations.
6. To suggest areas where further research is needed, either to deal with gaps in the knowledge related to energy requirements in specific groups or situations, or to facilitate the collection of normative data that will aid the process of arriving at future recommendations for energy requirements.

It was the sincere desire of the FAO Secretariat to ensure that the report of the expert consultation on human energy requirements be available within the shortest possible period after the experts met in Rome. The two-year gap before the interim report was available as a downloadable file on the FAO Web site, and a further period before it was available in hard copy were due to a series of post-consultation activities that were deemed essential before the release of the final report. Many of these post-consultation activities were in response to, and out of respect for, the experts who recommended a number of important pieces of work to be followed-up and completed for inclusion in the report.

An important recommendation of the expert group was to update and review the predictive equations for estimating basal metabolic rate (BMR) and to incorporate the updated equations into the new recommendations. These activities proved to be time-consuming, as they involved updating the global database on BMRs that was originally obtained for the 1985 report, reanalysing it with particular emphasis on looking at the influence of methodological biases and ethnic variations, and developing new BMR predictive equations with better predictive performance for international use (Annex 3). The reanalysis was followed by an exercise to test the validity of the new equations, and a further consultation with a sub-group of the expert panel for their final decision. However, after this long exercise the experts concluded that the international equations hitherto used continued to have enhanced precision and robustness. Following reanalysis of the global database, the recommendation to use a seamless single predictive BMR equation was not considered practical, and hence the expert consultation was not persuaded to replace the international equations provided in the 1985 report. These predictive equations have been widely used and are popular with the scientific community and nutritional planners, and the present report's recommendation is to continue using them.

One of the other recommendations that arose from the deliberations of the working group on analytical issues in food energy and composition, which was subsequently endorsed by the experts, was to convene a meeting to deliberate on food energy values. The objective was to ensure harmony between the expected adoption of new energy requirement values from this consultation, which are based solely on energy expenditure measurements or estimates, and energy requirements based on food intake measurements alone. FAO thus convened a Technical Workshop on Food Energy – Methods of Analysis and Conversion Factors, which was held in Rome from 3 to 6 December 2002. The report of this workshop was published as FAO Food and Nutrition Paper No. 77 in 2003, which complements the present report.

As part of the post-consultation activities in preparation for the release of the expert report, it was decided to produce an updated, Windows-compatible and user-friendly software application for the purpose of calculating population energy requirements and food needs. After the 1981 joint expert consultation report was released (WHO, 1985), FAO sponsored the development of a manual and software package (James and Schofield, 1990), recognizing that less attention had hitherto been paid to the matter of how to apply the requirements to practical food and nutrition planning. The success of this 1990 user's manual, which was sponsored by FAO and published by Oxford University Press, was constrained because it was a priced publication that was available separately from the 1985 joint expert report. For the 2001 consultation, it was decided to make the new software widely and readily available by releasing it alongside the report. FAO therefore had to find an organization that would assist us in developing such a product to be released at the same time as the expert report in 2004. Early discussions were conducted with the United States Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia, with the objective of developing the software and making it available as a downloadable version alongside CDC's popular EpiNut software. However, CDC was unable to collaborate in this venture, so other partners had to be sought. The Division of Nutrition, Institute of Population Health and Clinical Research at Bangalore, India and its Dean, Dr A. Kurpad, identified Jenesys Technologies, a software applications firm in India, which collaborated alongside the institute in the development of the software package and accompanying manual (Annex 4). This is now available on CD-ROM. For the first time, the software package is being issued together with the expert report in order to ensure that those interested in the report's recommendations have the means to investigate and ensure their practical applicability, as well as to benefit from the two outputs' complementarity. The user's manual and software application for calculating population energy requirements and food needs thus represent a further milestone in FAO's continued involvement in both the theoretical and the practical issues related to human energy requirements.

This expert consultation was convened nearly two decades after the last expert group met to deliberate on energy and protein requirements in 1981. In the interim, the International Dietary Energy Consultancy Group (IDECG), sponsored jointly by UNU and the International Union of Nutritional Sciences (IUNS), filled the lacuna by convening meetings to discuss important developments in this area. The IDECG meeting in London in 1994 on Energy and Protein Requirements (whose proceedings were published in *European Journal of Clinical Nutrition* Vol. 50, Supplement 1 in February 1996) was a seminal meeting that provided much of the preparatory background for this expert consultation. We would like to acknowledge and pay our tribute to the late, Dr Beat Schurch who, as Executive Secretary of IDECG, was the quiet engine behind this invaluable contribution to the advancement and dissemination of nutrition knowledge. FAO and WHO benefited greatly from IDECG's work and publications, in particular its review of human energy and protein requirements in 1994. While FAO was organizing the 2001 expert consultation, Beat Schurch knew that he was sick but planned to attend both the consultation and the working groups that preceded it. Unfortunately, his illness progressed more quickly than had been anticipated, and he had to decline the invitation. He approached his illness and its culmination with the same equanimity with which he approached most matters and wished the group well. His contribution and friendship will be sorely missed.

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1. INTRODUCTION

Since 1949, the Food and Agriculture Organization of the United Nations (FAO) and, since the early 1950s, the World Health Organization (WHO) have convened groups of experts to evaluate current scientific knowledge in order to define the energy requirements of humans and propose dietary energy recommendations for populations. The purpose of this information is to assist FAO and WHO in implementing their programmes. The United Nations University (UNU) became part of this joint initiative in 1981. The reports of these expert meetings (see the list of References at the end of this chapter) have become important guidelines on energy in human nutrition for academic scientists, nutritionists, physicians and other health workers, as well as for planners and policy-makers in both the agriculture and health sectors throughout the world.

New scientific knowledge generated in the 20 years since the last expert consultation was held prompted FAO, WHO and UNU to assemble a new expert consultation to make recommendations for energy requirements of populations throughout the life cycle (WHO, 1985). This consultation took place from 17 to 24 October 2001 at FAO headquarters in Rome. Its mandate was to revise and update the conclusions and recommendations of the preceding consultation, which was convened in 1981 and whose report was published in 1985. In preparation for the forthcoming expert consultation, well-known scientists with demonstrated expertise in this area of work were asked to examine and write background papers on various topics that required revision and updating. Several of the authors and other leading scientists constituted working groups that met in Rome in June 2001 to discuss and analyse critically the contents of the background papers, which were subsequently modified following the working group suggestions. The modified papers, the working groups' conclusions and other relevant documents were provided to all members of the expert consultation for analysis and consideration in their deliberations.[1]

Dr Eileen Kennedy was elected to chair this expert consultation, and Dr Benjamin Torun to be the rapporteur. Several conclusions and recommendations were the immediate results, while a number of topics were identified as requiring further research and analysis before the experts could finalize their recommendations. The rapporteur and other members of the consultation were given the task of pursuing the pending issues with assistance from the FAO Secretariat, and additional working papers were commissioned. This laborious task went on until the end of 2003, when almost all questions had been answered and gaps filled and the rapporteur was able to prepare the final draft for examination and approval by the other experts from the consultation. This report is the final result of those efforts.

1.1 WHAT IS NEW IN THIS REPORT?

Although the basic principles set forth in previous expert meetings have withstood the test of time, several modifications are proposed in this report. Members of the expert consultation and participants in the working groups recognize and accept the responsibility for proposing these modifications, and for the implications that they will have on health, agriculture, the food industry, economic planning, international aid and social programmes related to food and nutrition. It is their belief that the conclusions and recommendations in this report are well grounded, given the current state of the best scientific knowledge. A critical appraisal of their application will be the final proof of their accuracy, applicability and appropriateness.

The new concepts and recommendations set forth in this report include:

- calculation of energy requirements for all ages, based on measurements and estimates of total daily energy expenditure and on energy needs for growth, pregnancy and lactation;
- in the light of new data, modification of the requirements and dietary energy recommendations for infants and for older children and adolescents, in order to correct previous overestimations for the former and underestimations for the latter;

[1] Annex 1 gives the names of participants in the working groups and expert consultation. Annex 2 lists the titles and authors of the background documents.

- proposals for differentiating the requirements for populations with lifestyles that involve different levels of habitual physical activity, starting as early as six years of age;
- reassessment of energy requirements for adults, based on energy expenditure estimates expressed as multiples of basal metabolic rates;
- classification of physical activity levels based on the degree of habitual activity that is consistent with long-term good health and maintenance of a healthy body weight;
- recommendations for physical activity for children and adults to maintain fitness and health and to reduce the risk of developing obesity and co-morbid diseases associated with a sedentary lifestyle;
- an experimental approach for factorial estimates of energy needs during pregnancy and lactation;
- distribution in the two last trimesters of pregnancy of the recommendations for additional dietary energy needs.

1.2 INTENDED USE OF THIS REPORT

This report is briefer and less detailed than the reports of previous expert meetings and consultations. The commissioned background papers, which will be published in a peer-reviewed journal, complement the report with details on the sources, analysis and interpretation of the scientific information. In addition to a printed version, the report will be placed on the Internet for wider access and faster diffusion.

This report is not meant merely to describe the energy expenditures and requirements of population groups. It intends to be *prescriptive*, in order to support and maintain health and good nutrition. The recommendations, however, are meant for well-nourished and healthy populations, as the correction of malnutrition – either deficit or excess – involves different energy requirements and dietary recommendations. The report is not meant to be prescriptive for individual subjects, some of whom may be at either extreme of a normal distribution. Although estimates of requirements are derived from measurements of individuals with specific characteristics such as age, gender, body size, presumed body composition and physical activity, the data have been pooled to give the average energy requirements of *groups or classes of individuals* who have similar characteristics, but on whom measurements have not been made. Consequently, application of these results to any one individual for clinical or other purposes may lead to errors of diagnosis and improper management.

1.3 POLICY IMPLICATIONS

A science-based definition of human energy requirements is crucial for the control and prevention of undernutrition due to insufficient intake of food energy, which remains a major problem for many countries. It is also essential to efforts to curb the excessive intake of food energy that is a major determinant of nutrition-related chronic diseases, at present an important cause of worldwide morbidity and mortality among adults.

Insufficient food energy intake is almost always accompanied by a deficient intake of most nutrients. Awareness of the consequences of insufficient energy intakes in children and adults has influenced health and food and agriculture policies around the world. More recently, the consequences of increasing obesity and nutrition-related chronic diseases have also been recognized as major factors for the health, food and agriculture sectors. These problems are increasing globally as a result of changes in diets and lifestyles that are reflected in changing food cultures and physical activity patterns among all segments of society, and not only among affluent groups or in the richest countries. Undernutrition early in life, followed by an inappropriate diet and low physical activity in childhood and adult life increases vulnerability to chronic non-communicable diseases. Low-income groups in urban areas are especially vulnerable to the risk of obesity owing to a positive energy balance. The current increased incidence of overweight and obesity among children and adults in most countries leads to rapidly rising projections of disability and premature death to nutrition-related chronic diseases.

Prevention is the only feasible approach to control the double burden of under- and overnutrition. The cost of treating and managing the ensuing disabilities and diseases imposes an intolerable economic and health burden, especially for poorer countries. As inappropriate dietary intake and lack of physical activity are the main causes of nutritional problems, there is an urgent need for governments, in partnership with all relevant stakeholders, to integrate strategies that promote healthy diets and regular physical activity in all relevant policies and programmes, including those designed to fight undernutrition. Both undernutrition and obesity are preventable, as has been demonstrated by countries with successful programmes. In addition to health promotion, nutrition education and relevant agricultural and food policies, effective food and nutrition programmes must include community action to overcome the environmental, social and economic constraints that limit the improvement of access to food, and to promote better dietary quality and life style practices that encourage a physically active life.

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2. PRINCIPLES AND DEFINITIONS

Human energy requirements are estimated from measures of energy expenditure plus the additional energy needs for growth, pregnancy and lactation. Recommendations for dietary energy intake from food must satisfy these requirements for the attainment and maintenance of optimal health, physiological function and well-being. The latter (i.e. well-being) depends not only on health, but also on the ability to satisfy the demands imposed by society and the environment, as well as all the other energy-demanding activities that fulfil individual needs.

Energy balance is achieved when input (i.e. dietary energy intake) is equal to output (i.e. total energy expenditure), plus the energy cost of growth in childhood and pregnancy, or the energy cost to produce milk during lactation. When energy balance is maintained over a prolonged period, an individual is considered to be in a steady state. This can include short periods during which the day-to-day balance between intake and expenditure does not occur. An optimal steady state is achieved when energy intake compensates for total energy expenditure and allows for adequate growth in children, and pregnancy and lactation in women, without imposing metabolic, physiological or behavioural restrictions that limit the full expression of a person's biological, social and economic potential.

Within certain limits, humans can adapt to transient or enduring changes in energy intake through possible physiological and behavioural responses related to energy expenditure and/or changes in growth. Energy balance is maintained, and a new steady state is then achieved. However, adjustments to low or high energy intakes may sometimes entail biological and behavioural penalties, such as reduced growth velocity, loss of lean body mass, excessive accumulation of body fat, increased risk of disease, forced rest periods, and physical or social limitations in performing certain activities and tasks. Some of these adjustments are important and may even increase the chances of survival in times of food scarcity.

2.1 DEFINITIONS

An adequate, healthy diet must satisfy human needs for energy and all essential nutrients. Furthermore, dietary energy needs and recommendations cannot be considered in isolation of other nutrients in the diet, as the lack of one will influence the others. Thus, the following definitions are based on the assumption that requirements for energy will be fulfilled through the consumption of a diet that satisfies all nutrient needs.

Energy requirement is the amount of food energy needed to balance energy expenditure in order to maintain body size, body composition and a level of necessary and desirable physical activity consistent with long-term good health. This includes the energy needed for the optimal growth and development of children, for the deposition of tissues during pregnancy, and for the secretion of milk during lactation consistent with the good health of mother and child.

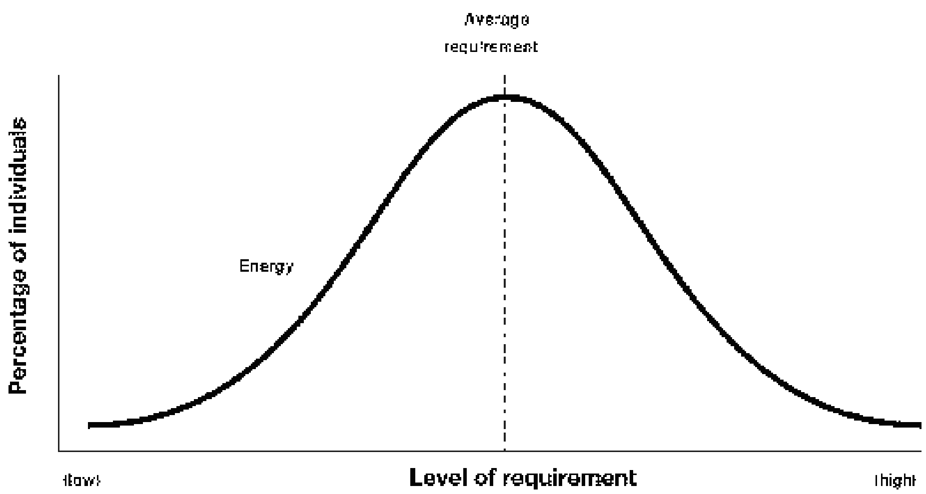
The recommended level of dietary energy intake for a population group is the mean energy requirement of the healthy, well-nourished individuals who constitute that group.

Based on these definitions, a main objective for the assessment of energy requirements is the prescription of dietary energy intakes that are compatible with long-term good health. Therefore, the levels of energy intake recommended by this expert consultation are based on estimates of the requirements of *healthy, well-nourished individuals*. It is recognized that some populations have particular public health characteristics that are part of their usual, "normal" life. Foremost among these are population groups in many developing countries where there are numerous infants and children who suffer from mild to moderate degrees of malnutrition and who experience frequent episodes of infectious diseases, mostly diarrhoeal and respiratory infections. Special considerations are made in this report for such sub-populations.

2.1.1 Daily energy requirements and daily energy intakes
Energy requirements and recommended levels of intake are often referred to as *daily requirements* or *recommended daily intakes*. These terms are used as a matter of convention and convenience, indicating that the requirement represents an average of energy needs over a certain number of days, and that the recommended energy intake is the amount of energy that should be ingested as a daily average over a certain period of time. There is no implication that exactly this amount of energy must be consumed every day, nor that the requirement and recommended intake are constant, day after day. Neither is there any biological basis for defining the number of days over which the requirement or intake must be averaged. As a matter of convenience, taking into account that physical activity and eating habits may vary on some days of the week, periods of seven days are often used when estimating the average daily energy expenditure and recommended daily intake.

2.1.2 Average requirement and inter-individual variation
Estimates of energy requirements are derived from measurements of individuals. Measurements of a collection of individuals of the same gender and similar age, body size and physical activity are grouped together to give the average energy requirement – or recommended level of dietary intake – for a *class* of people or a *population group*. These requirements are then used to predict the requirements and recommended levels of energy intake for other individuals with similar characteristics, but on whom measurements have not been made. Although individuals in a given class have been matched for characteristics that may affect requirements, such as gender, age, body size, body composition and lifestyle, there remain unknown factors that produce variations among individuals. Consequently, there is a distribution of requirements within the class or population group (WHO, 1985) (Figure 2.1).

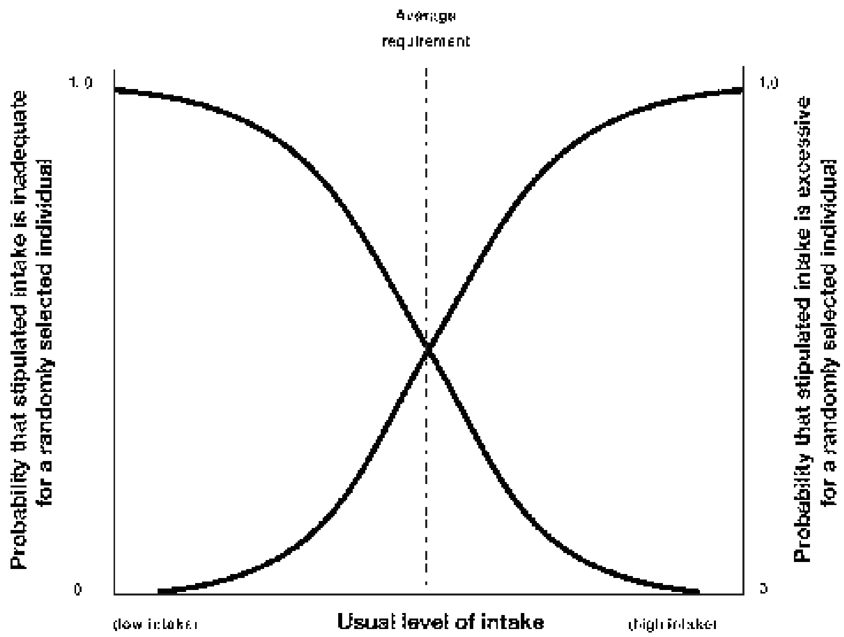
FIGURE 2.1
Distribution of energy requirements of a population group or class of individuals*



* It is assumed that individual requirements are randomly distributed about the mean requirement for the class of individuals, and that the distribution is Gaussian.
Source. WHO, 1985.

For most specific nutrients, a certain excess of intake will not be harmful. Thus, when dietary recommendations are calculated for these nutrients, the variation among individuals in a class or population group is taken into account, and the recommended level of intake is an amount that will meet or exceed the requirements of practically all individuals in the group. For example, the recommended safe level of intake for proteins is the average requirement of the population group, plus 2 standard deviations. This approach cannot be applied to dietary energy recommendations, because intakes that exceed requirements will produce a positive balance, which may lead to overweight and obesity in the long term. A high level of energy intake that assures a low probability of energy deficiency for most people (e.g. the average requirement plus 2 standard deviations) also implies a high probability of obesity for most people owing to a dietary energy excess (Figure 2.2). Therefore, in agreement with earlier reports, this expert consultation concluded that the descriptor of the dietary energy intake that could be safely recommended for a population group is the estimated *average energy requirement* of that group.

FIGURE 2.2
Probability that a particular energy intake is inadequate or excessive for an individual*



* Individuals are randomly selected among a class of people or a population group. The two probability curves overlap, so the level of energy intake that assures a low probability of dietary energy deficiency is the same level that implies a high probability of obesity owing to dietary energy excess.
Source: WHO, 1985.

2.2 SOURCES OF DIETARY ENERGY

Energy for the metabolic and physiological functions of humans is derived from the chemical energy bound in food and its macronutrient constituents, i.e. carbohydrates, fats, proteins and ethanol, which act as substrates or fuels. After food is ingested, its chemical energy is released and converted into thermic, mechanical and other forms of energy.

This report refers to energy requirements that must be satisfied with an adequately balanced diet, and does not make specific recommendations for carbohydrates, fats or proteins. Reports from other FAO and WHO expert groups address those topics. Nevertheless, it should be noted that fats and carbohydrates are the main sources of dietary energy, although proteins also provide important amounts of energy, especially when total dietary energy intake is limited. Ethanol is not considered part of a food system, but its contribution to total energy intake cannot be overlooked, particularly among populations that regularly consume alcoholic beverages. Allowing for the mean intestinal absorption, and for the nitrogenous portion of proteins that cannot be completely oxidized, the average values of metabolizable energy provided by substrates in a mixed diet are 16.7 kJ (4 kcal) per substrates determined by chemical analysis, or estimated from appropriate food composition tables. A recent related report from a FAO technical workshop provides more information on this topic (FAO, 2003).

2.3 COMPONENTS OF ENERGY REQUIREMENTS

Human beings need energy for the following:

- *Basal metabolism*. This comprises a series of functions that are essential for life, such as cell function and replacement; the synthesis, secretion and metabolism of enzymes and hormones to transport proteins and other substances and molecules; the maintenance of body temperature; uninterrupted work of cardiac and respiratory muscles; and brain function. The amount of energy used for basal metabolism in a period of time is called the *basal metabolic rate* (*BMR*), and is measured under standard conditions that include being awake in the supine position after ten to 12 hours of fasting and eight hours of physical rest, and being in a state of mental relaxation in an ambient environmental temperature that does not elicit heat-generating or heat-dissipating processes. Depending on age and lifestyle, BMR represents 45 to 70 percent of daily total energy expenditure, and it is determined mainly by the individual's age, gender, body size and body composition.
- *Metabolic response to food*. Eating requires energy for the ingestion and digestion of food, and for the absorption, transport, interconversion, oxidation and deposition of nutrients. These metabolic processes increase heat production and oxygen consumption, and are known by terms such as *dietary-induced thermogenesis*, *specific dynamic action of food* and *thermic effect of feeding*. The metabolic response to food increases total energy expenditure by about 10 percent of the BMR over a 24-hour period in individuals eating a mixed diet.
- *Physical activity*. This is the most variable and, after BMR, the second largest component of daily energy expenditure. Humans perform *obligatory* and *discretionary* physical activities. Obligatory activities can seldom be avoided within a given setting, and they are imposed on the individual by economic, cultural or societal demands. The term "obligatory" is more comprehensive than the term "occupational" that was used in the 1985 report (WHO, 1985) because, in addition to occupational work, obligatory activities include daily activities such as going to school, tending to the home and family and other demands made on children and adults by their economic, social and cultural environment.

  Discretionary activities, although not socially or economically essential, are important for health, well-being and a good quality of life in general. They include the regular practice of physical activity for fitness and health; the performance of optional household tasks that may contribute to family comfort and well-being; and the engagement in individually and socially desirable activities for personal enjoyment, social interaction and community development.
- *Growth*. The energy cost of growth has two components: 1) the energy needed to synthesize growing tissues; and 2) the energy deposited in those tissues. The energy cost of growth is about 35 percent of total energy requirement during the first three months of age, falls rapidly to about 5 percent at 12 months and about 3 percent in the second year, remains at 1 to 2 percent until mid-adolescence, and is negligible in the late teens.
- *Pregnancy*. During pregnancy, extra energy is needed for the growth of the foetus, placenta and various maternal tissues, such as in the uterus, breasts and fat stores, as well as for changes in maternal metabolism and the increase in maternal effort at rest and during physical activity.
- *Lactation*. The energy cost of lactation has two components: 1) the energy content of the milk secreted; and 2) the energy required to produce that milk. Well-nourished lactating women can derive part of this additional requirement from body fat stores accumulated during pregnancy.

2.4 CALCULATION OF ENERGY REQUIREMENTS

The total energy expenditure of free-living persons can be measured using the doubly labelled water technique (DLW) or other methods that give comparable results. Among these, individually calibrated heart rate monitoring has been successfully validated. Using these methods, measurements of total energy expenditure over a 24-hour period include the metabolic response to food and the energy cost of tissue synthesis. For adults, this is equivalent to daily energy requirements. Additional energy for deposition in growing tissues is needed to determine energy requirements in infancy, childhood, adolescence and during pregnancy, and for the production and secretion of milk during lactation. It can be estimated from calculations of growth (or weight gain) velocity and the composition of weight gain, and from the average volume and composition of breastmilk.

2.4.1 Factorial estimates of total energy expenditure

When experimental data on total energy expenditure are not available, it can be estimated by factorial calculations based on the time allocated to activities that are performed habitually and the energy cost of those activities. Factorial calculations combine two or more components or "factors", such as the sum of the energy spent while sleeping, resting, working, doing social or discretionary household activities, and in leisure. Energy spent in each of these components may in turn be calculated by knowing the time allocated to each activity, and its corresponding energy cost.

As discussed in the following sections of this report, the experimental measurement of total energy expenditure and the assessment of growth and tissue composition allow sound predictions to be made regarding energy requirements and dietary recommendations for infants and older children around the world. Special considerations and additional calculations assist the formulation of recommendations for children and adolescents with diverse lifestyles.

Total energy expenditure has also been measured in groups of adults, but this has been primarily in industrialized countries. Variations in body size, body composition and habitual physical activity among populations of different geographical, cultural and economic backgrounds make it difficult to apply the published results on a worldwide basis. Thus, in order to account for differences in body size and composition, energy requirements were initially calculated as multiples of BMR. They were then converted into energy units using a known BMR value for the population, or the mean BMR calculated from the population's mean body weight. To account for differences in the characteristic physical activity of the associated lifestyles, energy requirements of adults were estimated by factorial calculations that took into account the times allocated to activities demanding different levels of physical effort.

The extra needs for pregnancy and lactation were also calculated using factorial estimates for the growth of maternal and foetal tissues, the metabolic changes associated with pregnancy and the synthesis and secretion of milk during lactation.

2.4.2 Expression of requirements and recommendations

Measurements of energy expenditure and energy requirement recommendations are expressed in units of energy (joules, J), in accordance with the international system of units. Because many people are still used to the customary usage of thermochemical energy units (kilocalories, kcal), both are used in this report, with kilojoules given first and kilocalories second, within parenthesis and in a different font (Arial 9). In tables, values for kilocalories are given in italic type.[2]

Gender, age and body weight are the main determinants of total energy expenditure. Thus, energy requirements are presented separately for each gender and various age groups, and are expressed both as energy units per day and energy per kilogram of body weight. As body size and composition also influence energy expenditure, and are closely related to basal metabolism, requirements are also expressed as multiples of BMR.

[2] 1 joule (J) is the amount of mechanical energy required to displace a mass of 1 kg through a distance of 1 m with an acceleration of 1 m per second (1 J = 1 kg × 1 m^2 × 1 sec^{-2}). Multiples of 1 000 (kilojoules, kJ) or 1 million (megajoules, MJ) are used in human nutrition. The conversion factors between joules and calories are: 1 kcal = 4.184 kJ, or conversely, 1 kJ = 0.239 kcal.

2.5 RECOMMENDATIONS FOR PHYSICAL ACTIVITY

A certain amount of activity must be performed regularly in order to maintain overall health and fitness,[3] to achieve energy balance and to reduce the risk of developing obesity and associated diseases, most of which are associated with a sedentary lifestyle. This expert consultation therefore endorsed the proposition that recommendations for dietary energy intake must be accompanied by recommendations for an appropriate level of habitual physical activity. This report provides guidelines for desirable physical activity levels, and for the duration, frequency and intensity of physical exercise as recommended by various organizations with expertise in physical activity and health. It also emphasizes that appropriate types and amounts of physical activity can be carried out during the performance of either obligatory or discretionary activities and that recommendations must take into account the cultural, social and environmental characteristics of the target population.

2.6 GLOSSARY AND ABBREVIATIONS

In addition to those defined in the preceding sections, the following terms and abbreviations are used in this report. They are consistent with the definitions used in other related WHO and FAO documents (FAO, 2003; James and Schofield 1990; WHO, 1995).

Basal metabolic rate (BMR)**:** The minimal rate of energy expenditure compatible with life. It is measured in the supine position under standard conditions of rest, fasting, immobility, thermoneutrality and mental relaxation. Depending on its use, the rate is usually expressed per minute, per hour or per 24 hours.

Body mass index (BMI)**:** The indicator of weight adequacy in relation to height of older children, adolescents and adults. It is calculated as weight (in kilograms) divided by height (in meters), squared. The acceptable range for adults is 18.5 to 24.9, and for children it varies with age.

Doubly labelled water (DLW) technique**:** A method used to measure the average total energy expenditure of free-living individuals over several days (usually 10 to 14), based on the disappearance of a dose of water enriched with the stable isotopes ^{2}H and ^{18}O.

Energy requirement (ER)**:** The amount of food energy needed to balance energy expenditure in order to maintain body size, body composition and a level of necessary and desirable physical activity, and to allow optimal growth and development of children, deposition of tissues during pregnancy, and secretion of milk during lactation, consistent with long-term good health. For healthy, well-nourished adults, it is equivalent to total energy expenditure. There are additional energy needs to support growth in children and in women during pregnancy, and for milk production during lactation.

Heart rate monitoring (HRM)**:** A method to measure the daily energy expenditure of free-living individuals, based on the relationship of heart rate and oxygen consumption and on minute-by-minute monitoring of heart rate.

Total energy expenditure (TEE)**:** The energy spent, on average, in a 24-hour period by an individual or a group of individuals. By definition, it reflects the average amount of energy spent in a typical day, but it is not the exact amount of energy spent each and every day.

Physical activity level (PAL)**:** TEE for 24 hours expressed as a multiple of BMR, and calculated as TEE/BMR for 24 hours. In adult men and non-pregnant, non-lactating women, BMR times PAL is equal to TEE or the daily energy requirement.

[3] The term "fitness" encompasses cardiorespiratory health, appropriate body composition (including fat distribution), muscular strength, endurance and flexibility. Fitness can generally be described as the ability to perform moderate to vigorous physical activity without becoming excessively tired.

***Physical activity ratio (PAR)*:** The energy cost of an activity per unit of time (usually a minute or an hour) expressed as a multiple of BMR. It is calculated as energy spent in an activity/BMR, for the selected time unit.

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3. ENERGY REQUIREMENTS OF INFANTS FROM BIRTH TO 12 MONTHS

The principle of calculating energy requirements from total energy expenditure (TEE) plus the energy needs for growth applies to infants and children of all ages. However, the previous FAO/WHO/UNU expert consultation (WHO, 1985) estimated the energy requirements of infants from the observed intakes of healthy children growing normally, largely owing to the lack of sufficient information on total energy expenditure. For the last report, data on measurements of infants and children were compiled from studies of infants in Canada, Sweden, the United Kingdom and the United States (Whitehead, Paul and Cole, 1981). Results from developing countries were not included in the analysis "to ensure that the intakes represented those of groups of children who, on the average, were growing along the fiftieth percentile of the WHO reference standard". An additional 5 percent was added to compensate for a possible methodological bias in the calculation of energy intakes.

Scientific information generated in the intervening years has allowed the present consultation to base its estimates and recommendations for infants on energy expenditure plus the energy needs for growth. This assumes that the energy intake of infants is self-regulated and matches energy needs (Fomon, 1974; Dewey and Lönnerdal, 1986). In keeping with the principles followed by preceding expert groups, it was decided to base the analyses, conclusions and recommendations on results of studies carried out on healthy, well-nourished, non-stunted infants born at full term with adequate birth weight, and growing along the trajectory of the WHO reference standards (WHO, 1983). This permits the prescription of dietary recommendations consistent with the optimal growth of healthy, well-nourished infant populations. Special considerations must be made for groups with particular needs, such as undernourished infants and those with low weight or size at birth.

3.1 MEASUREMENT OF TOTAL ENERGY EXPENDITURE

The use of the doubly labelled water (DLW) ($^2H_2{}^{18}O$) technique to calculate total production of carbon dioxide (CO_2) over several days and, from this, total energy expenditure was originally developed for use in small mammals (Lifson, Gordon and McClintock, 1955), and its application was later validated in humans (Schoeller and van Santen, 1982; Klein *et al.,* 1984; Coward *et al.,* 1984). Although questions have been raised about the appropriateness of the assumptions used for the calculation of TEE, DLW is currently considered the most accurate technique for measuring TEE in free-living individuals. TEE measured by this method includes basal metabolism, the metabolic response to food, thermoregulatory needs, physical activity costs, and the energy cost to synthesize growing tissues. Consequently, energy requirements are calculated as the sum of TEE plus the energy deposited as protein and fat in growing tissues and organs.

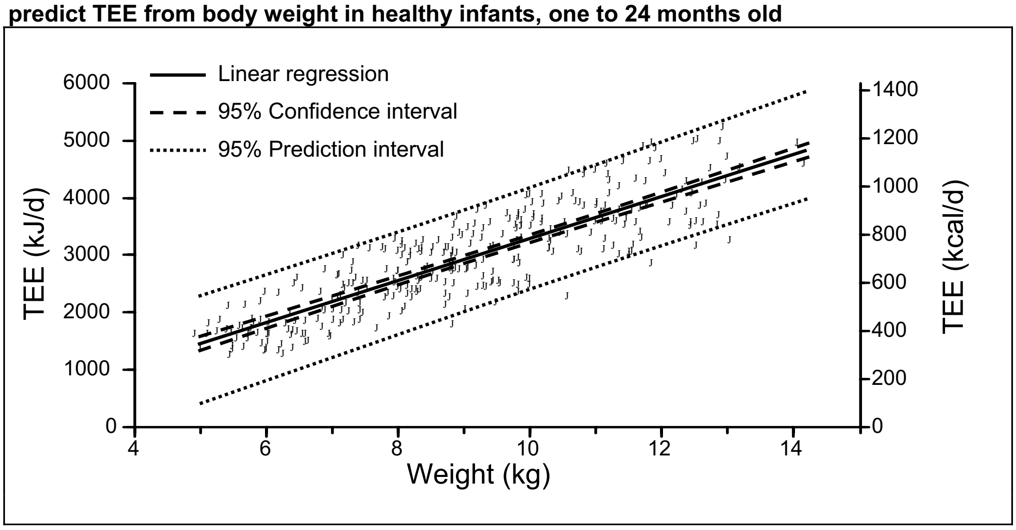
This consultation examined an analysis of 13 studies with DLW performed on a total of 417 healthy, well-nourished, non-stunted infants of from 0 to 12 months of age (Butte, 2001). Eleven investigations were carried out in the United Kingdom (Lucas *et al.,* 1987; Roberts *et al.,* 1988; Davies, Ewing and Lucas, 1989; Wells and Davies, 1995; Wells, Cole and Davies, 1996; Davies *et al.,* 1997), the United States (Butte *et al.,* 1990; Stunkard *et al.,* 1999; Butte *et al.,* 2000b) and the Netherlands (de Bruin *et al.,* 1998), one in Chile (Salazar *et al.,* 2000) and one in China (Jiang *et al.,* 1998). Several studies conducted repeated measurements of TEE at intervals of two to three months, increasing the number of TEE data points to 854. One such study showed that the coefficient of variation among individuals was fairly uniform from three to 24 months of age, ranging from 15 to 21 percent for TEE/day (average: 18 percent), and from 13 to 17 percent for TEE/kg/day (average: 15 percent) (Butte *et al.,* 2000b). The average inter-individual variation was similar to that observed among older children (19 percent for TEE/day, and 17 percent for TEE/kg/day; see section 4.1).

3.2 EQUATIONS TO PREDICT ENERGY EXPENDITURE

Longitudinal measurements of TEE with DLW at three-month intervals for the first two years of life on 76 healthy infants (40 breastfed and 36 formula-fed) showed that there is a good linear relationship between TEE and body weight (Butte *et al.,* 2000b). TEE was significantly affected by age, gender, weight and length. Age, weight and height were all good predictors of TEE, with a slight advantage for weight. Because the three parameters were highly correlated (r = 0.91 – 0.96), and there were no independent effects of age, gender and length when weight was used as the predictor, the latter was used to develop the following equation (Butte, 2001), which is graphically displayed in Figure 3.1.

TEE (MJ/day) = – 0.416 + 0.371 kg; n = 320, r = 0.85, see = 0.456 MJ/day (109 kcal/day)
TEE (kcal/day) = – 99.4 + 88.6 kg
(n = number of observations; see = standard error of estimate)

FIGURE 3.1
Linear relationship and 95 percent confidence and prediction intervals of equation to predict TEE from body weight in healthy infants, one to 24 months old



TEE (MJ/d) = – 0.416 + 0.371 kg; n = 320, r = 0.85, see = 0.456 MJ/d (*109 kcal/d*).
TEE (kcal/d) = – 99.4 + 88.6 kg.
Source: Butte, 2001.

The relationship between TEE and weight in the 13 studies mentioned in Section 3.1 was explored using the mean values for TEE and body weight. Some studies included longitudinal or cross-sectional data at various ages throughout infancy, or from groups of either breastfed or formula-fed infants. A total of 40 sets of TEE and body weight values, weighted for sample size, gave the following linear regression equation, which does not differ significantly from that shown above:

TEE (MJ/day) = – 0.399 + 0.369 kg; n = 40, r = 0.99, see = 0.527 MJ/day (126 kcal/day)
TEE (kcal/day) = – 95.4 + 88.3 kg

As the equation was derived from the mean values of each study, the regression coefficient and standard error of estimate (see) do not reflect individual variation.

3.2.1 Breastfed and formula-fed infants

Four studies with breastfed and formula-fed infants showed that the formula-fed infants had higher TEE during the first year of life (Butte *et al.,* 1990; Butte *et al.,* 2000b; Jiang *et al.,* 1998; Davies *et al.,* 1990). Compared with their breastfed counterparts, formula-fed infants had on average 12, 7, 6 and 3 percent higher TEE at three, six, nine and 12 months of age, respectively. At 18 and 24 months, there was no difference between infants who still received breastmilk and those who did not (Butte, 2001). The equations to predict TEE from body weight are as follows:

Breastfed:
TEE (MJ/day) = – 0.635 + 0.388 kg; n = 195, r = 0.87, see = 0.453 MJ/day (108 kcal/day)
TEE (kcal/day) = – 152.0 + 92.8 kg

Formula-fed:
TEE (MJ/day) = – 0.122 + 0.346 kg; n = 125, r = 0.85, see = 0.463 MJ/day (110 kcal/day)
TEE (kcal/day) = – 29.0 + 82.6 kg

3.3 ENERGY NEEDS FOR GROWTH

Growth is a sensitive indicator of whether an infant's energy requirements are satisfied. Energy demands for growth constitute about 35 percent of the total energy requirement during the first three months of life (40 percent in the first month), this proportion is halved in the next three months (i.e. to about 17.5 percent), and further reduced to one-third of that during the ensuing six months (i.e. to less than 6 percent) and to only 3 percent at 12 months. Energy for growth falls to less than 2 percent of daily requirements in the second year, remains between 1 and 2 percent until mid-adolescence, and gradually disappears by 20 years of age.

Energy needs for growth have two components: 1) the energy used to synthesize growing tissues, which is part of the total energy expenditure measured with DLW; and 2) the energy deposited in those tissues, basically as fat and protein, because carbohydrate content is insignificant. Hence, energy requirements in infancy can be calculated by adding the energy deposited in growing tissues to TEE.

Much previous knowledge on the energy cost of growth was based on studies in pre-term infants or in children recovering from malnutrition, and used energy balance and the two-component body composition techniques (WHO, 1985; Butte, Wong and Garza, 1989). Methodological advances have allowed a better assessment of body composition changes during infancy through serial measurements of total body electrical conductivity (de Bruin *et al.,* 1998), or with a multi-component body composition model based on measurements of total body water, total body potassium and bone mineral content (Butte *et al.,* 2000a). This permits calculation of the gains in protein and fat, as well as of the corresponding energy deposition assuming that the energy equivalents of protein and fat are 23.6 and 38.7 kJ/g (5.65 and 9.25 kcal/g), respectively. As Table 3.1 shows, energy accrued per gram of weight gain decreased from approximately 26 kJ (6.3 kcal) in the first three months of life to about 10 kJ (2.3 kcal) at nine to 12 months.

TABLE 3.1
Protein, fat and energy deposition during growth in the first year of life

Age months	**Protein gain** g/d	**Fat mass gain** g/d	**Weight gain** g/d	**Energy accrued in normal growth*** kJ/g	*kcal/g*
Boys					
0–3	2.6	19.6	32.7	25.1	*6.0*
3–6	2.3	3.9	17.7	11.6	*2.8*
6–9	2.3	0.5	11.8	6.2	*1.5*
9–12	1.6	1.7	9.1	11.4	*2.7*
Girls					
0–3	2.2	19.7	31.1	26.2	*6.3*
3–6	1.9	5.8	17.3	15.6	*3.7*
6–9	2.0	0.8	10.6	7.4	*1.8*
9–12	1.8	1.1	8.7	9.8	*2.3*

* Energy equivalents: 1 g protein = 23.6 kJ (*5.65 kcal*); 1 g fat = 38.7 kJ (*9.25 kcal*).
Source: Butte *et al.,* 2000a.

TABLE 3.2

Energy requirements of infants during the first year of life*

Age	Weight	Weight gain	Total energy expenditure[a]		Energy deposition[b]		Daily energy requirement[c]			
months	kg	g/d	MJ/d	*kcal/d*	MJ/d	*kcal/d*	MJ/d	*kcal/d*	kJ/kg/d	*kcal/kg/d*
Boys										
0–1	4.58	35.2	1.282	*306*	0.884	*211*	2.166	*518*	473	*113*
1–2	5.50	30.4	1.623	*388*	0.764	*183*	2.387	*570*	434	*104*
2–3	6.28	23.2	1.912	*457*	0.582	*139*	2.494	*596*	397	*95*
3–4	6.94	19.1	2.157	*515*	0.224	*53*	2.380	*569*	343	*82*
4–5	7.48	16.1	2.357	*563*	0.189	*45*	2.546	*608*	340	*81*
5–6	7.93	12.8	2.524	*603*	0.150	*36*	2.674	*639*	337	*81*
6–7	8.30	11.0	2.661	*636*	0.069	*17*	2.730	*653*	329	*79*
7–8	8.62	10.4	2.780	*664*	0.065	*16*	2.845	*680*	330	*79*
8–9	8.89	9.0	2.880	*688*	0.057	*14*	2.936	*702*	330	*79*
9–10	9.13	7.9	2.969	*710*	0.089	*21*	3.058	*731*	335	*80*
10–11	9.37	7.7	3.058	*731*	0.087	*21*	3.145	*752*	336	*80*
11–12	9.62	8.2	3.150	*753*	0.093	*22*	3.243	*775*	337	*81*
Girls										
0–1	4.35	28.3	1.197	*286*	0.746	*178*	1.942	*464*	447	*107*
1–2	5.14	25.5	1.490	*356*	0.672	*161*	2.162	*517*	421	*101*
2–3	5.82	21.2	1.742	*416*	0.559	*134*	2.301	*550*	395	*94*
3–4	6.41	18.4	1.960	*469*	0.285	*68*	2.245	*537*	350	*84*
4–5	6.92	15.5	2.149	*514*	0.239	*57*	2.389	*571*	345	*83*
5–6	7.35	12.8	2.309	*552*	0.199	*47*	2.507	*599*	341	*82*
6–7	7.71	11.0	2.442	*584*	0.083	*20*	2.525	*604*	328	*78*
7–8	8.03	9.2	2.561	*612*	0.069	*17*	2.630	*629*	328	*78*
8–9	8.31	8.4	2.665	*637*	0.063	*15*	2.728	*652*	328	*78*
9–10	8.55	7.7	2.754	*658*	0.074	*18*	2.828	*676*	331	*79*
10–11	8.78	6.6	2.839	*679*	0.063	*15*	2.902	*694*	331	*79*
11–12	9.00	6.3	2.920	*698*	0.060	*14*	2.981	*712*	331	*79*

* Calculated from linear regression analysis of total energy expenditure on weight, plus allowance for energy deposition in tissues during growth.

[a] TEE (MJ/d) = – 0.416 + 0.371 kg (section 3.2).

[b] Weight gain × energy accrued in normal growth (Table 3.1).

[c] Requirement = total energy expenditure + energy deposition.

Sources: Butte, 2001. Weight and weight gain data from WHO, 1994.

3.4 CALCULATION OF ENERGY REQUIREMENTS

Table 3.2 shows the average energy requirements of infants from one to 12 months of age, combining the needs of breastfed and formula-fed infants. TEE was calculated with the predictive linear equations described in section 3.2 and the median weight for age of the WHO pooled breastfed data set (WHO, 1994). The rate of median weight gain at monthly intervals was calculated from the same source. Energy deposited in growing tissues was estimated by multiplying the monthly weight gain by the mean energy accrued in each three-month period (Table 3.1). The sum of TEE and energy deposition is the mean daily energy requirement (in MJ or kcal). It is calculated as energy units per kilogram of body weight, dividing the daily requirement by the median weight at each month of age.

Breastmilk is the best food for infants, and exclusive breastfeeding is strongly recommended during the first six months of life, followed by a combination of breastmilk and complementary foods throughout infancy. As TEE is lower among breastfed than formula-fed infants during the first year of life, the energy requirements of breastfed infants are also lower. This is illustrated in Table 3.3, in which requirements are calculated for breastfed and formula-fed infants with the same body weights using the predictive equations described in section 3.2.1. For the purpose of simplicity, the values have been rounded off to the closest 5 kJ/kg/day, or 1 kcal/kg/day. These figures are consistent with the fact that a healthy woman can produce enough milk to provide the energy required by a healthy, exclusively breastfed infant of up to six months of age.

TABLE 3.3
Energy requirements of breastfed, formula-fed and all infants*

Age	Breastfed[a]			Formula-fed[b]			All (breast- and formula-fed)[c]		
Months	Boys	Girls	Mean	Boys	Girls	Mean	Boys	Girls	Mean
kJ/kg/d									
1	445	415	430	510	490	500	475	445	460
2	410	395	405	460	455	460	435	420	430
3	380	375	380	420	420	420	395	395	395
4	330	335	330	360	370	365	345	350	345
5	330	330	330	355	365	360	340	345	345
6	325	330	330	350	355	355	335	340	340
7	320	315	320	340	340	340	330	330	330
8	320	320	320	340	340	340	330	330	330
9	325	320	320	340	340	340	330	330	330
10	330	325	325	340	340	340	335	330	335
11	330	325	325	340	340	340	335	330	335
12	330	325	330	345	340	340	335	330	335
kcal/kg/d									
1	*106*	*99*	*102*	*122*	*117*	*120*	*113*	*107*	*110*
2	*98*	*95*	*97*	*110*	*108*	*109*	*104*	*101*	*102*
3	*91*	*90*	*90*	*100*	*101*	*100*	*95*	*94*	*95*
4	*79*	*80*	*79*	*86*	*89*	*87*	*82*	*84*	*83*
5	*79*	*79*	*79*	*85*	*87*	*86*	*81*	*82*	*82*
6	*78*	*79*	*78*	*83*	*85*	*84*	*81*	*81*	*81*
7	*76*	*76*	*76*	*81*	*81*	*81*	*79*	*78*	*79*
8	*77*	*76*	*76*	*81*	*81*	*81*	*79*	*78*	*79*
9	*77*	*76*	*77*	*81*	*81*	*81*	*79*	*78*	*79*
10	*79*	*77*	*78*	*82*	*81*	*81*	*80*	*79*	*80*
11	*79*	*77*	*78*	*82*	*81*	*81*	*80*	*79*	*80*
12	*79*	*77*	*78*	*82*	*81*	*81*	*81*	*79*	*80*

* Numbers rounded to the closest 5 kJ/kg/d, and 1 kcal/kg/d, using the mean body weight and energy deposition in Table 3.1 and the following predictive equations for TEE:
[a] TEE (MJ/kg/d) = (– 0.635 + 0.388 weight) / weight.
[b] TEE (MJ/kg/d) = (– 0.122 + 0.346 weight) / weight.
[c] TEE (MJ/kg/d) = (– 0.416 + 0.371 weight) / weight.

3.4.1 Comparison with previous requirements

Compared with the values in the 1985 FAO/WHO/UNU report, energy requirements proposed by this consultation are about 12 percent lower in the first three months of life, 17 percent lower from three to nine months, and 20 percent lower from nine to 12 months (Table 3.4 and Figure 3.2). The requirements for breastfed infants are 17, 20 and 22 percent lower than the 1985 estimates at ages 0 to three, three to nine and nine to 12 months, respectively. That the 1985 consultation overestimated requirements of this group had already been suggested from an analysis of 3 573 data points of energy intakes of well-nourished infants recorded after 1980 (Butte, 1996).

TABLE 3.4
Comparison of present estimates of energy requirements (kJ/kg/d) of infants with those calculated in the previous (1985) FAO/WHO/UNU report

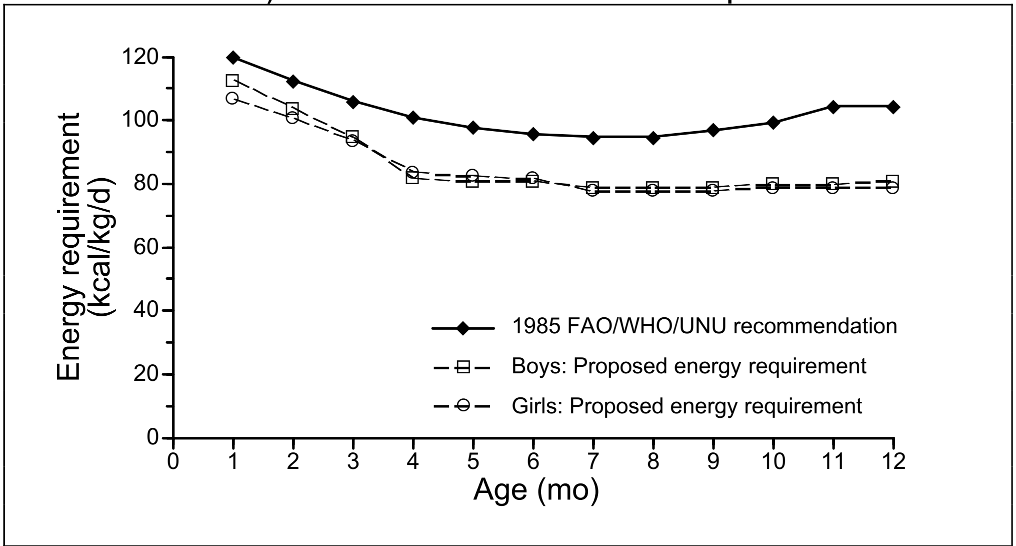
Age	Present estimates		1985 estimates	% difference from 1985	
months	All infants	Breastfed		All infants	Breastfed
0–1	460	430	519	-11	-17
1–2	430	405	485	-11	-16
2–3	395	380	456	-13	-17
3–4	345	330	431	-20	-23
4–5	345	330	414	-17	-20
5–6	340	330	404	-16	-18
6–7	330	320	397	-17	-19
7–8	330	320	395	-16	-19
8–9	330	320	397	-17	-19
9–10	335	325	414	-19	-21
10–11	335	325	418	-20	-22
11–12	335	330	437	-23	-24

3.4.2 Basal metabolic rate and physical activity level

The 1981 FAO/WHO/UNU expert consultation estimated the energy requirements of adults as multiples of BMR (WHO, 1985). This was later called "physical activity level" (PAL) in a manual commissioned by FAO for the calculation of human energy requirements. PAL is defined as the total energy required over 24 hours divided by the basal metabolic rate over 24 hours (James and Schofield, 1990). The 2001 expert consultation upheld this approach to estimating requirements for adults (section 5). However, the approach must be used with caution or avoided altogether in relation to the energy requirements of infants and young children, as PAL values may cause confusion owing to differences in the factors that determine energy requirements among children and among adults. In non-pregnant, non-lactating women energy requirements are equal to TEE. In children, however, energy requirements are equal to TEE plus energy accrued or deposited during growth (E_g). These differences are quantitatively small after two years of age, when E_g represents less than 1 or 2 percent of the total energy requirement of the child; but they are increasingly larger at less than two years of age. For example, E_g is about 40 and 23 percent of the energy requirement in the first and third months of life, respectively. Consequently, energy requirement expressed as a function of BMR is much higher (i.e. > 2.0 at one month of age and > 1.7 at three months) in comparison with a PAL value (which is based on measured total energy expenditure) of 1.2 and 1.3 respectively.

BMR of term infants has been studied extensively producing variable results that range from 180 to 250 kJ/kg/day (43 to 60 kcal/kg/day) (Butte, 2001). This high variability has been attributed to biological differences, mainly in body composition at different stages of infancy, and to differences in methods and experimental conditions. For example, some investigators measured "basal" metabolism in infants who were sleeping spontaneously or under the effect of a sedative, which decreases BMR, and others did the measurements in the fed state, which increases BMR. The 1981 expert consultation endorsed the use of predictive equations to estimate the BMR of children under three years of age, derived from approximately 300 data points obtained by a variety of investigators using different methods and under diverse conditions (Schofield, Schofield and James, 1985). These equations underestimate BMR by about 5 to 12 percent from one to nine months of age (Butte, 1989; Wells *et al.,* 1996). This could partly be owing to the lack of uniformity in the conditions when BMR was measured, and hence could have an important impact on the calculation of PAL.

FIGURE 3.2
Comparison of present estimates of energy requirements of infants (combining breastfed and formula-fed infants) with those in the 1985 FAO/WHO/UNU report



Source: Butte, 2001.

3.5 CATCH-UP GROWTH

Assessment of requirements and dietary recommendations for premature, small for gestational age and malnourished infants is beyond the scope of this report. The consultation recognized, however, that many populations around the world have large numbers of newborns with intrauterine growth retardation, and malnourished children less than one year of age. In addition to proper health, social and emotional support, these infants require special nutritional care for a rapid, catch-up growth that will allow them to attain the expected weight and height of normal children born with adequate size at term, and who have never been malnourished. To this end, high growth velocities can be achieved that, compared with the weight gain of normal, well-nourished children, can be up to 20 times higher among underweight, wasted children and about three to five times higher among short, stunted infants.

Diets for catch-up growth must provide all nutrients and energy sources in amounts that are proportionally higher than those required by well-nourished infants of adequate size. However, it is difficult to generalize about the quantitative energy requirements for catch-up growth, as these must often be assessed on an individual basis. Dietary needs, and hence recommendations, may vary with the extent of and the causes of growth retardation, which include the duration of pregnancy; metabolic, physiological and nutritional alterations during intrauterine development; pre- and postpartum infections; and pre- and postpartum primary or secondary malnutrition. The age of onset and duration of the causes leading to growth retardation must also be considered for appropriate dietary interventions. Because the target body weight and length are not fixed but increase with time in a growing child, the longer the period of growth deficit, the greater the gap to be filled.

There are conflicting reports on whether BMR is depressed in severely malnourished children (Montgomery, 1962; Parra *et al.,* 1973) and rises in the early stages of nutritional rehabilitation. Studies with DLW (Fjeld and Schoeller, 1988) suggest that during the early phases of recovery TEE is about 5 to 10 percent higher than expected in well-nourished children, and this increment disappears in the late stages of nutritional treatment. This is probably a reflection of the accelerated rates of tissue synthesis and deposition. There are also reports with varying results on whether the rate of catch-up growth influences the composition of weight gain in children treated for severe malnutrition. Most agree that during the early phases of recovery, 15 to 20 percent of the weight gain seems to be protein, with the rest equally divided between fat and water (Graham *et al.,* 1969; MacLean and Graham, 1980; Fjeld, Schoeller and Brown, 1989).

The influence of malnutrition and the effect of infections on energy requirements are further addressed in section 4.6 of this report, where tentative recommendations are made for populations with high prevalence of infant malnutrition.

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4. ENERGY REQUIREMENTS OF CHILDREN AND ADOLESCENTS

In the 20 years since the 1981 joint FAO/WHO/UNU consultation (WHO, 1985), significant experimental evidence has been collected on the TEE of children and adolescents. This makes it possible to estimate energy requirements from measurements of TEE and energy needs for growth, rather than from food intake data or from estimates of time allocation and energy costs, as were previously used. The 2001 expert consultation analysed a number of studies on TEE, growth and habitual activity patterns of children and adolescents in different parts of the world (Torun, 2001). As the objective of this report is to make recommendations for healthy, well-nourished populations – thus excluding data from undernourished, overweight and stunted groups – the analysis was restricted to information from groups of healthy, well-nourished individuals.

4.1 MEASUREMENT OF TOTAL ENERGY EXPENDITURE

Studies using the DLW technique were the starting point for estimating energy requirements of children and adolescents. However, most of the existing data on TEE measured with DLW were obtained in industrialized countries, where energy expenditure is influenced by modern technology, school environments, sedentary pastimes, mechanized transportation and social and economic support systems that demand relatively low physical effort (i.e. in developed countries or affluent societies) compared with countries and societies where cultural, economic, social and developmental circumstances require greater physical effort from an early age (i.e. in developing countries or poorer, largely rural societies). On the other hand, several investigations on TEE of healthy, well-nourished children and adolescents have been done in a broader spectrum of countries and societies using minute-by-minute heart rate monitoring (HRM) and individual calibrations of the relationship between heart rate and oxygen consumption. The mean TEE measured with this technique is comparable with the mean value obtained using DLW or whole body calorimetry (Spurr *et al.,* 1988; Ceesay *et al.,* 1989; Livingstone *et al.,* 1990; Livingstone *et al.,* 1992; Emons *et al.,* 1992; Maffeis *et al.,* 1995; van den Berg-Emons *et al.,* 1996; Davidson *et al.,* 1997; Ekelund *et al.,* 2000). Therefore, studies using either DLW or HRM were included in this evaluation in order to encompass data on children and adolescents with a wider variety of lifestyles, and to include age groups with limited information, if based on DLW alone.

The studies reviewed for this consultation involved a total of 801 boys and 808 girls of one to 18 years of age (Torun, 2001). Most (56 percent of the boys, 68 percent of the girls) were from the United States or the United Kingdom; 18 percent of the boys and 18 percent of the girls were from Canada, Denmark, Italy, Sweden or the Netherlands; and 26 percent of the boys and 14 percent of the girls were from Brazil, Chile, Colombia, Guatemala or Mexico. The Latin American children were four to 15 years old, and all lived in urban areas. Inter-individual coefficients of variation ranged from 9 to 34 percent within studies with DLW, and from 9 to 27 percent within studies with HRM. The overall mean coefficient of variation was 19 percent for energy expenditure calculated as TEE/day, and 17 percent when calculated as TEE/kg/day. The inter-individual variability was similar to that observed with DLW among infants (18 percent for TEE/day, and 15 percent for TEE/kg/day; see section 3.1).

4.2 EQUATIONS TO PREDICT TOTAL ENERGY EXPENDITURE

Predictive equations were derived from the studies of TEE. Because many publications did not present results on individual children, the mean values for boys or girls of a specific age, or within a reasonably narrow age range, were used in the calculations, weighting the results of each study on the number of children. Various mathematical models (e.g. linear, multiple, polynomial, etc.) were evaluated, with age and/or body weight as predictors of TEE. Age and weight were highly correlated, with a tolerance of 0.078 among boys and 0.061 among girls. Weight was selected as the single predictor, since it played a greater role than age in predicting TEE, and the exclusion of age from the predictive models did not increase the error of the estimate. The lowest errors of estimation were obtained with the following quadratic polynomial regression equations for boys and girls (Figure 4.1) (Torun, 2001):

Boys:
TEE (MJ/day) = 1.298 + 0.265 kg – 0.0011 kg^2; $n_{weighted}$ = 801, r = 0.982, r^2 = 0.964, see = 0.518
TEE (kcal/day) = 310.2 + 63.3 kg – 0.263 kg^2

Girls:
TEE (MJ/day) = 1.102 + 0.273 kg – 0.0019 kg^2; $n_{weighted}$ = 808, r = 0.955, r^2 = 0.913, see = 0.650
TEE (kcal/day) = 263.4 + 65.3 kg – 0.454 kg^2

The equations were validated internally by dividing the studies into model-building sub-samples (70 percent of the studies, n = 549–618 boys or girls) and validation sub-samples (30 percent of the studies, n = 183–252 boys or girls). The validation sub-samples were randomly selected for each gender after stratifying the studies on quintiles of mean body weight – the method used to measure TEE (DLW or HRM) – and categorizing according to whether the study was done in an industrialized or a developing country. The correlation coefficients of the quadratic equations derived from the model-building sub-samples ranged from 0.959 to 0.982, with standard errors of the estimate from 0.504 to 0.651 MJ/day. Mean differences between predicted and measured values among boys were within ± 1 percent, with a standard deviation of 6 percent; and among girls, within ± 3 percent, with a standard deviation of 9 percent (Torun, 2001).

4.3 ENERGY NEEDS FOR GROWTH

Energy needs for growth have two components: 1) the energy used to synthesize growing tissues; and 2) the energy deposited in those tissues, basically as fat and protein, because carbohydrate content is negligible. Energy spent in tissue synthesis is part of TEE measured with either DLW or HRM. Hence, only the energy deposited in growing tissues was added to TEE in order to calculate energy requirements.

Table 4.1 shows the mean weight gain of boys and girls calculated from the WHO weight-for-age standards (WHO, 1983). The composition of weight gain was based on measurements at one and two years of age (Butte *et al.,* 2000; Butte, 2001), assuming that the composition of normally growing tissues does not change much between the end of infancy and the onset of puberty. It was estimated as 10 percent fat with an energy content of 38.7 kJ/g (9.25 kcal/g), 20 percent protein of 23.6 kJ/g (5.65 kcal/g) energy content, and 70 percent water, carbohydrate and minerals with negligible content of energy. The average energy deposited in growing tissues was then about 8.6 kJ (2 kcal) per gram of weight gain. Even if this amount of energy were an over- or underestimation as large as 50 percent, it would only produce an error of about ± 1 percent in the calculations of energy requirements in childhood and adolescence.

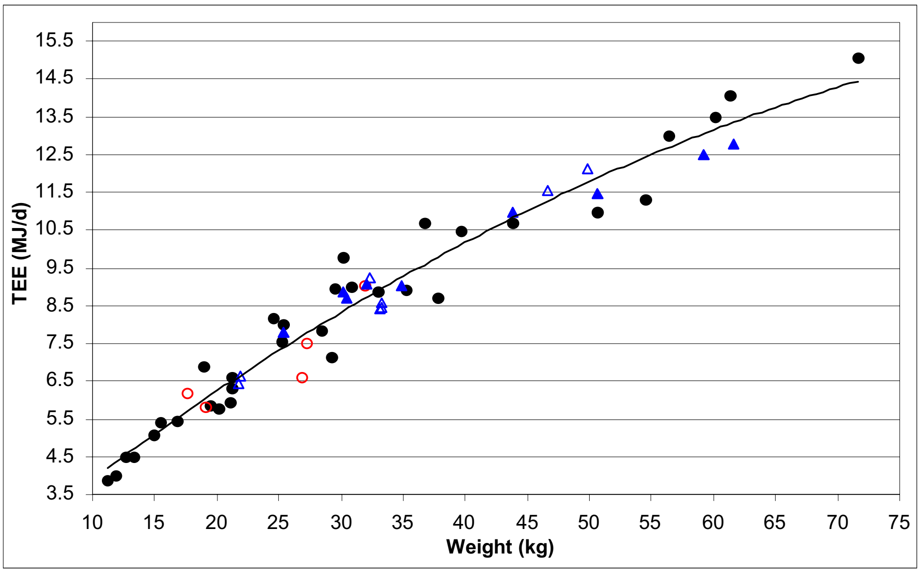
4.4 CALCULATION OF ENERGY REQUIREMENTS

TEE was calculated using the predictive quadratic equations and the WHO reference values of weight-for-age (Torun, 2001; WHO, 1983). The median weight at the midpoint of each year of age was used for the ages of between one and 17 years (i.e. median weights at 1.5, 2.5..., 17.5 years). At the lower end of the weight distribution, which corresponds to infants between one and two years of age, predicted values were about 7 percent higher than the actual measurements of TEE. When reduced by that percentage, TEE estimates fell in line with those of 12-month-old infants (Butte, 2001). The small transient increment in TEE/kg/day between one and three years is probably associated with the effort of children starting to walk and run.

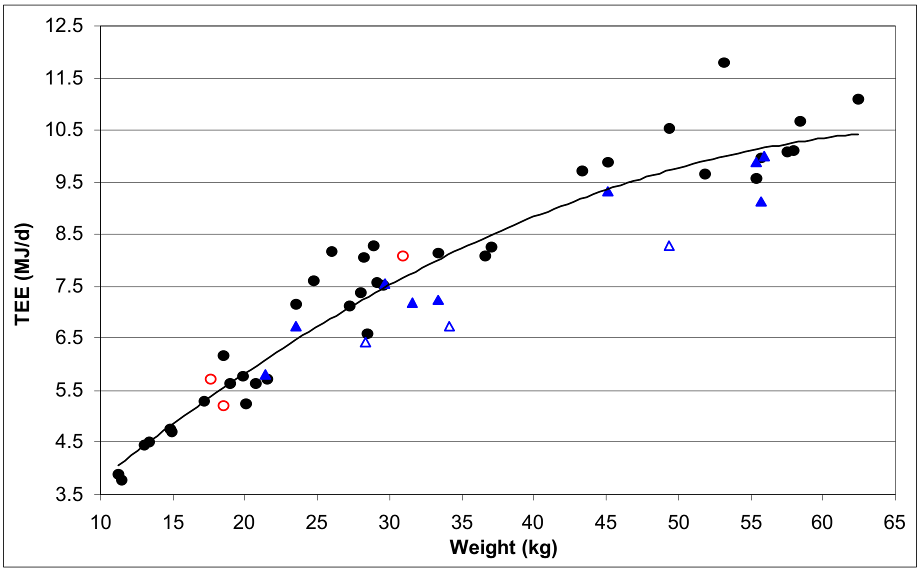
Energy deposited in growing tissues was estimated by multiplying the mean daily weight gain at each year of age (Table 4.1), by the average energy deposited in growing tissues (8.6 kJ or 2 kcal per gram of weight gain). The sum of energy deposition and TEE is the mean daily energy requirement (MJ or kcal/day, Tables 4.2 and 4.3). This was then divided by the median weight at each year to express requirements as energy units per kilogram of body weight.

FIGURE 4.1
Quadratic polynomial regression of total energy expenditure on body weight, weighting each data point by the number of children in the study

BOYS



GIRLS



Boys: $y = 1.298 + 0.265x - 0.0011x^2$; $n_{weighted} = 801$, $r = 0.982$, see = 0.518.
Girls: $y = 1.102 + 0.273x - 0.0019x^2$; $n_{weighted} = 808$, $r = 0.955$, see = 0.650.
Solid circles: DLW, industrialized countries. Clear circles: DLW, developing countries.
Solid triangles: HRM, industrialized countries. Clear triangles: HRM, developing countries.
Source: Torun, 2001.

TABLE 4.1
Mean weight gain of boys and girls, one to 17 years of age

Age	Boys		Girls	
years	kg/year	g/day	kg/year	g/day
1–2	2.4	6.6	2.4	6.6
2–3	2.0	5.5	2.2	6.0
3–4	2.1	5.8	1.9	5.2
4–5	2.0	5.5	1.7	4.7
5–6	2.0	5.5	1.8	4.9
6–7	2.2	6.0	2.3	6.3
7–8	2.4	6.6	3.0	8.2
8–9	2.8	7.7	3.7	10.1
9–10	3.3	9.0	4.0	11.0
10–11	3.9	10.7	4.5	12.3
11–12	4.5	12.3	4.5	12.3
12–13	5.2	14.2	4.6	12.6
13–14	5.8	15.9	4.2	11.5
14–15	5.9	16.2	3.4	9.3
15–16	5.4	14.8	2.2	6.0
16–17	4.2	11.5	0.8	2.2
17–18	2.6	7.1	0	0

Source: Calculated from WHO references of weight by age (WHO,1983).

BMR was estimated by using the equations endorsed in the report of the 1985 FAO/WHO/UNU expert consultation (Schofield, 1985), and upheld by this consultation (section 5.2, Table 5.2), using the median weight for every year of age. Mean PAL was calculated as a multiple of BMR, dividing total energy expenditure by the estimated BMR. As discussed in section 3.4.2, PAL calculated in this manner is on average 1 percent lower than when daily energy requirement is divided by BMR (James and Schofield, 1990) because growth contributes that proportion to the total energy requirement in childhood and adolescence. Thus, to estimate the energy requirement, the energy accrued during growth must be added, or the PAL value of children and adolescents must be multiplied by 1.01 (i.e. to make it 1 percent higher).

4.4.1 Comparison with previous requirements

In Table 4.4 and Figure 4.2 the new requirements are compared with those of the 1985 report. The cross-over of the curves at ten to 11 years is most probably artificial and the result of the different approaches used by the 1981 consultation to calculate requirements of children under ten years of age (dietary intake) and over ten years (factorial estimate of energy expenditure) (WHO, 1985). Compared with previous estimates, energy requirements proposed by this consultation are on average 18 percent lower for boys and 20 percent lower for girls under seven years of age, and 12 and 5 percent lower, respectively, for boys and girls seven to ten years of age. From 12 years onwards, the proposed requirements are an average of 12 percent higher for both boys and girls.

4.4.2 Influence of habitual physical activity on energy requirements

Energy requirements vary with the level of habitual physical activity. Most studies of TEE were carried out on random or convenient subject samples. Children and adolescents in these samples had different levels of habitual activity, resulting in inter-individual coefficients of variability as high as ± 34 percent (Torun, 2001). Thus, the values shown in Tables 4.2 and 4.3 may be regarded as the requirements of child and adolescent populations with "average" or "moderate" (i.e. not predominantly sedentary nor vigorous) physical activity.

Children and adolescents in rural, traditional communities in developing countries are more active than their counterparts in urban areas or in developed, industrialized countries. The quantitative differences were assessed from factorial estimates of TEE, calculated from 42 studies with time allocation data that involved approximately 4 000 boys and girls in industrialized countries, and 2 400 in rural or urban areas of developing countries (Torun, 2001; 1996). On average, TEE of boys and girls five to nine, ten to 14 and 15 to 19 years of age was, respectively, about 10, 15 and 25 percent higher in rural developing countries than in cities or industrialized countries. Based on these values, on the within-study coefficients of variation of TEE measured with DLW or HRM and on the mean errors of estimation of the predictive equations for TEE, this consultation endorsed the recommendation to reduce or increase by 15 percent the requirement of population groups that are less or more active than average, starting at six years of age (Torun, 2001).

4.4.3 Requirements of populations with different levels of physical activity

Energy requirements were calculated for children over five years of age and for adolescents with lifestyles involving three levels of habitual physical activity, subtracting or adding 15 percent from the requirements shown in Tables 4.2 and 4.3 for children and adolescents with "average" physical activity. Population groups with less, similar or more than average activity were classified as leading "light", "moderate" or "vigorous" lifestyles, respectively. Their requirements are shown in Tables 4.5 and 4.6. To facilitate recollection, values were rounded to the closest 0.1 MJ (25 kcal)/day, 5 kJ (1 kcal)/kg/day, and 0.05 PAL units.

The following general descriptions may help to decide which level of energy requirement is more appropriate for a specific population group.

Examples of populations with *light* physical lifestyles, or that are *less active than average*, are children and adolescents who every day spend several hours at school or in sedentary occupations; do not practise physical sports regularly; generally use motor vehicles for transportation; and spend most leisure time in activities that require little physical effort, such as watching television, reading, using computers or playing without much body displacement.

Examples of populations with *vigorous* lifestyles, or that are *more active than average*, are children and adolescents who every day walk long distances or use bicycles for transportation; engage in high energy-demanding occupations, or perform high energy-demanding chores for several hours each day; and/or practise sports or exercise that demand a high level of physical effort for several hours, several days of the week.

Children and adolescents with habitual physical activity that is more strenuous than the examples given for a light lifestyle, but not as demanding as the examples for vigorous lifestyle, would qualify in the category of *average* or *moderate* physically active lifestyles.

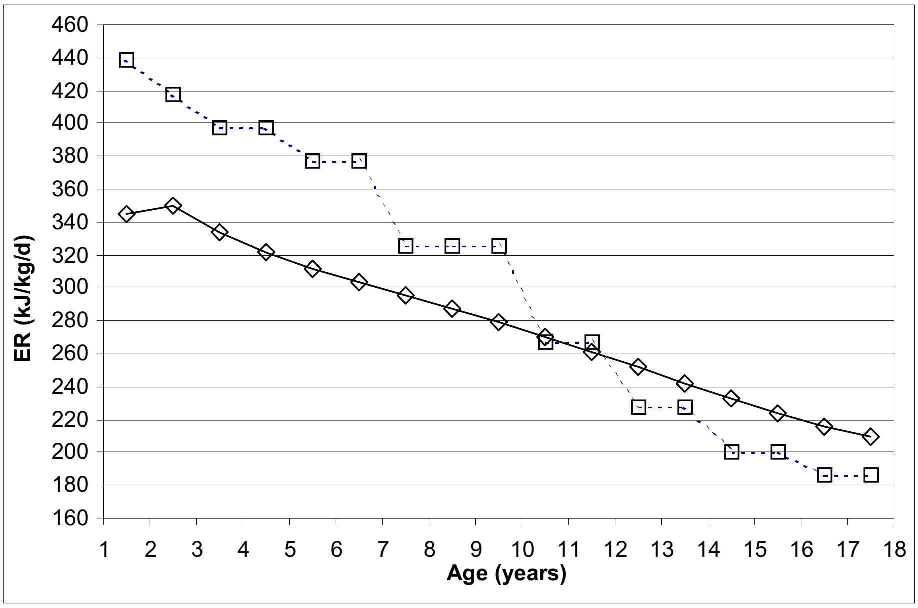
4.5 RECOMMENDATIONS FOR REGULAR PHYSICAL ACTIVITY

A certain amount of habitual physical activity is desirable for biological and social well-being. The regular performance of physical activity by children, in conjunction with good nutrition, is associated with health, adequate growth and well-being, and probably with lower risk of disease in adult life (Viteri and Torun, 1981; Torun and Viteri, 1994; Boreham and Riddoch, 2001). Children who are physically active explore their environment and interact socially more than their less active counterparts. There may also be a behavioural carry-over into adulthood, whereby active children are more likely to be active as adults, with the ensuing health benefits of exercise (Boreham and Riddoch, 2001).

On the other hand, sedentary lifestyles are increasing in most societies around the world, mainly owing to increased access to effort-saving technology and devices and to structural and social constraints. Examples of these are increased use of automobiles and buses for transportation, piped water and electrical appliances in the household, electronic equipment and computers in the workplace, elevators and escalators in buildings, and television sets and computers for entertainment, as well as a reduction in outdoor playing and walking caused by concerns about crime and the safety of pedestrians and cyclists. Sedentary children often eat amounts of food that exceed their relatively lower energy requirements, go into a positive energy balance and are at risk of becoming overweight or obese (Bar-Or *et al.,* 1998; Goran and Treuth, 2001; Dietz and Gortmaker, 2001).

FIGURE 4.2
Comparison of proposed energy requirements with FAO/WHO/UNU 1985 requirements

BOYS



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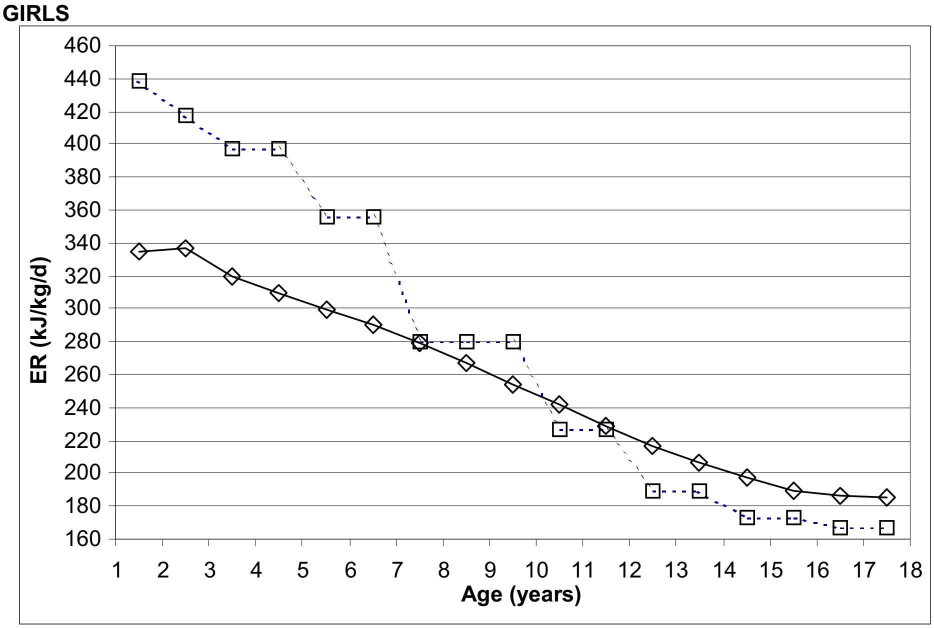

Continuous line: proposed energy requirements. Interrupted line: 1985 requirements.
Source: Torun, 2001.

TABLE 4.2

Boy's energy requirements calculated by quadratic regression analysis of TEE on weight, plus allowance for energy deposition in tissues during growth (E_g)

Age	Weight	TEE[a]		E_g[b]		BMR_{est}[c]		Daily energy requirement				PAL[d]
years	kg	MJ/d	*kcal/d*	MJ/d	*kcal/d*	MJ/d	*kcal/d*	MJ/d	*kcal/d*	kJ/kg/d	*kcal/kg/d*	TEE/BMR
1–2[e]	11.5	3.906	*934*	0.057	*14*	2.737	*654*	3.963	*948*	345	*82.4*	1.43
2–3	13.5	4.675	*1 117*	0.047	*11*	3.235	*773*	4.722	*1 129*	350	*83.6*	1.45
3–4	15.7	5.187	*1 240*	0.049	*12*	3.602	*861*	5.236	*1 252*	334	*79.7*	1.44
4–5	17.7	5.644	*1 349*	0.047	*11*	3.792	*906*	5.691	*1 360*	322	*76.8*	1.49
5–6	19.7	6.092	*1 456*	0.047	*11*	3.982	*952*	6.139	*1 467*	312	*74.5*	1.53
6–7	21.7	6.531	*1 561*	0.052	*12*	4.172	*997*	6.583	*1 573*	303	*72.5*	1.57
7–8	24.0	7.024	*1 679*	0.057	*14*	4.390	*1 049*	7.081	*1 692*	295	*70.5*	1.60
8–9	26.7	7.589	*1 814*	0.066	*16*	4.647	*1 111*	7.655	*1 830*	287	*68.5*	1.63
9–10	29.7	8.198	*1 959*	0.078	*19*	4.932	*1 179*	8.276	*1 978*	279	*66.6*	1.66
10–11	33.3	8.903	*2 128*	0.092	*22*	5.218	*1 247*	8.995	*2 150*	270	*64.6*	1.71
11–12	37.5	9.689	*2 316*	0.106	*25*	5.529	*1 321*	9.795	*2 341*	261	*62.4*	1.75
12–13	42.3	10.539	*2 519*	0.123	*29*	5.884	*1 406*	10.662	*2 548*	252	*60.2*	1.79
13–14	47.8	11.452	*2 737*	0.137	*33*	6.291	*1 504*	11.588	*2 770*	242	*57.9*	1.82
14–15	53.8	12.371	*2 957*	0.139	*33*	6.735	*1 610*	12.510	*2 990*	233	*55.6*	1.84
15–16	59.5	13.171	*3 148*	0.127	*30*	7.157	*1 711*	13.298	*3 178*	224	*53.4*	1.84
16–17	64.4	13.802	*3 299*	0.099	*24*	7.520	*1 797*	13.901	*3 322*	216	*51.6*	1.84
17–18	67.8	14.208	*3 396*	0.061	*15*	7.771	*1 857*	14.270	*3 410*	210	*50.3*	1.83

[a] TEE (MJ/d) = 1.298 + 0.265 kg – 0.0011 kg^2.
[b] 8.6 kJ or *2 kcal*/g weight gain.
[c] BMR_{est}: basal metabolic rate estimated with predictive equations on body weight (Schofield, 1985).
[d] PAL_{est}: physical activity level = TEE/BMR_{est}. To calculate requirements, add E_g or multiply by 1.01 (see text).
[e] Requirements for 1 to 2 years reduced by 7 percent to fit with energy requirements of infants (see text).
Source: Torun, 2001.

TABLE 4.3

Girls' energy requirements calculated by quadratic regression analysis of TEE on weight, plus allowance for energy deposition in tissues during growth (E_g)

Age	Weight	TEE[a]		E_g[b]		BMR_{est}[c]		Daily energy requirement				PAL[d]
years	kg	MJ/d	*kcal/d*	MJ/d	*kcal/d*	MJ/d	*kcal/d*	MJ/d	*kcal/d*	kJ/kg/d	*kcal/kg/d*	TEE/BMR
1–2[e]	10.8	3.561	*851*	0.057	*14*	2.505	*599*	3.618	*865*	335	*80.1*	1.42
2–3	13.0	4.330	*1 035*	0.052	*12*	3.042	*727*	4.382	*1 047*	337	*80.6*	1.42
3–4	15.1	4.791	*1 145*	0.045	*11*	3.317	*793*	4.836	*1 156*	320	*76.5*	1.44
4–5	16.8	5.152	*1 231*	0.040	*10*	3.461	*827*	5.192	*1 241*	309	*73.9*	1.49
5–6	18.6	5.522	*1 320*	0.042	*10*	3.614	*864*	5.564	*1 330*	299	*71.5*	1.53
6–7	20.6	5.920	*1 415*	0.054	*13*	3.784	*904*	5.974	*1 428*	290	*69.3*	1.56
7–8	23.3	6.431	*1 537*	0.071	*17*	4.014	*959*	6.502	*1 554*	279	*66.7*	1.60
8–9	26.6	7.019	*1 678*	0.087	*21*	4.294	*1 026*	7.106	*1 698*	267	*63.8*	1.63
9–10	30.5	7.661	*1 831*	0.094	*23*	4.626	*1 105*	7.755	*1 854*	254	*60.8*	1.66
10–11	34.7	8.287	*1 981*	0.106	*25*	4.841	*1 157*	8.393	*2 006*	242	*57.8*	1.71
11–12	39.2	8.884	*2 123*	0.106	*25*	5.093	*1 217*	8.990	*2 149*	229	*54.8*	1.74
12–13	43.8	9.414	*2 250*	0.108	*26*	5.351	*1 279*	9.523	*2 276*	217	*52.0*	1.76
13–14	48.3	9.855	*2 355*	0.099	*24*	5.603	*1 339*	9.954	*2 379*	206	*49.3*	1.76
14–15	52.1	10.168	*2 430*	0.080	*19*	5.816	*1 390*	10.248	*2 449*	197	*47.0*	1.75
15–16	55.0	10.370	*2 478*	0.052	*12*	5.978	*1 429*	10.421	*2 491*	189	*45.3*	1.73
16–17	56.4	10.455	*2 499*	0.019	*5*	6.056	*1 447*	10.474	*2 503*	186	*44.4*	1.73
17–18	56.7	10.473	*2 503*	0.000	*0*	6.073	*1 451*	10.473	*2 503*	185	*44.1*	1.72

[a] TEE (MJ/d) = 1.102 + 0.273 kg – 0.0019 kg^2.
[b] 8.6 kJ or *2 kcal*/g weight gain.
[c] BMR_{est}: basal metabolic rate estimated with predictive equations on body weight (Schofield, 1985).
[d] PAL_{est}: physical activity level = TEE/BMR_{est}. To calculate requirements, add E_g or multiply by 1.01 (see text).
[e] Requirements for 1 to 2 years reduced by 7 percent to fit with energy requirements of infants (see text).
Source: Torun, 2001.

TABLE 4.4
Comparison of new proposal for daily energy requirements with the 1985 FAO/WHO/UNU report

Age	Boys				Girls			
	New values		FAO/WHO/UNU, 1985		New values		FAO/WHO/UNU, 1985	
years	kJ/kg/d	*kcal/kg/d*	kJ/kg/d	% diff [a]	kJ/kg/d	*kcal/kg/d*	kJ/kg/d	% diff [a]
1–2	345	*82.4*	439	-21.4	335	*80.1*	439	-23.7
2–3	350	*83.6*	418	-16.3	337	*80.6*	418	-19.4
3–4	334	*79.7*	397	-15.9	320	*76.5*	397	-19.4
4–5	322	*76.8*	397	-18.9	309	*73.9*	397	-22.2
5–6	312	*74.5*	377	-17.2	299	*71.5*	356	-16.0
6–7	303	*72.5*	377	-19.6	290	*69.3*	356	-18.5
7–8	295	*70.5*	326	-9.5	279	*66.7*	280	-0.4
8–9	287	*68.5*	326	-12.0	267	*63.8*	280	-4.6
9–10	279	*66.6*	326	-14.4	254	*60.8*	280	-9.3
10–11	270	*64.6*	267	1.1	242	*57.8*	227	6.6
11–12	261	*62.4*	267	-2.2	229	*54.8*	227	0.9
12–13	252	*60.2*	228	10.5	217	*52.0*	189	14.8
13–14	242	*57.9*	228	6.1	206	*49.3*	189	9.0
14–15	233	*55.7*	200	16.5	197	*47.0*	173	13.9
15–16	224	*53.4*	200	12.0	189	*45.3*	173	9.2
16–17	216	*51.6*	186	16.1	186	*44.4*	167	11.4
17–18	210	*50.3*	186	12.9	185	*44.1*	167	10.8

[a] % difference = new value/FAOWHOUNU × 100 – 100.
Source: Torun, 2001.

TABLE 4.5
Boys' energy requirements in populations with three levels of habitual physical activity

Age	Weight	Light physical activity					Moderate physical activity					Heavy physical activity				
		Daily energy requirement				PAL	Daily energy requirement				PAL	Daily energy requirement				PAL
years	kg	MJ/d	*kcal/d*	kJ/kg/d	*kcal/kg/d*		MJ/d	*kcal/d*	kJ/kg/d	*kcal/kg/d*		MJ/d	*kcal/d*	kJ/kg/d	*kcal/kg/d*	
1–2	11.5						4.0	*950*	345	*82*	1.45					
2–3	13.5						4.7	*1 125*	350	*84*	1.45					
3–4	15.7						5.2	*1 250*	335	*80*	1.45					
4–5	17.7						5.7	*1 350*	320	*77*	1.50					
5–6	19.7						6.1	*1 475*	310	*74*	1.55					
6–7	21.7	5.6	*1 350*	260	*62*	1.30	6.6	*1 575*	305	*73*	1.55	7.6	*1 800*	350	*84*	1.80
7–8	24.0	6.0	*1 450*	250	*60*	1.35	7.1	*1 700*	295	*71*	1.60	8.2	*1 950*	340	*81*	1.85
8–9	26.7	6.5	*1 550*	245	*59*	1.40	7.7	*1 825*	285	*69*	1.65	8.8	*2 100*	330	*79*	1.90
9–10	29.7	7.0	*1 675*	235	*56*	1.40	8.3	*1 975*	280	*67*	1.65	9.5	*2 275*	320	*76*	1.90
10–11	33.3	7.7	*1 825*	230	*55*	1.45	9.0	*2 150*	270	*65*	1.70	10.4	*2 475*	310	*74*	1.95
11–12	37.5	8.3	*2 000*	220	*53*	1.50	9.8	*2 350*	260	*62*	1.75	11.3	*2 700*	300	*72*	2.00
12–13	42.3	9.1	*2 175*	215	*51*	1.55	10.7	*2 550*	250	*60*	1.80	12.3	*2 925*	290	*69*	2.05
13–14	47.8	9.8	*2 350*	205	*49*	1.55	11.6	*2 775*	240	*58*	1.80	13.3	*3 175*	275	*66*	2.05
14–15	53.8	10.6	*2 550*	200	*48*	1.60	12.5	*3 000*	235	*56*	1.85	14.4	*3 450*	270	*65*	2.15
15–16	59.5	11.3	*2 700*	190	*45*	1.60	13.3	*3 175*	225	*53*	1.85	15.3	*3 650*	260	*62*	2.15
16–17	64.4	11.8	*2 825*	185	*44*	1.55	13.9	*3 325*	215	*52*	1.85	16.0	*3 825*	245	*59*	2.15
17–18	67.8	12.1	*2 900*	180	*43*	1.55	14.3	*3 400*	210	*50*	1.85	16.4	*3 925*	240	*57*	2.15

Notes:
Body weight at mid-point of age interval (WHO, 1983).
Moderate physical activity: MJ/d = (1.298 + 0.265 kg – 0.0011 kg^2) + 8.6 kJ/g daily weight gain.
Vigorous physical activity: 15 percent > moderate physical activity.
Source: Torun, 2001.

Numbers rounded to the closest 0.1 MJ/d, *25 kcal/d*, 5 kJ/kg/d, *1 kcal/kg/d*, 0.05 PAL unit.
Light physical activity: 15 percent < moderate physical activity.
PAL = TEE/(predicted BMR/d).

TABLE 4.6
Girls' energy requirements in populations with three levels of habitual physical activity

Age	Weight	Light physical activity					Moderate physical activity					Heavy physical activity				
		Daily energy requirement				PAL	Daily energy requirement				PAL	Daily energy requirement				PAL
Years	kg	MJ/d	*kcal/d*	kJ/kg/d	*kcal/kg/d*		MJ/d	*kcal/d*	kJ/kg/d	*kcal/kg/d*		MJ/d	*kcal/d*	kJ/kg/d	*kcal/kg/d*	
1–2	10.8						3.6	*850*	335	*80*	1.40					
2–3	13.0						4.4	*1 050*	335	*81*	1.40					
3–4	15.1						4.8	*1 150*	320	*77*	1.45					
4–5	16.8						5.2	*1 250*	310	*74*	1.50					
5–6	18.6						5.6	*1 325*	300	*72*	1.55					
6–7	20.6	5.1	*1 225*	245	*59*	1.30	6.0	*1 425*	290	*69*	1.55	6.9	*1 650*	335	*80*	1.80
7–8	23.3	5.5	*1 325*	235	*57*	1.35	6.5	*1 550*	280	*67*	1.60	7.5	*1 775*	320	*77*	1.85
8–9	26.6	6.0	*1 450*	225	*54*	1.40	7.1	*1 700*	265	*64*	1.65	8.2	*1 950*	305	*73*	1.90
9–10	30.5	6.6	*1 575*	215	*52*	1.40	7.7	*1 850*	255	*61*	1.65	8.9	*2 125*	295	*70*	1.90
10–11	34.7	7.1	*1 700*	205	*49*	1.45	8.4	*2 000*	240	*58*	1.70	9.6	*2 300*	275	*66*	1.95
11–12	39.2	7.6	*1 825*	195	*47*	1.50	9.0	*2 150*	230	*55*	1.75	10.3	*2 475*	265	*63*	2.00
12–13	43.8	8.1	*1 925*	185	*44*	1.50	9.5	*2 275*	215	*52*	1.75	11.0	*2 625*	245	*60*	2.00
13–14	48.3	8.5	*2 025*	175	*42*	1.50	10.0	*2 375*	205	*49*	1.75	11.4	*2 725*	235	*57*	2.00
14–15	52.1	8.7	*2 075*	165	*40*	1.50	10.2	*2 450*	195	*47*	1.75	11.8	*2 825*	225	*54*	2.00
15–16	55.0	8.9	*2 125*	160	*39*	1.50	10.4	*2 500*	190	*45*	1.75	12.0	*2 875*	220	*52*	2.00
16–17	56.4	8.9	*2 125*	160	*38*	1.50	10.5	*2 500*	185	*44*	1.75	12.0	*2 875*	215	*51*	2.0
17–18	56.7	8.9	*2 125*	155	*37*	1.45	10.5	*2 500*	185	*44*	1.70	12.0	*2 875*	215	*51*	1.95

Notes:
Body weight at mid-point of age interval (WHO, 1983).
Moderate physical activity: MJ/d = (1.102 + 0.273 kg – 0.0019 kg^2) + 8.6 kJ/g daily weight gain.
Vigorous physical activity: 15 percent > moderate physical activity.
Source: Torun, 2001.
Numbers rounded to the closest 0.1 MJ/d, *25 kcal/d*, 5 kJ/kg/d, *1 kcal/kg/d*, 0.05 PAL unit.
Light physical activity: 15 percent < moderate physical activity.
PAL = TEE/(predicted BMR/d).

It is therefore important that recommendations for appropriate levels of physical activity accompany recommendations for dietary energy intakes. There is no direct experimental or epidemiological evidence on the minimal or optimal frequency, duration and intensity of exercise that promotes health and well-being in children, but it has been suggested that children should perform a minimum of 60 minutes per day of moderate-intensity physical activity, which may be carried out in cumulative bouts of ten or more minutes, and which should be supplemented by activities that promote flexibility, muscle strength and increase in bone mass (Boreham and Riddoch, 2001). This can be pursued by promoting walking, climbing stairs or cycling as part of everyday activities, and encouraging participation in games and sports that involve body displacement and a certain degree of physical effort. In making such recommendations, local culture, social customs and environmental characteristics must be taken into account.

4.6 INFECTIONS AND MILD MALNUTRITION

Nutritional requirements and dietary energy recommendations for children who are severely malnourished or chronically ill, such as owing to HIV/AIDS, are beyond the scope of this report. It must be recognized, however, that many populations around the world include large proportions of children with some degree of weight deficit and growth retardation as a result of mild to moderate chronic malnutrition and/or repeated bouts of infections (UNICEF, 2001). As was pointed out in the report from the 1985 FAO/WHO/UNU expert consultation (WHO, 1985), when a public health problem is of such magnitude that it affects the energy and protein requirements of a significant part of the population, it may not be ignored in the assessment of such requirements or in the recommendations that are made.

Situations that promote malnutrition also favour a high incidence of infectious diseases, which in turn further contribute to the malnutrition. For many children under five – and particularly those under three – years of age who live in these conditions, being sick or convalescing from diarrhoea or a respiratory infection is part of "normal life", because they experience this several times a year, with each episode lasting two to 15 days and requiring up to twice that time to achieve full recovery, provided that an intervening new episode of disease does not interrupt the recovery process (Mata, 1978; Black and Lanata, 1995; Steinhoff, 2000). Infections of this nature often result in negative energy balance resulting from poor appetite, decreased absorption of nutrients during diarrhoeal episodes and increased metabolic rate, particularly in febrile processes (Waterlow and Tomkins, 1992; Torun, 2000). This leads to chronic mild wasting (i.e. low weight-for-height) and stunting (i.e. low height-for-age), which may be prevented, ameliorated or corrected if adequate care and food are available, especially in the periods between infectious episodes when appetite has been re-established. If, on the contrary conditions do not improve, the status quo of mild malnutrition is maintained, the possibility for catch-up is reduced and the consequences of malnutrition will continue to prevail in those societies.

Diets for catch-up weight gain must provide all nutrients and energy sources in amounts that surpass the requirements of well-nourished, healthy children. Quantitative estimates of energy requirements for catch-up are difficult to establish for two reasons: 1) the target body weight is not fixed but increases with time in a growing child, so that the longer the period of nutritional deficit, the greater the gap to be filled; and 2) a low weight for a given age may be owing either to a reduction in weight below the acceptable range of weight-for-height (i.e. wasting) or to a low height (i.e. stunting) with a concomitant decrease in weight. In the latter case, if the decrease in weight is proportional to the reduced growth in height, the child will not have a weight deficit as such, and provision of additional dietary energy may lead to overweight, as catch-up in height is much slower and less likely to be achieved than increase in weight.

The extra amounts of energy needed for catch-up growth of a child with actual weight deficit (i.e. low weight-for-height) have been estimated in studies on the rehabilitation of malnourished children as 21 kJ (5 kcal) per gram of tissue to be laid down (Fomon, 1971; Ashworth, 1969; Kerr *et al.,* 1973; Whitehead, 1973; Spady *et al.,* 1976; Krieger and Whitten, 1976). The recommended daily amounts of energy will depend on the rate at which catch-up is expected to occur. Under optimal clinical conditions, children with severe malnutrition can gain weight at rates of up to 20 or more times faster than normal growth. However, at the community level, catch-up rates of free-living children with mild to moderate degrees of weight deficit should realistically be expected to be no more than two or three times the normal rate.

In relation to the energy demands imposed by repeated bouts of infection, the paucity of data concerning illness, convalescence and post-convalescence does not allow estimates of energy requirements for infants and children to be based on direct measurements of energy expenditure and growth. This leads to the suggested use of a factorial estimate of theoretical needs during acute illness and/or convalescence. In addition to basal metabolism, the energy costs of normal growth and the energy needs for obligatory and discretionary activities, the factors involved in the estimate also include faecal energy losses owing to malabsorption from diarrhoeal disease, and increased energy needs imposed by fever and other responses to stress. This is no easy task owing to the variability in clinical and metabolic responses to illnesses of different aetiologies and different degrees of severity. A number of studies in different countries have attempted to quantify the proportion of the growth deficit that can be attributed to infections and the extra requirements for recovery from them, but the results have been inconsistent (WHO, 1985).

As was stated by the previous joint FAO/WHO/UNU expert consultation (WHO, 1985), it is still impossible to generalize about the amounts of additional energy needed for catch-up growth in children who have become malnourished, usually as a result of the combined effects of inadequate intake and frequent infection. The relative contributions of these two factors, and their severity, will vary in different communities and at different times. In many countries there are also important seasonal effects on food supply and incidence of infections. This consultation could not give a better recommendation than that previously offered, which was based on theoretical estimates to allow for twice the normal rate of weight gain among infants in countries with high prevalence of infant and childhood malnutrition. As shown in Table 4.7, this ranges from an increase in energy requirements – and intakes – of 14.5 percent at six to nine months of age, to 3.5 percent at 18 to 24 months. To restore growth, diets with a high energy density may be needed during the short anabolic periods following episodes of weight loss.

TABLE 4.7
Increase in energy requirements needed to allow for twice the normal growth rate of children six to 24 months old*

Age months	**Average weight gain** g/kg/day	**% increase over energy requirement**
6–9	1.83	14.5
9–12	1.15	8.5
12–18	0.67	5
18–24	0.51	3.5

* It was assumed that the requirements for normal growth were 1.5 times the theoretical estimates based on weight gain.
Source: adapted from WHO, 1985.

In practice, children should be fed according to appetite, with food of good overall quality that satisfies the needs for all nutrients. To counteract the effects of anorexia and the metabolic losses that accompany infection, sufficient amounts of food should be available in periods when appetite is restored and the child is recovering from infection. It must also be recognized that supplying the child's increased requirement is only one of the measures needed to counteract the effects of periodic infectious episodes. The primary need is for prevention through improved sanitation and other public health measures.

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5. ENERGY REQUIREMENTS OF ADULTS

The principles followed by the 1985 FAO/WHO/UNU expert consultation (WHO, 1985) were adhered to, and energy requirements of adults were calculated from factorial estimates of habitual TEE. The use of techniques such as DLW and HRM confirmed the large diversity of TEE – and hence of energy requirements – among adult societies, which were previously reported by time–motion studies. Growth is no longer an energy-demanding factor in adulthood, and BMR is relatively constant among population groups of a given age and gender. Consequently, habitual physical activity and body weight are the main determinants for the diversity in energy requirements of adult populations with different lifestyles (James and Schofield, 1990).

5.1 FACTORIAL ESTIMATION OF TOTAL ENERGY EXPENDITURE AND PHYSICAL ACTIVITY LEVEL

The diversity in body size, body composition and habitual physical activity among adult populations with different geographic, cultural and economic backgrounds does not allow a universal application of energy requirements based on TEE measured with DLW (or HRM) in groups with a specific lifestyle. Hence, to account for the differences in physical activity, TEE was estimated through factorial calculations that combined the time allocated to habitual activities and the energy cost of those activities. Table 5.1 shows examples of these calculations. To account for differences in body size and composition, the energy cost of activities was calculated as a multiple of BMR per minute, also referred to as the physical activity ratio (PAR), and the 24-hour energy requirement was expressed as a multiple of BMR per 24 hours by using the PAL value (James and Schofield, 1990). Together with BMR of the population, PAL when known or when derived using BMR estimated from age and gender-specific predictive equations based on the average body weight of the population provides an estimate of TEE and hence the mean energy requirement for that population.

To simplify calculations, the previous expert consultation classified the PAL of adult population groups as light, moderate or heavy, depending on their occupational or other work, and multiplied it by the corresponding BMR to arrive at requirements (WHO, 1985). The present consultation considered that the 24-hour PAL should not be based only on the physical effort demanded by occupational work, as there are people with light occupations who perform vigorous physical activity in their spare time, and people with heavy work who are quite sedentary the rest of the day. As discussed in section 5.3, it was decided to base the factorial estimates of energy requirements on the energy expenditure associated with lifestyles that combine occupational and discretionary physical activities.

This consultation also agreed that the average energy cost of activities expressed as a multiple of BMR, or PAR, should be similar for men and women. The effect of gender comes out when the PAR value is converted into energy units, because men have higher BMR for their body weight than women, and this difference is accentuated by the heavier weight of men. Consequently, the energy cost of most activities listed in Table 5.1 as a function of BMR is applicable to both men and women. Notable exceptions are vigorous activities that demand a level of effort proportional to muscle mass and strength, which tend to be greater among men (for example, lifting and carrying heavy loads, cutting wood or working with a sledgehammer).

5.2 ESTIMATION OF BASAL METABOLIC RATE

BMR constitutes about 45 to 70 percent of TEE in adults, and is determined principally by gender, body size, body composition and age. It can be measured accurately with small intra-individual variation by direct or indirect calorimetry under standard conditions, which include being awake in the supine position, ten to 12 hours after a meal, following eight hours of physical rest and no strenuous exercise in the preceding day, and being in a state of mental relaxation and an ambient environmental temperature that does not evoke shivering or sweating. BMR can be measured only under laboratory conditions and in small groups of representative individuals. There is a need to estimate BMR at the population level when using the factorial approach to estimate TEE from the average BMR and PAL value attributable to that population. Hence, the alternative has been to estimate a group's mean BMR using predictive equations based on measurements that are easier to obtain, such as body weight and/or height.

TABLE 5.1
Factorial calculations of total energy expenditure for a population group

Main daily activities	Time allocation hours	Energy cost[a] PAR	Time × energy cost	Mean PAL[b] multiple of 24-hour BMR
Sedentary or light activity lifestyle				
Sleeping	8	1	8.0	
Personal care (dressing, showering)	1	2.3	2.3	
Eating	1	1.5	1.5	
Cooking	1	2.1	2.1	
Sitting (office work, selling produce, tending shop)	8	1.5	12.0	
General household work	1	2.8	2.8	
Driving car to/from work	1	2.0	2.0	
Walking at varying paces without a load	1	3.2	3.2	
Light leisure activities (watching TV, chatting)	2	1.4	2.8	
Total	**24**		**36.7**	**36.7/24 = 1.53**
Active or moderately active lifestyle				
Sleeping	8	1	8.0	
Personal care (dressing, showering)	1	2.3	2.3	
Eating	1	1.5	1.5	
Standing, carrying light loads (waiting on tables, arranging merchandise)[c]	8	2.2	17.6	
Commuting to/from work on the bus	1	1.2	1.2	
Walking at varying paces without a load	1	3.2	3.2	
Low intensity aerobic exercise	1	4.2	4.2	
Light leisure activities (watching TV, chatting)	3	1.4	4.2	
Total	**24**		**42.2**	**42.2/24 = 1.76**
Vigorous or vigorously active lifestyle				
Sleeping	8	1	8.0	
Personal care (dressing, bathing)	1	2.3	2.3	
Eating	1	1.4	1.4	
Cooking	1	2.1	2.1	
Non-mechanized agricultural work (planting, weeding, gathering)	6	4.1	24.6	
Collecting water/wood	1	4.4	4.4	
Non-mechanized domestic chores (sweeping, washing clothes and dishes by hand)	1	2.3	2.3	
Walking at varying paces without a load	1	3.2	3.2	
Miscellaneous light leisure activities	4	1.4	5.6	
Total	**24**		**53.9**	**53.9/24 = 2.25**

[a] Energy costs of activities, expressed as multiples of basal metabolic rate, or PAR, are based on Annex 5 of the previous consultation's report (WHO, 1985) (see also Annex 5 of this report).
[b] PAL = physical activity level, or energy requirement expressed as a multiple of 24-hour BMR.
[c] Composite of the energy cost of standing, walking slowly and serving meals or carrying a light load.
Examples:
Sedentary or light activity: If this PAL was from a female population, 30 to 50 years old, with mean weight of 55 kg and mean BMR of 5.40 MJ/day (*1 290 kcal/day*), TEE = 1.53 × 5.40 = 8.26 MJ (*1 975 kcal*), or 150 kJ (*36 kcal*)/kg/d.
Active or moderately active: If this PAL was from a female population, 20 to 25 years old, with mean weight of 57 kg and mean BMR of 5.60 MJ/day (*1 338 kcal/day*), TEE = 1.76 × 5.60 = 9.86 MJ (*2 355 kcal*), or 173 kJ (*41 kcal*)/kg/d.
Vigorous or vigorously active: If this PAL was from a male population, 20 to 25 years old, with mean weight of 70 kg and mean BMR of 7.30 MJ/day (*1 745 kcal/day*), TEE = 2.25 × 7.30 = 16.42 MJ (*3 925 kcal*), or 235 kJ (*56 kcal*)/kg/d.

The report from the 1985 FAO/WHO/UNU expert consultation used a set of equations derived mostly from studies in Western Europe and North America (Schofield, 1985). Almost half of the data used to generate the equations for adults were from studies carried out in the late 1930s and early 1940s on Italian men with relatively high BMR values, and questions have been raised about the universal applicability of those equations (Soares and Shetty, 1988; de Boer *et al.,* 1988; Henry and Rees, 1991; Arciero *et al.,* 1993; Piers and Shetty, 1993; Soares, Francis and Shetty, 1993; Hayter and Henry, 1993 and 1994; Valencia *et al.,* 1994; Cruz, da Silva and dos Anjos, 1999; Henry, 2001; Ismail *et al.,* 1998). The use of closed-circuit indirect calorimetry in most studies has also been questioned, as this technique might overestimate oxygen consumption and energy expenditure. For the present consultation, predictive equations derived from a database with broader geographical and ethnic representation were evaluated (Henry, 2001; Cole, 2002). The predictive accuracies of the new equations and of those from 1985 were compared with published measurements of BMR in adults from different parts of the world, which were not part of the databases used to generate the predictive equations (Ramirez-Zea, 2002). Although the new equations had some merits, such as small reductions in the error of prediction and the overestimation bias among men, this consultation concluded that these were not robust enough to justify their adoption at present. For the time being, it was decided to retain the equations proposed in 1985 by Schofield (Table 5.2), and to pursue a more thorough analysis of existing information, or to promote a prospective study with broad global geographic and ethnic representation.

TABLE 5.2
Equations for estimating BMR from body weight*

Age *Years*	No.	BMR: MJ/day	see[a]	BMR: kcal/day	see[a]
Males					
< 3	162	0.249kg – 0.127	0.292	59.512kg – 30.4	70
3–10	338	0.095kg + 2.110	0.280	22.706kg + 504.3	67
10–18	734	0.074kg + 2.754	0.441	17.686kg + 658.2	105
18–30	2879	0.063kg + 2.896	0.641	15.057kg + 692.2	153
30–60	646	0.048kg + 3.653	0.700	11.472kg + 873.1	167
≥ 60	50	0.049kg + 2.459	0.686	11.711kg + 587.7	164
Females					
< 3	137	0.244kg – 0.130	0.246	58.317kg – 31.1	59
3–10	413	0.085kg + 2.033	0.292	20.315kg + 485.9	70
10–18	575	0.056kg + 2.898	0.466	13.384kg + 692.6	111
18–30	829	0.062kg + 2.036	0.497	14.818kg + 486.6	119
30–60	372	0.034kg + 3.538	0.465	8.126kg + 845.6	111
≥ 60	38	0.038kg + 2.755	0.451	9.082kg + 658.5	108

* Weight is expressed in kg. Predictive equations for children and adolescents are presented for the sake of completeness.
Source: Schofield, 1985.
[a] see = standard error of estimate.

5.3 PHYSICAL ACTIVITY LEVEL

The average PAL of healthy, well-nourished adults is a major determinant of their total energy requirement. As growth does not contribute to energy needs in adulthood, PAL can be measured or estimated from the average 24-hour TEE and BMR (i.e. PAL = TEE/BMR). Multiplying the PAL by the BMR gives the actual energy requirements. For example, a male with a PAL of 1.75 and a mean BMR of 7.10 MJ/day (1 697 kcal/day) would have a mean energy requirement of 1.75 × 7.10 = 12.42 MJ/day (2 970 kcal/day).[4] Other examples of these calculations are shown at the bottom of each panel in Table 5.1.

PAL has been calculated in several studies from measurements of TEE and measurements or estimates of BMR. Most of the existing data on the TEE of adults are from studies in industrialized societies, although some investigations have been done in developing countries where many people

[4] When the averages of the PAL and of the BMR of a population are known, the average energy requirement of the population can be estimated.

have lifestyles associated with levels of physical activity that differ from those in industrialized countries (Coward, 1998). A meta-analysis of studies that involved a total of 411 men and women from 18 to 64 years of age showed a modal value for PAL of 1.60 (range 1.55 to 1.65) for both men and women (Black *et al.,* 1996). For the most part, subjects were from affluent societies in developed countries. All were healthy, but 13 percent of the women and 9 percent of the men were overweight or obese, with BMI > 30. Typical sub-populations included students, housewives, white-collar or professional workers, and unemployed or retired individuals; only three persons were specifically identified as manual workers. Hence, the authors of the meta-analysis defined the study participants as people with a "predominantly sedentary Western lifestyle". An expert panel of the International Obesity Task Force (IOTF) suggested a somewhat lower PAL range of 1.50 to 1.55 as being representative of sedentary individuals (Erlichman, Kerbey and James, 2001).

The PAL values that can be sustained for a long period of time by free-living adult populations range from about 1.40 to 2.40. This consultation agreed that a desirable PAL includes the regular practice of physical activity at work or in spare time with an intensity and duration that will reduce the risk of becoming overweight and developing a variety of non-communicable chronic diseases usually associated as co-morbidities with obesity. As discussed in section 5.6, this corresponds to PAL values of 1.75 and higher. On the other hand, a minimum "maintenance" energy requirement was not defined, reaffirming the position of the previous expert consultation which stated that "any figure chosen would reflect a value judgement on what levels of activity above the minimum for survival could be appropriately included in the term "maintenance" (WHO, 1985).

5.3.1 Classification of physical activity levels

Energy requirements are highly dependent on habitual physical activity. This consultation classified the intensity of a population's habitual physical activity into three categories, as was done by the 1981 FAO/WHO/UNU expert consultation (WHO, 1985). However, in contrast with the 1981 consultation, a range of PAL values, rather than a mean PAL value, was established for each category. Furthermore, the same PAL values were used to assign men and women to a PAL category, for the reasons discussed in section 5.1.

The categories shown in Table 5.3 represent the different levels of activity associated with a population's lifestyle. These categories indicate the physical activity most often performed by most individuals in the population, over a period of time. Although there is no physiological basis for establishing the duration of that period, it may be defined as one month or longer.

The term "lifestyle" was preferred to "occupational work", as was used in the 1985 report, because there are groups of people with light or sedentary occupations who perform vigorous discretionary activities regularly, and therefore have a lifestyle that falls more appropriately within the "active" or "vigorously active" categories. It should also be borne in mind that some populations undergo cyclic changes in lifestyle, such as those related to the agricultural cycle among traditional rural societies, or those related to the seasons of the year where hot or mild summers alternate with cold winters. Energy requirements of such populations will change with the energy demands of their cyclical lifestyles.

TABLE 5.3
Classification of lifestyles in relation to the intensity of habitual physical activity, or PAL

Category	PAL value
Sedentary or light activity lifestyle	1.40-1.69
Active or moderately active lifestyle	1.70-1.99
Vigorous or vigorously active lifestyle	2.00-2.40*

* PAL values > 2.40 are difficult to maintain over a long period of time.

5.3.2 Examples of lifestyles with different levels of energy demands

Sedentary or light activity lifestyles. These people have occupations that do not demand much physical effort, are not required to walk long distances, generally use motor vehicles for transportation, do not exercise or participate in sports regularly, and spend most of their leisure time sitting or standing, with little body displacement (e.g. talking, reading, watching television, listening to the radio, using computers). One example is male office workers in urban areas, who only occasionally engage in physically demanding activities during or outside working hours. Another example are rural women living in villages that have electricity, piped water and nearby paved roads, who spend most of the time selling produce at home or in the marketplace, or doing light household chores and caring for children in or around their houses.

Active or moderately active lifestyles. These people have occupations that are not strenuous in terms of energy demands, but involve more energy expenditure than that described for sedentary lifestyles. Alternatively, they can be people with sedentary occupations who regularly spend a certain amount of time in moderate to vigorous physical activities, during either the obligatory or the discretionary part of their daily routine. For example, the daily performance of one hour (either continuous or in several bouts during the day) of moderate to vigorous exercise, such as jogging/running, cycling, aerobic dancing or various sports activities, can raise a person's average PAL from 1.55 (corresponding to the sedentary category) to 1.75 (the moderately active category). Other examples of moderately active lifestyles are associated with occupations such as masons and construction workers, or rural women in less developed traditional villages who participate in agricultural chores or walk long distances to fetch water and fuelwood.

Vigorous or vigorously active lifestyles. These people engage regularly in strenuous work or in strenuous leisure activities for several hours. Examples are women with non-sedentary occupations who swim or dance an average of two hours each day, or non-mechanized agricultural labourers who work with a machete, hoe or axe for several hours daily and walk long distances over rugged terrains, often carrying heavy loads.

Extremes of low and high PALs. Extremely low levels of energy expenditure allow for survival, but they are not compatible with long-term health, moving around freely, or earning a living. Such levels have been reported, for example, in elderly mental patients (Prentice *et al.,* 1989), adolescents with cerebral palsy or myelodysplasia (Bandini *et al.,* 1991) and resting adults confined to a whole body calorimeter (Ravussin *et al.,* 1991; Schulz *et al.,* 1992). The mean PAL of 1.21, which is similar to the baseline energy need of 1.27 estimated in the 1985 report, is suggested for short-term survival of totally inactive dependent people in conditions of crisis (WHO, 1985). The present consultation felt that such a value is too low and should not be used in emergency relief programmes, as people are not completely inactive in situations of crisis and the various stresses that impinge on them may increase their energy demands. The consultation hence suggests that food supplies to satisfy a PAL of 1.40, which represents the lower limit of the sedentary lifestyle range shown in Table 5.3, would be more appropriate for short-term relief interventions.

At the other end of the scale, studies have shown PAL values as high as 4.5 to 4.7 during three weeks of competitive cycling (Westerterp *et al.,* 1986), or hauling sleds across the Arctic (Stroud, Coward and Sawyer, 1993). However, such levels of energy expenditure are not sustainable in the long term.

5.4 ENERGY REQUIREMENTS AND DIETARY ENERGY RECOMMENDATIONS

5.4.1 Calculation of energy requirements

Energy requirements were calculated from the factorial estimates of PAL described in the preceding sections. They were converted into energy units (i.e. joules and calories) by multiplying the PAL value by the BMR. In order to express requirements as energy units per kilogram of body weight, they were divided by the weight used in the equations to predict BMR. The following example to calculate the average energy requirement of a female population 20 to 30 years of age with a moderately active lifestyle and a mean body weight of 55 kg illustrates these calculations:

BMR (calculated with the predictive equation in Table 5.2): 5.45 MJ/day (1 302 kcal/day).
PAL (mid-point of the moderately active lifestyle in Table 5.3): 1.85.
Energy requirement: 5.45 × 1.85 = 10.08 MJ/day (2 410 kcal/day), or 10.08/55 = 183 kJ/kg/day (44 kcal/kg/day).

The variation in requirements around the mid-point of the PAL ranges in each lifestyle category in Table 5.3 is between ± 8 percent and ± 10 percent (e.g. PAL for moderately active lifestyle = 1.70 to 1.99 = 1.85 ± 8 percent). However, there are individuals with BMR or PAL values at the extremes of a normal distribution around the population mean. Consequently, within each lifestyle category there are people whose *individual energy requirement* is beyond the limits shown in Table 5.3. This reiterates the fact that the energy requirements and dietary energy recommendations in this report are to be applied to population groups and not to individuals. Requirements of a specific individual must be based on that person's actual TEE or BMR, or on estimates that take into account the individual's habitual physical activity and lifestyle characteristics.

Tables 5.4 to 5.9 show the average energy requirements of populations with various levels of habitual physical activity and various mean body weights. Requirements for groups with other weights and/or mean PAL can be calculated easily, as in the following example for men 20 to 25 years of age with an average weight of 68 kg and an estimated PAL of 1.80:

a) Use Table 5.4 for men aged 18 to 30 years.
b) Calculate the 24-hour BMR by interpolating between body weights of 65 and 70 kg and multiply the interpolated BMR/kg by the population's average weight of 68 kg: mean of 108 and 104 = 106 kJ/kg × 68 kg = 7 208 kJ/day.
c) Multiply the 24-hour BMR by the estimated average PAL of the population: average daily requirement = 7 208 kJ/day × 1.80 = 12.97 MJ/day (3 100 kcal/day).

Another option for calculations is:

a) Use Table 5.4 for men aged 18 to 30 years.
b) Calculate the approximate energy requirement by interpolating between the daily requirements of men weighing 65 and 70 kg, and with a PAL level near that of the population (in this example, 1.75): mean of 12.2 and 12.8 MJ/day = 12.5 MJ/day.
c) Multiply the approximate requirement by the ratio between the population's PAL and the PAL of the column used in Table 5.5: 12.5 × (1.80/1.75) = 12.86 MJ/day (3 074 kcal/day).

5.4.2 Recommendation for daily energy intake

Dietary energy intake of a healthy, well-nourished population should allow for maintaining an adequate BMI at the population's usual level of energy expenditure. At the individual level, a normal range of 18.5 to 24.9 kg/m^2 BMI is generally accepted (WHO 1995 and 2000). At a population level, a median BMI of 21.0 was recently suggested by the joint WHO/FAO Expert Consultation on Diet, Nutrition and the Prevention of Chronic Diseases (WHO/FAO, 2002).

As BMI is a function of weight and height, heights corresponding to a BMI of 18.5, 21.0 and 24.9 were included in Tables 5.4 to 5.9 for each mean weight shown in the first column of each table. This facilitates recommendations for dietary energy intakes aimed at maintaining those values or range of BMI. For example, in the case of a male population 18 to 30 years old with an average height of 1.70 m and an activity lifestyle with a mean PAL of 1.75, the recommended energy intake would be around 11.7 MJ/day or 195 kJ/kg/day, which corresponds to the average requirement of men with a height of 1.69 m and a BMI of 21.0 who have a PAL of 1.75 × BMR (Table 5.4).

In the same example, a range of approximately 11.1 to 12.8 MJ/day or 185 to 200 kJ/kg/day would allow the maintenance of a BMI between 18.5 and 24.9 kg/m^2. These figures were obtained from the PAL column of 1.75 × BMR in Table 5.4, between the lowest row with height ≥ 1.70 m in the column of 18.5 BMI (in this example, the second row with a height of 1.72 m) and the highest row with height ≤ 1.70 m in the column of 24.9 BMI (in this example, the fifth row with a height of 1.68 m).

TABLE 5.4

Daily average energy requirement for men aged 18 to 29.9 years*

Mean weight	BMR/kg[a]		Daily energy requirement according to BMR factor (or PAL) and body weight indicated																								Height (m) for BMI values:[b]		
			1.45 × BMR				1.60 × BMR				1.75 × BMR				1.90 × BMR				2.05 × BMR				2.20 × BMR						
kg	kJ	*kcal*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	24.9	21.0	18.5
50	121	*29*	8.8	175	*2 100*	*42*	9.7	195	*2 300*	*46*	10.6	210	*2 550*	*51*	11.5	230	*2 750*	*55*	12.4	250	*2 950*	*59*	13.3	265	*3 200*	*64*	1.42	1.54	1.64
55	116	*28*	9.2	170	*2 200*	*40*	10.2	185	*2 450*	*44*	11.1	200	*2 650*	*48*	12.1	220	*2 900*	*53*	13.0	235	*3 100*	*57*	14.0	255	*3 350*	*61*	1.49	1.62	1.72
60	111	*27*	9.7	160	*2 300*	*39*	10.7	180	*2 550*	*43*	11.7	195	*2 800*	*47*	12.7	210	*3 050*	*51*	13.7	230	*3 250*	*55*	14.7	245	*3 500*	*59*	1.55	1.69	1.80
65	108	*26*	10.1	155	*2 400*	*37*	11.2	170	*2 650*	*41*	12.2	190	*2 900*	*45*	13.3	205	*3 150*	*49*	14.3	220	*3 450*	*53*	15.4	235	*3 700*	*57*	1.62	1.76	1.87
70	104	*25*	10.6	150	*2 550*	*36*	11.7	165	*2 800*	*40*	12.8	185	*3 050*	*44*	13.9	200	*3 300*	*47*	15.0	215	*3 600*	*51*	16.1	230	*3 850*	*55*	1.68	1.83	1.95
75	102	*24*	11.1	145	*2 650*	*35*	12.2	165	*2 900*	*39*	13.3	180	*3 200*	*42*	14.5	195	*3 450*	*46*	15.6	210	*3 750*	*50*	16.8	225	*4 000*	*53*	1.74	1.89	2.01
80	99	*24*	11.5	145	*2 750*	*34*	12.7	160	*3 050*	*38*	13.9	175	*3 300*	*41*	15.1	190	*3 600*	*45*	16.3	205	*3 900*	*49*	17.5	220	*4 150*	*52*	1.79	1.95	2.08
85	97	*23*	12.0	140	*2 850*	*34*	13.2	155	*3 150*	*37*	14.4	170	*3 450*	*41*	15.7	185	*3 750*	*44*	16.9	200	*4 050*	*48*	18.2	215	*4 350*	*51*	1.85	2.01	2.14
90	95	*23*	12.4	140	*2 950*	*33*	13.7	150	*3 300*	*36*	15.0	165	*3 600*	*40*	16.3	180	*3 900*	*43*	17.6	195	*4 200*	*47*	18.8	210	*4 500*	*50*	1.90	2.07	2.21

* Values rounded to closest 0.1 MJ/d, *50 kcal/d*, 5 kJ/kg/d, *1 kcal/kg/d*.

[a] BMR calculated for each weight from the equations in Table 5.2. Values of BMR/kg are presented for ease of calculations for those who wish to use different PAL values or different weights.

[b] Height ranges are presented for each mean weight for ease of making dietary energy recommendations to maintain an adequate BMI based on a population's mean height and PAL. For example, the recommended mean energy intake for a male population of this age group with a mean height of 1.70 m and a lifestyle with a mean PAL of 1.75, is about 11.7 MJ (*2 800 kcal*)/day or 195 kJ (*47 kcal*)/kg/day to maintain an optimum population median BMI of 21.0 (WHO/FAO, 2002), with an individual range of about 11.1 to 12.8 MJ (*2 650 to 3 050 kcal*)/day or 185 to 200 kJ (*44 to 48 kcal*)/kg/day to maintain the individual BMI limits of 18.5 to 24.9 (WHO, 2000).

TABLE 5.5

Daily average energy requirement for men aged 30 to 59.9 years*

Mean weight	BMR/kg[a]		Daily energy requirement according to BMR factor (or PAL) and body weight indicated																								Height (m) for BMI values:[b]		
			1.45 × BMR				1.60 × BMR				1.75 × BMR				1.90 × BMR				2.05 × BMR				2.20 × BMR						
kg	kJ	*kcal*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	24.9	21.0	18.5
50	121	*29*	8.8	175	*2 100*	*42*	9.7	195	*2 300*	*46*	10.6	210	*2 550*	*51*	11.5	230	*2 750*	*55*	12.4	250	*2 950*	*59*	13.3	265	*3 200*	*64*	1.42	1.54	1.64
55	114	*27*	9.1	165	*2 200*	*40*	10.1	185	*2 400*	*44*	11.0	200	*2 650*	*48*	12.0	215	*2 850*	*52*	12.9	235	*3 100*	*56*	13.8	250	*3 300*	*60*	1.49	1.62	1.72
60	109	*26*	9.5	160	*2 250*	*38*	10.5	175	*2 500*	*42*	11.4	190	*2 750*	*46*	12.4	205	*2 950*	*49*	13.4	225	*3 200*	*53*	14.4	240	*3 450*	*57*	1.55	1.69	1.80
65	104	*25*	9.8	150	*2 350*	*36*	10.8	165	*2 600*	*40*	11.9	180	*2 850*	*44*	12.9	200	*3 100*	*47*	13.9	215	*3 300*	*51*	14.9	230	*3 550*	*55*	1.62	1.76	1.87
70	100	*24*	10.2	145	*2 450*	*35*	11.2	160	*2 700*	*38*	12.3	175	*2 950*	*42*	13.3	190	*3 200*	*45*	14.4	205	*3 450*	*49*	15.4	220	*3 700*	*53*	1.68	1.83	1.95
75	97	*23*	10.5	140	*2 500*	*34*	11.6	155	*2 750*	*37*	12.7	170	*3 050*	*40*	13.8	185	*3 300*	*44*	14.9	200	*3 550*	*47*	16.0	215	*3 800*	*51*	1.74	1.89	2.01
80	94	*22*	10.9	135	*2 600*	*32*	12.0	150	*2 850*	*36*	13.1	165	*3 150*	*39*	14.2	180	*3 400*	*43*	15.4	190	*3 650*	*46*	16.5	205	*3 950*	*49*	1.79	1.95	2.08
85	91	*22*	11.2	130	*2 700*	*32*	12.4	145	*2 950*	*35*	13.5	160	*3 250*	*38*	14.7	175	*3 500*	*41*	15.9	185	*3 800*	*45*	17.0	200	*4 050*	*48*	1.85	2.01	2.14
90	89	*21*	11.6	130	*2 750*	*31*	12.8	140	*3 050*	*34*	14.0	155	*3 350*	*37*	15.1	170	*3 600*	*40*	16.3	180	*3 900*	*43*	17.5	195	*4 200*	*47*	1.90	2.07	2.21

* Values rounded to closest 0.1 MJ/d, *50 kcal/d*, 5 kJ/kg/d, *1 kcal/kg/d*.

[a] BMR calculated for each weight from the equations in Table 5.2. Values of BMR/kg are presented for ease of calculations for those who wish to use different PAL values or different weights.

[b] Height ranges are presented for each mean weight for ease of making dietary energy recommendations to maintain an adequate BMI based on a population's mean height and PAL. For example, the recommended mean energy intake for a male population of this age group with a mean height of 1.70 m and a lifestyle with a mean PAL of 1.75, is about 11.4 MJ (*2 750 kcal*)/day or 190 kJ (*46 kcal*)/kg/day to maintain an optimum population median BMI of 21.0 (WHO/FAO, 2002), with an individual range of about 11.0 to 12.3 MJ (*2 650 to 2 950 kcal*)/day or 175 to 200 kJ (*42 to 48 kcal*)/kg/day to maintain the individual BMI limits of 18.5 to 24.9 (WHO, 2000).

TABLE 5.6

Daily average energy requirement for men aged ≥ 60 years*

Mean weight	BMR/kg[a]		Daily energy requirement according to BMR factor (or PAL) and body weight indicated																								Height (m) for BMI values:[b]		
			1.45 × BMR				1.60 × BMR				1.75 × BMR				1.90 × BMR				2.05 × BMR				2.20 × BMR						
kg	kJ	*kcal*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	24.9	21.0	18.5
50	98	*23*	7.1	140	*1 700*	*34*	7.9	155	*1 900*	*38*	8.6	170	*2 050*	*41*	9.3	185	*2 250*	*45*	10.1	200	*2 400*	*48*	10.8	215	*2 600*	*52*	1.42	1.54	1.64
55	94	*22*	7.5	135	*1 800*	*33*	8.2	150	*1 950*	*35*	9.0	165	*2 150*	*39*	9.8	180	*2 350*	*43*	10.6	190	*2 550*	*46*	11.3	205	*2 700*	*49*	1.49	1.62	1.72
60	90	*22*	7.8	130	*1 850*	*31*	8.6	145	*2 050*	*34*	9.4	155	*2 250*	*38*	10.3	170	*2 450*	*41*	11.1	185	*2 650*	*44*	11.9	200	*2 850*	*48*	1.55	1.69	1.80
65	87	*21*	8.2	125	*1 950*	*30*	9.0	140	*2 150*	*33*	9.9	150	*2 350*	*36*	10.7	165	*2 550*	*39*	11.6	180	*2 750*	*42*	12.4	190	*2 950*	*45*	1.62	1.76	1.87
70	84	*20*	8.5	120	*2 050*	*29*	9.4	135	*2 250*	*32*	10.3	145	*2 450*	*35*	11.2	160	*2 650*	*38*	12.1	170	*2 900*	*41*	13.0	185	*3 100*	*44*	1.68	1.83	1.95
75	82	*20*	8.9	120	*2 150*	*29*	9.8	130	*2 350*	*31*	10.7	145	*2 550*	*34*	11.7	155	*2 800*	*37*	12.6	170	*3 000*	*40*	13.5	180	*3 250*	*43*	1.74	1.89	2.01
80	80	*19*	9.2	115	*2 200*	*28*	10.2	130	*2 450*	*31*	11.2	140	*2 650*	*33*	12.1	150	*2 900*	*36*	13.1	165	*3 150*	*39*	14.0	175	*3 350*	*42*	1.79	1.95	2.08
85	78	*19*	9.6	115	*2 300*	*27*	10.6	125	*2 550*	*30*	11.6	135	*2 750*	*32*	12.6	150	*3 000*	*35*	13.6	160	*3 250*	*38*	14.6	170	*3 500*	*41*	1.85	2.01	2.14
90	76	*18*	10.0	110	*2 400*	*27*	11.0	120	*2 650*	*29*	12.0	135	*2 850*	*32*	13.1	145	*3 100*	*34*	14.1	155	*3 350*	*37*	15.1	170	*3 600*	*40*	1.90	2.07	2.21

* Values rounded to closest 0.1 MJ/d, *50 kcal/d*, 5 kJ/kg/d, *1 kcal/kg/d*.

[a] BMR calculated for each weight from the equations in Table 5.2. Values of BMR/kg are presented for ease of calculations for those who wish to use different PAL values or different weights.

[b] Height ranges are presented for each mean weight for ease of making dietary energy recommendations to maintain an adequate BMI based on a population's mean height and PAL. For example, the recommended mean energy intake for a male population of this age group with a mean height of 1.70 m and a lifestyle with a mean PAL of 1.75, is about 9.4 MJ (*2 250 kcal*)/day or 155 kJ (*38 kcal*)/kg/day to maintain an optimum population median BMI of 21.0 (WHO/FAO, 2002), with an individual range of about 9.0 to 10.3 MJ (*2 150 to 2 450 kcal*)/day or 145 to 160 kJ (*35 to 39 kcal*)/kg/day to maintain the individual BMI limits of 18.5 to 24.9 (WHO, 2000).

TABLE 5.7

Daily average energy requirement for women aged 18 to 29.9 years*

Mean weight	BMR/kg[a]		Daily energy requirement according to BMR factor (or PAL) and body weight indicated																								Height (m) for BMI values:[b]		
			1.45 × BMR				1.60 × BMR				1.75 × BMR				1.90 × BMR				2.05 × BMR				2.20 × BMR						
kg	kJ	*kcal*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	24.9	21.0	18.5
45	107	*26*	7.0	155	*1 650*	*37*	7.7	170	*1 850*	*41*	8.4	190	*2 000*	*44*	9.2	205	*2 200*	*49*	9.9	220	*2 350*	*52*	10.6	235	*2 550*	*57*	1.34	1.46	1.56
50	103	*25*	7.4	150	*1 800*	*36*	8.2	165	*1 950*	*39*	9.0	180	*2 150*	*43*	9.8	195	*2 350*	*47*	10.5	210	*2 500*	*50*	11.3	225	*2 700*	*54*	1.42	1.54	1.64
55	99	*24*	7.9	145	*1 900*	*35*	8.7	160	*2 100*	*38*	9.5	175	*2 300*	*42*	10.3	190	*2 450*	*45*	11.2	205	*2 650*	*48*	12.0	220	*2 850*	*52*	1.49	1.62	1.72
60	96	*23*	8.3	140	*2 000*	*33*	9.2	155	*2 200*	*37*	10.1	170	*2 400*	*40*	10.9	180	*2 600*	*43*	11.8	195	*2 800*	*47*	12.7	210	*3 050*	*51*	1.55	1.69	1.80
65	93	*22*	8.8	135	*2 100*	*32*	9.7	150	*2 300*	*35*	10.6	165	*2 550*	*39*	11.5	175	*2 750*	*42*	12.4	190	*2 950*	*45*	13.3	205	*3 200*	*49*	1.62	1.76	1.87
70	91	*22*	9.2	130	*2 200*	*31*	10.2	145	*2 450*	*35*	11.2	160	*2 650*	*38*	12.1	175	*2 900*	*41*	13.1	185	*3 100*	*44*	14.0	200	*3 350*	*48*	1.68	1.83	1.95
75	89	*21*	9.7	130	*2 300*	*31*	10.7	145	*2 550*	*34*	11.7	155	*2 800*	*37*	12.7	170	*3 050*	*41*	13.7	185	*3 300*	*44*	14.7	195	*3 500*	*47*	1.74	1.89	2.01
80	87	*21*	10.1	125	*2 400*	*30*	11.2	140	*2 700*	*34*	12.2	155	*2 950*	*37*	13.3	165	*3 200*	*40*	14.3	180	*3 450*	*43*	15.4	190	*3 700*	*46*	1.79	1.95	2.08
85	86	*21*	10.6	125	*2 550*	*30*	11.7	140	*2 800*	*33*	12.8	150	*3 050*	*36*	13.9	165	*3 300*	*39*	15.0	175	*3 600*	*42*	16.1	190	*3 850*	*45*	1.85	2.01	2.14

* Values rounded to closest 0.1 MJ/d, *50 kcal/d*, 5 kJ/kg/d, *1 kcal/kg/d*.

[a] BMR calculated for each weight from the equations in Table 5.2. Values of BMR/kg are presented for ease of calculations for those who wish to use different PAL values or different weights.

[b] Height ranges are presented for each mean weight for ease of making dietary energy recommendations to maintain an adequate BMI based on a population's mean height and PAL. For example, the recommended mean energy intake for a female population of this age group with a mean height of 1.70 m and a lifestyle with a mean PAL of 1.75, is about 10.1 MJ (*2 400 kcal*)/day or 170 kJ (*40 kcal*)/kg/day to maintain an optimum population median BMI of 21.0 (WHO/FAO, 2002), with an individual range of about 9.5 to 11.2 MJ (*2 300 to 2 650 kcal*)/day or 160 to 175 kJ (*38 to 42 kcal*)/kg/day to maintain the individual BMI limits of 18.5 to 24.9 (WHO, 2000).

TABLE 5.8

Daily average energy requirement for women aged 30 to 59.9 years*

Mean weight	BMR/kg[a]		Daily energy requirement according to BMR factor (or PAL) and body weight indicated																								Height (m) for BMI values:[b]		
			1.45 × BMR				1.60 × BMR				1.75 × BMR				1.90 × BMR				2.05 × BMR				2.20 × BMR						
kg	kJ	*kcal*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	24.9	21.0	18.5
45	113	*27*	7.3	165	*1 750*	*39*	8.1	180	*1 950*	*43*	8.9	195	*2 100*	*47*	9.6	215	*2 300*	*51*	10.4	230	*2 500*	*56*	11.1	250	*2 650*	*59*	1.34	1.46	1.56
50	105	*25*	7.6	150	*1 800*	*36*	8.4	170	*2 000*	*40*	9.2	185	*2 200*	*44*	10.0	200	*2 400*	*48*	10.7	215	*2 550*	*51*	11.5	230	*2 750*	*55*	1.42	1.54	1.64
55	98	*24*	7.8	145	*1 850*	*34*	8.7	155	*2 050*	*37*	9.5	170	*2 250*	*41*	10.3	185	*2 450*	*45*	11.1	200	*2 650*	*48*	11.9	215	*2 850*	*52*	1.49	1.62	1.72
60	93	*22*	8.1	135	*1 950*	*33*	8.9	150	*2 150*	*36*	9.8	165	*2 350*	*39*	10.6	175	*2 550*	*43*	11.4	190	*2 750*	*46*	12.3	205	*2 950*	*49*	1.55	1.69	1.80
65	88	*21*	8.3	130	*2 000*	*31*	9.2	140	*2 200*	*34*	10.1	155	*2 400*	*37*	10.9	170	*2 600*	*40*	11.8	180	*2 800*	*43*	12.6	195	*3 000*	*46*	1.62	1.76	1.87
70	85	*20*	8.6	125	*2 050*	*29*	9.5	135	*2 250*	*32*	10.4	150	*2 500*	*36*	11.2	160	*2 700*	*39*	12.1	175	*2 900*	*41*	13.0	185	*3 100*	*44*	1.68	1.83	1.95
75	81	*19*	8.8	120	*2 100*	*28*	9.7	130	*2 350*	*31*	10.7	140	*2 550*	*34*	11.6	155	*2 750*	*37*	12.5	165	*3 000*	*40*	13.4	180	*3 200*	*43*	1.74	1.89	2.01
80	78	*19*	9.1	115	*2 150*	*27*	10.0	125	*2 400*	*30*	11.0	135	*2 600*	*33*	11.9	150	*2 850*	*36*	12.8	160	*3 050*	*38*	13.8	170	*3 300*	*41*	1.79	1.95	2.08
85	76	*18*	9.3	110	*2 250*	*26*	10.3	120	*2 450*	*29*	11.2	130	*2 700*	*32*	12.2	145	*2 900*	*34*	13.2	155	*3 150*	*37*	14.1	165	*3 400*	*40*	1.85	2.01	2.14

* Values rounded to closest 0.1 MJ/d, *50 kcal/d*, 5 kJ/kg/d, *1 kcal/kg/d*.

[a] BMR calculated for each weight from the equations in Table 5.2. Values of BMR/kg are presented for ease of calculations for those who wish to use different PAL values or different weights.

[b] Height ranges are presented for each mean weight for ease of making dietary energy recommendations to maintain an adequate BMI based on a population's mean height and PAL. For example, the recommended mean energy intake for a female population of this age group with a mean height of 1.70 m and a lifestyle with a mean PAL of 1.75, is about 9.8 MJ (*2 350 kcal*)/day or 165 kJ (*39 kcal*)/kg/day to maintain an optimum population median BMI of 21.0 (WHO/FAO, 2002), with an individual range of about 9.5 to 10.4 MJ (*2 250 to 2 500 kcal*)/day or 150 to 170 kJ (*36 to 41 kcal*)/kg/day to maintain the individual BMI limits of 18.5 to 24.9 (WHO, 2000).

TABLE 5.9

Daily average energy requirement for women aged ≥ 60 years*

Mean weight	BMR/kg[a]		Daily energy requirement according to BMR factor (or PAL) and body weight indicated																								Height (m) for BMI values:[b]		
			1.45 × BMR				1.60 × BMR				1.75 × BMR				1.90 × BMR				2.05 × BMR				2.20 × BMR						
kg	kJ	*kcal*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	24.9	21.0	18.5
45	99	*24*	6.5	145	*1 550*	*34*	7.1	160	*1 700*	*38*	7.8	175	*1 850*	*41*	8.5	190	*2 050*	*45*	9.2	205	*2 200*	*49*	9.8	220	*2 350*	*52*	1.34	1.46	1.56
50	93	*22*	6.7	135	*1 600*	*32*	7.4	150	*1 800*	*36*	8.1	165	*1 950*	*39*	8.8	175	*2 100*	*42*	9.5	190	*2 300*	*46*	10.2	205	*2 450*	*49*	1.42	1.54	1.64
55	88	*21*	7.0	130	*1 700*	*31*	7.8	140	*1 850*	*34*	8.5	155	*2 050*	*37*	9.2	165	*2 200*	*40*	9.9	180	*2 350*	*43*	10.7	195	*2 550*	*46*	1.49	1.62	1.72
60	84	*20*	7.3	120	*1 750*	*29*	8.1	135	*1 950*	*32*	8.8	145	*2 100*	*35*	9.6	160	*2 300*	*38*	10.3	170	*2 450*	*41*	11.1	185	*2 650*	*44*	1.55	1.69	1.80
65	80	*19*	7.6	115	*1 800*	*28*	8.4	130	*2 000*	*31*	9.1	140	*2 200*	*34*	9.9	155	*2 350*	*37*	10.7	165	*2 550*	*39*	11.5	175	*2 750*	*42*	1.62	1.76	1.87
70	77	*18*	7.9	110	*1 900*	*27*	8.7	125	*2 050*	*30*	9.5	135	*2 250*	*32*	10.3	145	*2 450*	*35*	11.1	160	*2 650*	*38*	11.9	170	*2 850*	*41*	1.68	1.83	1.95
75	75	*18*	8.1	110	*1 950*	*26*	9.0	120	*2 150*	*29*	9.8	130	*2 350*	*31*	10.6	140	*2 550*	*34*	11.5	155	*2 750*	*37*	12.3	165	*2 950*	*39*	1.74	1.89	2.01
80	72	*17*	8.4	105	*2 000*	*25*	9.3	115	*2 200*	*28*	10.1	125	*2 400*	*30*	11.0	140	*2 650*	*33*	11.9	150	*2 850*	*35*	12.7	160	*3 050*	*38*	1.79	1.95	2.08
85	70	*17*	8.7	100	*2 050*	*24*	9.6	115	*2 300*	*27*	10.5	125	*2 500*	*29*	11.4	135	*2 700*	*32*	12.3	145	*2 950*	*34*	13.2	155	*3 150*	*37*	1.85	2.01	2.14

* Values rounded to closest 0.1 MJ/d, *50 kcal/d*, 5 kJ/kg/d, *1 kcal/kg/d*.

[a] BMR calculated for each weight from the equations in Table 5.2. Values of BMR/kg are presented for ease of calculations for those who wish to use different PAL values or different weights.

[b] Height ranges are presented for each mean weight for ease of making dietary energy recommendations to maintain an adequate BMI based on a population's mean height and PAL. For example, the recommended mean energy intake for a female population of this age group with a mean height of 1.70 m and a lifestyle with a mean PAL of 1.75, is about 8.8 MJ (*2 100 kcal*)/day or 145 kJ (*35 kcal*)/kg/day to maintain an optimum population median BMI of 21.0 (WHO/FAO, 2002), with an individual range of about 8.5 to 9.5 MJ (*2 050 to 2 250 kcal*)/day or 135 to 155 kJ (*32 to 37 kcal*)/kg/day to maintain the individual BMI limits of 18.5 to 24.9 (WHO, 2000).

5.5 OLDER ADULTS AND THE ELDERLY

Many age-related changes that influence energy requirements occur continually throughout the adult life cycle. A decline in BMR with age has been recognized since the studies of Keys, Taylor and Grande (1973), who estimated it at a rate of 1 to 2 percent per decade. Average decreases of 2.9 and 2.0 percent per decade, respectively, for men and women of normal weight (BMI of 18.5 to 25.0 kg/m^2) were calculated more recently (Roberts and Dalall, 2001; Food and Nutrition Board/Institute of Medicine, 2002). The decreases were 3.1 and 1.9 percent per decade among overweight men and women, respectively (Roberts and Dalall, 2001). The decline is not linear, and has a suggested breakpoint at about 40 years of age in men and 50 years in women (Poehlman, 1992; Poehlman *et al.,* 1993). The organization of the data in Table 5.10 by decades points to a breakpoint at about 50 years of age for both genders. This decrease in BMR has been explained partly by the reduction in fat-free mass that occurs with ageing, and by changes in the composition of that fat-free mass (Piers *et al.,* 1998). Several studies, however, suggest that even after adjusting for changes in fat-free mass, BMR is 5 percent lower in older persons compared with young adults (Roberts and Dalall, 2001).

On the other hand, body weight tends to increase with age in many societies. For example, there are more overweight men and women (defined as BMI > 25) than people with BMI ≤ 25 in the database of the United States Academy of Sciences (Table 5.10) (Food and Nutrition Board/Institute of Medicine, 2002). The largest series currently available of TEE and BMR measurements in people 70 to 79 years old involved 150 men and 150 women randomly recruited in two large cities of the United States. Average weight and BMI were 82.4 kg and 27.4 among men, and 70.6 kg and 27.3 among women (Blanc *et al.,* 2001). Overweight and obesity increase BMR and TEE owing to the increase in the fat-free mass needed to carry the extra weight and to the increased energy cost of activities. However, BMR per unit of body weight is reduced in overweight and obese subjects owing to the larger gain in fat mass relative to metabolically active fat-free mass.

Habitual physical activity, and hence TEE, decrease after a given age (Black *et al.,* 1996; Roberts, 1996). However, studies with standardized activity protocols in a whole body calorimeter did not show differences in TEE between young and old adults (Vaughan, Zurlo and Ravussin, 1991; Pannemans and Westerterp, 1995). Furthermore, although maximal oxygen consumption decreases progressively with age (Suominen *et al.,* 1980), some elderly individuals who have remained physically active are able to maintain high levels of energy expenditure, with PAL values as high as 2.48 (Reilly *et al.,* 1993; Withers *et al.,* 1998). This indicates that the age at which TEE and energy requirements start decreasing depends on individual, social and cultural features that promote or limit habitual physical activity among older adults.

Calculation of energy requirements for the elderly based on PAL is highly dependent on the accuracy with which BMR is measured or estimated. For example, the preliminary TEE results – and therefore energy requirements – of 70 to 79 year-old people in a United States study on health, ageing and body composition (Blanc *et al.,* 2001) were 10.1 ± 1.8 MJ/day for men, and 8.0 ± 1.5 MJ/day for women. Based on actual measurements of BMR (men: 5.9 ± 0.1 MJ/day BMR; women: 4.8 ± 0.1 MJ/day BMR), mean PAL was 1.72 among men and 1.68 among women, but using the predictive equations in Table 5.2, PAL would be 1.55 for men and 1.47 for women. The error in prediction may have been associated with the excessive weight of this population group.

In conclusion, energy requirements for older adults and the elderly should be calculated on the basis of PALs, just as they are calculated for younger adults. Therefore, the accuracy with which BMR of older adults can be estimated becomes of primary importance. As more reliable information on BMR of older adults with differing lifestyles, body composition and physical activity becomes available, it may be necessary to revise the predictive equations for this age group in order to make better estimations of their energy requirements. Allowances must be made for population groups who are more or less active at an advanced age, rather than using age as the single cut-off point to define energy requirements for the elderly.

TABLE 5.10
Daily energy expenditure, basal metabolic rate and physical activity level measured in United States adults

Age	No.	Weight	TEE measured with DLW				BMR measured individually				PAL
years		kg	MJ	kJ/kg	*kcal*	*kcal/kg*	MJ	kJ/kg	*kcal*	*kcal/kg*	
Men, BMI 18.5–25.0											
20–30	48	70.7	12.7	180	*3 047*	*43*	7.4	105	*1 770*	*25*	1.75
30–40	47	71.7	12.4	173	*2 964*	*41*	7.0	98	*1 676*	*23*	1.78
40–50	22	70.6	12.8	181	*3 048*	*43*	7.0	100	*1 683*	*24*	1.84
50–60	8	73.1	10.5	144	*2 513*	*34*	6.7	91	*1 590*	*22*	1.60
60–70	14	67.8	10.0	148	*2 397*	*35*	6.2	92	*1 487*	*22*	1.61
70–80	30	70.0	10.1	144	*2 407*	*34*	6.3	89	*1 497*	*21*	1.62
80–90	4	67.1	7.1	106	*1 700*	*25*	6.1	91	*1 457*	*22*	1.17
>90	6	65.6	8.1	123	*1 935*	*29*	5.9	90	*1 415*	*22*	1.38
Women, BMI 18.5–25.0											
20–30	76	59.4	10.2	171	*2 428*	*41*	5.7	96	*1 361*	*23*	1.79
30–40	59	58.7	10.1	172	*2 412*	*41*	5.6	95	*1 328*	*23*	1.83
40–50	8	58.2	10.2	175	*2 441*	*42*	5.4	93	*1 300*	*22*	1.89
50–60	18	59.8	9.1	153	*2 182*	*36*	5.2	87	*1 241*	*21*	1.75
60–70	48	59.0	8.5	145	*2 042*	*35*	5.1	86	*1 219*	*21*	1.69
70–80	14	59.0	7.9	134	*1 888*	*32*	5.1	87	*1 229*	*21*	1.55
80–90	6	51.9	5.8	111	*1 382*	*27*	4.8	92	*1 143*	*22*	1.21
>90	9	52.2	5.7	109	*1 356*	*26*	4.9	94	*1 168*	*22*	1.17
Overweight men											
20–30	10	89.9	13.5	150	*3 224*	*36*	7.8	86	*1 858*	*21*	1.90
30–40	53	102.4	15.5	151	*3 703*	*36*	8.6	84	*2 046*	*20*	1.81
40–50	37	94.6	14.5	153	*3 465*	*37*	7.9	83	*1 878*	*20*	1.88
50–60	17	100.3	14.5	144	*3 458*	*34*	7.8	77	*1 857*	*19*	1.88
60–70	30	87.8	11.9	136	*2 851*	*32*	7.1	80	*1 687*	*19*	1.71
70–80	34	84.8	11.0	129	*2 624*	*31*	7.2	85	*1 713*	*20*	1.55
80–90	7	78.1	9.6	123	*2 294*	*29*	6.5	83	*1 558*	*20*	1.47
>90	2	77.5	7.8	101	*1 863*	*24*	6.5	84	*1 550*	*20*	1.29
Overweight women											
20–30	33	83.4	11.4	136	*2 713*	*33*	6.4	77	*1 536*	*18*	1.78
30–40	41	83.9	11.7	139	*2 794*	*33*	6.6	79	*1 587*	*19*	1.78
40–50	14	96.9	12.7	131	*3 032*	*31*	7.1	73	*1 696*	*18*	1.80
50–60	29	83.3	9.8	118	*2 349*	*28*	5.9	71	*1 409*	*17*	1.68
60–70	46	78.2	8.6	110	*2 061*	*26*	5.7	74	*1 374*	*18*	1.52
70–80	19	69.3	7.8	113	*1 868*	*27*	5.2	75	*1 234*	*18*	1.51
80–90	6	62.8	7.3	116	*1 748*	*28*	5.2	82	*1 233*	*20*	1.42
>90	7	74.8	7.4	99	*1 766*	*24*	5.6	75	*1 332*	*18*	1.33

Sources: Roberts and Dallal, 2001; Food and Nutrition Board/Institute of Medicine, 2002.

5.6 RECOMMENDATIONS FOR REGULAR PHYSICAL ACTIVITY

The practice of regular physical activity is associated with the maintenance of adequate body weight, cardiovascular and respiratory health, and fitness,[5] and a lower risk of developing chronic non-communicable diseases associated with diet and lifestyle (Erlichman, Kerbey and James, 2001; WHO, 2000; WHO/FAO, 2002; Pollock *et al.,* 1998; Ferro-Luzzi and Martino, 1996; Schoeller, 1998; WHO, 2002; Erlichman, Kerbey and James, no date; American Heart Association, 2002; IARC, 2002; CDC, 1996; World Cancer Research Fund/American Institute for Cancer Research, 1997; Saris *et al.,* 2003). Consequently, dietary energy recommendations to satisfy requirements should be accompanied by recommendations to perform adequate amounts of physical activity regularly.

There is consensus among experts that a habitual PAL of 1.70 or higher is associated with a lower risk of overweight and obesity, cardiovascular disease, diabetes and several types of cancer (Black *et al.,* 1996; Erlichman, Kerbey and James, 2001; Pollock *et al.,* 1998; Ferro-Luzzi and Martino, 1996; Schoeller, 1998; Erlichman, Kerbey and James, no date; World Cancer Research Fund/American Institute for Cancer Research, 1997; Saris *et al.,* 2003). Therefore, it is particularly important to recommend regular physical activity to populations and individuals with a sedentary lifestyle or one of light activity. Those with moderately or vigorously physically active lifestyles already have a habitual physical activity close to, or higher than, the health-associated PAL threshold of 1.70 times BMR. Recommendations for these individuals should be aimed at the maintenance of that activity level.

5.6.1 Frequency, duration and intensity of physical activity

Table 5.11 summarizes the minimum amounts of exercise, expressed in terms of frequency, duration and intensity, advocated by several organizations to maintain and promote health among adults (WHO/FAO, 2002; Pollock *et al.,* 1998; WHO, 2002; American Heart Association, 2002; IARC, 2002; CDC, 1996; World Cancer Research Fund/American Institute for Cancer Research, 1997; Saris *et al.,* 2003). The conclusions reached in the cited publications can be summarized as follows:

- There is consensus that, in order to promote general health, at least 30 minutes of moderate to vigorous activity should be performed, three or more days per week.
- Sedentary people and those with low physical fitness levels will benefit from the lower amounts of exercise prescribed in Table 5.11 (i.e. 30 minutes of moderate activity, three days per week). To obtain increased benefits, those with better conditions should exercise longer and/or at a higher intensity (e.g. 60 minutes of moderate or vigorous activity, five or more days per week).
- Longer periods of exercise are required to maintain a healthy body weight and to reduce the risk of obesity than are needed to help reduce the risk of chronic diseases such as coronary heart disease and diabetes mellitus.
- Sixty minutes of daily exercise have been advocated to increase the PAL of sedentary people to a value of 1.75 or greater, assist in weight maintenance and play a part in the prevention of some types of cancer, especially colorectal and breast cancer.
- Any activity that is rhythmic and aerobic in nature, uses large muscle groups and can be maintained continuously is recommended for general health and fitness. Activities that can be practised as part of everyday life are particularly useful. Examples include brisk walking, climbing stairs, cycling, dancing, jogging/running, hiking, low-impact aerobic exercises, swimming, skipping rope, ice/roller skating and various endurance games and sport activities.
- Duration is related to intensity. Thus, when ranges are given in Table 5.11 (e.g. 30 to 60 minutes at 50 to 80 percent capacity), lower-intensity activity should be conducted over a longer period of time (i.e. 60 minutes at 50 percent capacity [moderate activity], or 30 minutes at 80 percent aerobic capacity [vigorous activity]).

[5] The term “fitness” encompasses cardiorespiratory health, appropriate body composition (including fat distribution), muscular strength, endurance and flexibility, and it can generally be described as the ability to perform moderate to vigorous physical activity without becoming excessively tired (Pollock *et al.,* 1998).

TABLE 5.11
Minimum frequency, duration and intensity of physical activity advocated by selected organizations

Organization	Recommendation
World Health Organization (WHO, 2002)	30 minutes of moderate activity every day.
World Cancer Research Fund/American Institute for Cancer Research (1997)	30 minutes of vigorous or 60 minutes of moderate activity daily, plus additional 30 to 60 minutes of vigorous activity once a week.
United States Centers for Disease Control and Prevention (CDC, 1996)	30 minutes of moderate activity on all or most days of the week.
American Heart Association (2002)	30 to 60 minutes of exercise at 50 to 80% aerobic capacity, at least 3 to 4 days per week.
American College of Sports Medicine (Pollock *et al.,* 1998)	*For cardio-respiratory fitness and body composition*: 20 to 60 minutes of continuous or intermittent (bouts of at least 10 minutes) aerobic activity at 55 to 90% maximum heart rate, or at 40 to 85% maximum oxygen uptake, 3 to 5 days per week. *For muscular strength and endurance, body composition and flexibility:* One set of 8 to 10 exercises, with 8 to 12 repetitions of each exercise, 2 to 3 days per week.
International Agency for Research on Cancer (IARC, 2002)	*To maintain healthy body weight*: 60 minutes moderate activity on all or most days of the week.[a] *For cancer prevention*: Substitute moderate for vigorous activity several times per week.
International Association for the Study of Obesity (Saris *et al.,* 2002)	*To prevent weight regain in formerly obese individuals*: 60 to 90 minutes of moderate activity daily, or shorter periods of vigorous activity. *To prevent transition to overweight or obesity*: 45 to 60 minutes of moderate activity daily, or 1.7 PAL. For children, more activity time is recommended.

[a] Endorsed by the joint WHO/FAO Expert Consultation on Diet, Nutrition and the Prevention of Chronic Diseases (FAO/WHO, 2002).

- An activity regimen of moderate- rather than high-intensity exercise is recommended, and total fitness is more readily attained with longer sessions. Consequently, it may be better to suggest activity of moderate intensity for 60 minutes than of high intensity for 30 minutes.
- Although longer sessions are generally preferable, their duration may hinder compliance among some people. In these cases it may be appropriate to recommend accumulated bouts of activity for shorter durations throughout the day (e.g. 15 minutes two or four times daily, instead of 30 or 60 minutes once daily).

For general populations, particularly those with sedentary occupations, a joint WHO/FAO Expert Consultation on Diet, Nutrition and the Prevention of Chronic Diseases (WHO/FAO, 2002) recently advocated the performance of moderate-intensity activity, such as brisk walking, for a total of one hour per day on most days of the week to help maintain a healthy body weight and reduce the risk of co-morbid diseases associated with overweight. This level of exercise may be considered part of the daily routine of people with occupations entailing moderate or vigorous, energy-demanding physical activity for one or more hours, five or more days per week.

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6. ENERGY REQUIREMENTS OF PREGNANCY

Dietary intake during pregnancy must provide the energy that will ensure the full-term delivery of a healthy newborn baby of adequate size and appropriate body composition by a woman whose weight, body composition and PAL are consistent with long-term good health and well-being. The ideal situation is for a woman to enter pregnancy at a normal weight and with good nutritional status. Therefore, the energy requirements of pregnancy are those needed for adequate maternal gain to ensure the growth of the foetus, placenta and associated maternal tissues, and to provide for the increased metabolic demands of pregnancy, in addition to the energy needed to maintain adequate maternal weight, body composition and physical activity throughout the gestational period, as well as for sufficient energy stores to assist in proper lactation after delivery. Special considerations must be made for women who are under- or overweight when they enter pregnancy.

This consultation reviewed recent information on the association of maternal weight gain and body composition with the newborn birth weight, on the influence of birth weight on infant mortality, and on the associated metabolic demands of pregnancy (WHO, 1995a; Kelly *et al.,* 1996; Butte and King, 2002), in order to perform factorial calculations of the extra energy required during this period. It was acknowledged that estimates of energy requirements and recommendations for energy intake of pregnant women should be population-specific, because of differences in body size, lifestyle and underlying nutritional status. Well-nourished women raised in affluent or economically developed societies may have different energy needs in pregnancy than women from low-income developing societies; pregnancy energy requirements of stunted or undernourished women may differ from those of overweight and obese women; and physical activity patterns may change during pregnancy to an extent that is determined by socio-economic and cultural factors. Even within a particular society, high variability is seen in the rates of gestational weight gain and energy expenditure of pregnant women, and therefore in their energy requirements.

6.1 GESTATIONAL WEIGHT GAIN AND OPTIMAL PREGNANCY OUTCOME

The WHO Collaborative Study on Maternal Anthropometry and Pregnancy Outcomes (WHO, 1995a; Kelly *et al.,* 1996) reviewed information on 110 000 births from 20 countries to determine anthropometric indicators associated with poor foetal outcomes, such as low birth weight (LBW), intrauterine growth retardation (IUGR) and pre-term birth, and with poor maternal outcomes, such as pre-eclampsia, eclampsia, need for assisted delivery, and postpartum haemorrhage. Attained maternal weight (pre-pregnancy weight plus weight gain) was the most significant predictor of LBW and IUGR (with odds ratios of 2.5 and 3.1, respectively). Low pre-pregnancy weight and BMI, and weight gain between 20 and 28 weeks of gestation were moderate predictors of pre-term delivery (odds ratios of 1.3 and 1.4, respectively), and low maternal height (e.g. 146 compared with 160 cm) was a moderate predictor of caesarean delivery (odds ratio: 1.6) (Merchant, Villar and Kestler, 2001).

Women with short stature, especially in developing countries with inadequate health care systems and high prevalence of impaired growth during childhood, are also at high risk of LBW and pre-term delivery, and of obstetric complications during labour and delivery (WHO, 1995a; Martorell *et al.,* 1981). A study of healthy women with uncomplicated pregnancies in the United States showed a positive association between maternal height and birth weight among white, black and Asian women, but not Hispanic women (Picket, Abrams and Selvin, 2000).

6.1.1 Desirable birth weight and gestational weight gain

Weight gain during pregnancy comprises the products of conception (foetus, placenta, amniotic fluid), the growth of various maternal tissues (uterus, breasts) and the increase in blood, extracellular fluid and maternal fat stores. The desirable amount of weight to be gained is that which is associated with optimal outcome for the mother, in terms of preventing maternal mortality and complications of pregnancy, labour and delivery, and allowing adequate postpartum body weight and lactation performance; and with optimal outcome for the infant, in terms of allowing adequate foetal growth and maturation, and in the prevention of gestational and perinatal morbidity and mortality. The WHO Collaborative Study on Maternal Anthropometry and Pregnancy Outcomes showed that birth weights between 3.1 and 3.6 kg, with a mean of 3.3 kg, were associated with the optimal ratio of good foetal and maternal outcomes (WHO, 1995a; Kelly *et al.,* 1996). The range of maternal gestational weight gains associated with such birth weights was between 10 and 14 kg, with a mean of 12 kg. This is in agreement with earlier estimates that healthy women in developing countries, who eat in accordance with appetite, gain 10 to 12 kg (Institute of Medicine, 1992). An analysis of gestational weight gains associated with optimal outcomes and full-term delivery of 3- to 4-kg infants in the United States gave a similar although somewhat higher range (11.5 to 16.0 kg) for women with pre-pregnancy BMI between 19.8 and 26.0 (Institute of Medicine/Food and Nutrition Board, 1990; Abrams, Altman and Pickett, 2000).

This consultation endorsed the WHO recommendation that healthy, well-nourished women should gain 10 to 14 kg during pregnancy, with an average of 12 kg, in order to increase the probability of delivering full-term infants with an average birth weight of 3.3 kg, and to reduce the risk of foetal and maternal complications.

6.2 DETERMINANTS OF THE ENERGY COST OF PREGNANCY

The energy cost of pregnancy is determined by the energy needed for maternal gestational weight gain, which is associated with protein and fat accretion in maternal, foetal and placental tissues, and by the increase in energy expenditure associated with basal metabolism and physical activity. It was estimated by previous FAO/WHO/UNU expert committees and consultations (FAO/WHO, 1973; WHO, 1985) through factorial calculations based on a theoretical model that assumed an average gestational weight gain of 12.5 kg, an average infant birth weight of 3.4 kg, cumulative deposition of 925 g protein and 3 825 g fat, an efficiency of energy utilization of 90 percent, and a cumulative increment of 150 MJ in BMR (Hytten, 1980; Hytten and Chamberlain, 1991). Since then, several longitudinal studies in developed and developing countries have allowed for the revision of these theoretical estimates.

6.2.1 Protein and fat deposition during pregnancy

Protein is deposited predominantly in the foetus (42 percent), but also in the uterus (17 percent), blood (14 percent), placenta (10 percent) and breasts (8 percent) (Hytten, 1980; Hytten and Chamberlain, 1991). Total protein deposition has been estimated indirectly from calculations of total body potassium accretion, measured by whole body counting in a number of studies of pregnant women (Butte and King, 2002). Based on results of the most reliable longitudinal studies, which involved 93 women in Sweden (Forsum, Sadurskis and Wager, 1988), the United Kingdom (Pipe *et al.,* 1979) and the United States (King, Calloway and Margen, 1973; Butte *et al.,* 2003), and assuming a potassium to nitrogen (K:N) ratio of 2.15 meq K/g N in foetal tissues, protein deposition was estimated at 686 g, in association with a gestational weight gain of 13.8 kg (Butte and King, 2002). The corresponding protein gain associated with the mean weight gain of 12 kg (range 10 to 14 kg) observed in the WHO collaborative study would be 597 g (range 497 to 696 g).

Cumulative fat deposition in foetal and maternal tissues contributes substantially to the overall energy cost of pregnancy. Therefore, methodological errors in the estimation of fat accretion can affect significantly the calculation of energy requirements. Calculations based on skin-fold measurements lack the precision for an accurate estimate of changes in fat mass during pregnancy, because fat accumulation is not distributed evenly in all parts of the body. Two-component body composition models based on measurement of total body water, body density or total body potassium are acceptable only if they include appropriate corrections to account for pregnancy-related changes in the hydration, density and potassium content of fat-free mass (Butte and King, 2002). Three- and four-component models where the hydration or density of fat-free mass is measured are acceptable to calculate body fat at various stages of pregnancy.

Fat accretion was calculated from the results of 11 longitudinal studies that used three- and four-component body composition models, or two-component models with corrected constants, in 273 well-nourished pregnant women from the Netherlands (van Raaij *et al.,* 1988; Spaaij, 1993; de Groot *et al.,* 1994), Sweden (Forsum, Sadurskis and Wager, 1988; Sohlström and Forsum, 1997), the United Kingdom (Pipe *et al.,* 1979; Goldberg *et al.,* 1993) and the United States (Butte *et al.,* 2003; Lederman *et al.,* 1997; Lindsay *et al.,* 1997; Kopp-Hoolihan *et al.,* 1999a). Mean fat accretion measured up to 36 weeks of gestation was 3.7 kg, associated with a mean weight gain of 11.9 kg. Extrapolating the calculations to 40 weeks of gestation increased mean fat accretion to 4.3 kg, associated with a mean weight gain of 13.8 kg (Butte and King, 2002). The fat gain associated with the mean weight gain of 12 kg (range 10 to 14 kg) observed in the WHO collaborative study would be 3.7 kg (range 3.1 to 4.4 kg).

Rates of fat accretion during the first, second and third trimesters of pregnancy were available in a subset of the studies mentioned (Forsum, Sadurskis and Wager, 1988; Pipe *et al.,* 1979; Butte *et al.,* 2003; de Groot *et al.,* 1994; Goldberg *et al.,* 1993; Kopp-Hoolihan *et al.,* 1999a). These were, on average, 8 g/day in the first trimester, and 26 g/day in the second trimester. Results varied markedly in the third trimester, from –7 to 23 g/day (average: 8 g/day), but if the three studies with very low mean values (–7.0, –1.4 and 4.8 g/day) are excluded from calculations, the average accretion rate would be 18 g fat/day in the third trimester.

6.2.2 Basal metabolism in pregnancy

Basal metabolism increases in pregnancy as a result of accelerated tissue synthesis, increased active tissue mass, and increased cardiovascular and respiratory work. Several studies have measured basal or resting metabolic rate at several stages of pregnancy. As energy requirements should be based on healthy populations with favourable pregnancy outcomes, this consultation only considered the results of studies that involved healthy, well-nourished groups of women with adequate weight gains during pregnancy, who gave birth to infants with adequate weights (Table 6.1) (Forsum, Sadurskis and Wager, 1988; de Groot *et al.,* 1994; Goldberg *et al.,* 1993; Durnin *et al.,* 1987; van Raaij *et al.,* 1987; Spaaij *et al.,* 1994; Piers *et al.,* 1995; Muthayya, 1998; Kopp-Hoolihan *et al.,* 1999b; Cikrikci, Gokbel and Bediz, 1999).

As Table 6.1 shows, the cumulative increment in BMR calculated in relation to pre-pregnancy values, or to early pregnancy values when pre-pregnancy BMR was not available, ranged from 124 to 200 MJ, with an average increase of 154 MJ for the entire gestational period. The average increases in BMR over pre-pregnancy values were in the order of 5, 10 and 25 percent for the first, second and third trimesters, respectively. The coefficient of variability of the cumulative increase in BMR was 16 percent between studies, but the variability between women in each study was higher, with a cumulative variability of 45 to 70 percent in many cases. This demonstrates once again that the application of mean population requirements to specific individuals may lead to large errors. The variation in BMR during pregnancy, which is further illustrated by a striking reduction well into the third trimester of pregnancy found among undernourished Gambian women (Lawrence *et al.,* 1987), a depression in BMR up to 24 weeks of gestation reported in groups of well-nourished United Kingdom (Prentice *et al.,* 1989) and Netherlands (Spaaij, 1993) women, and a cumulative reduction or low increase in BMR during pregnancy among some United States women (Kopp-Hoolihan *et al.,* 1999b).

Cumulative increases in BMR are significantly correlated with gestational weight gain ($r = 0.79$; $p < 0.001$) and pre-pregnancy percentage fat mass ($r = 0.72$; $p < 0.001$) (Prentice *et al.,* 1996). Hence, the cumulative increase of 154 MJ associated with an average gestational weight gain of 12.5 kg (Table 6.1) would correspond to 148 MJ for a weight gain of 12 kg. These values are remarkably close to the 150 MJ estimated from changes in oxygen consumption of individual organs (Hytten, 1980), which was used by previous expert consultations (FAO/WHO, 1973; WHO, 1985).

6.2.3 Total energy expenditure during pregnancy

A review of 122 studies on practices related to work and pregnancy indicated that in most societies women were expected to continue with partial or full household and other duties throughout most of pregnancy (Institute of Medicine, 1992). Similarly, a review and summary of time–motion studies in Scotland, the Netherlands, Thailand, the Philippines, the Gambia and Nepal did not find conclusive evidence that women engaged in less activity during pregnancy and thus reduced their energy expenditure (Prentice *et al.,* 1996). But these studies did not give information about changes in the intensity of the effort associated with habitual tasks. However, there was a suggestion of increased efficiency in energy utilization for physical activity during pregnancy, as the energy cost of weight-bearing activities remained fairly constant during the first two trimesters of pregnancy, even though body weight had increased by 5 to 8 kg by the end of the second trimester (Prentice *et al.,* 1996).

Longitudinal measurements with DLW in free-living, well-nourished women in Sweden (Forsum *et al.,* 1992), the United Kingdom (Goldberg *et al.,* 1993 and 1991) and the United States (Butte *et al.,* 2003; Kopp-Hoolihan *et al.,* 1999b) showed a mean increase of 16.5 percent in TEE by the third trimester of pregnancy, compared with non-pregnant values (Table 6.2). Some of these studies provided information at each trimester of pregnancy and in the non-pregnant state, suggesting that TEE increased by about 1, 6 and 17 percent in the first, second and third trimesters of pregnancy, respectively. This was proportional to recorded increments in weight gain of 2, 8 and 18 percent during the same periods ((Butte and King, 2002). The relationship between TEE and weight gain is reflected in the lack of difference between non-pregnant and pregnant women when TEE is expressed per kilogram of body weight (Table 6.2). The estimated increments in TEE were 100, 400 and 1 500 kJ/day (25, 95 and 360 kcal/day) in the first, second and third trimesters of pregnancy, respectively, in association with an average weight gain of 13.8 kg (Butte and King, 2002). For an average gain of 12 kg, the corresponding values would be 85, 350 and 1 300 kJ/day (20, 85 and 310 kcal/day).

Because of the larger increment in BMR, especially in the second and third trimesters of pregnancy (Table 6.1), PAL declined from 1.74 prior to pregnancy to 1.60 in late gestation (Table 6.2). Compared with non-pregnant values, total energy expenditure to activity (activity energy expenditure [AEE]) near the end of gestation ranged from a decrease of 22 percent to an increase of 17 percent, but on average did not differ significantly between non-pregnant women and women in the third trimester of pregnancy (3 percent ± 15 percent, Table 6.2). However, when expressed per unit of body weight, there was a tendency towards lower AEE/kg/day in the last trimester of pregnancy.

Cross-sectional studies with DLW, HRM or time–motion techniques in Colombia (Dufour, Reina and Spurr, 1999), Nepal (Panter-Brick, 1993), and two (Heini *et al.,* 1991; Lawrence and Whitehead, 1988) of three (including Singh *et al.,* 1989) studies in the Gambia, showed a slight decrease in TEE, ranging from 1 to 7 percent, and larger reductions, from 10 to 38 percent, in AEE by the third trimester of pregnancy, relative to non-pregnant controls (Butte and King, 2002). This was consistent with observations that many women perform less arduous tasks as they approach the end of pregnancy.

6.3 CALCULATION OF ENERGY REQUIREMENTS FOR PREGNANCY

The extra amount of energy required during pregnancy was calculated in association with a mean gestational weight gain of 12 kg by two factorial approaches, using either the cumulative increment in BMR during pregnancy (section 6.2.2) or the cumulative increment in TEE (section 6.2.3), plus the energy deposited as protein and fat (section 6.2.1). In the calculations using the increment in BMR, it was assumed that the efficiency in energy utilization to synthesize protein and fat was 90 percent. Adjustments for efficiency of energy utilization were not necessary in the calculations that used the increment in TEE, as TEE measured with DLW includes the energy cost of synthesis. As Table 6.3 shows, the estimates of the additional energy required during pregnancy were very similar using either BMR or TEE for the calculations: 323 MJ (77 100 kcal) and 320 MJ (76 500 kcal), respectively. These values, which were based on experimental data, differ by only 4 percent from the theoretical estimate of 335 MJ (80 000 kcal) made by the 1981 FAO/WHO/UNU expert consultation (WHO, 1985).

The energy cost of pregnancy is not distributed equally throughout the gestational period. The deposition of protein occurs primarily in the second (20 percent) and third trimesters (80 percent). Assuming that the rate of fat deposition follows the same pattern as the rate of gestational weight gain, 11, 47 and 42 percent of fat is deposited in the first, second and third trimesters, respectively (Institute of Medicine/Food and Nutrition Board, 1990). The increments in BMR in these trimesters are about 5, 10 and 25 percent, respectively (section 6.2.2 and Table 6.2), whereas the increase in TEE for women gaining 12 kg in pregnancy was estimated at about 85, 350 kcal/day and 1 300 kJ/day per trimester (section 6.2.3).

TABLE 6.1
Cumulative increase in basal metabolic rate of well-nourished women during pregnancy

Country (reference)	No.	Weight gain in 40 weeks kg[a]	Mean BMR MJ/d				Cumulative increase in BMR at 40 weeks MJ[b]	Percentage (%) change in BMR relative to:				
								Pre-pregnancy			*1st trimester*	
			Pre-pregnancy	1st trim.	2nd trim.	3rd trim.		1st trim.	2nd trim.	3rd trim.	2nd trim.	3rd trim.
UK (Durnin *et al.,* 1987)	88	12.4	6.0	6.3	6.5	7.3	126	5	8	22	3	16
Netherlands (van Raaij *et al.,* 1987)	57	11.6					144					
Sweden (Forsum, Sadurskis and Wager, 1988)	22	13.4	5.6		6.0	7.3	200		7	30		
UK (Goldberg *et al.,* 1993)	12	13.7	6.0	6.3	6.4	7.2	124	5	7	20	2	14
Netherlands (van Raaij *et al.,* 1987)	26	13.7	5.4	5.7	6.2	6.6	189	6	15	22	9	16
Netherlands (de Groot *et al.,* 1994)	12	11.6	5.8	6.3	6.5	7.2	149	9	12	24	3	14
India (Piers *et al.,* 1995)	18	12.0		5.1	5.6	6.2	143				10	22
India (Muthayya, 1998)	26	11.3	4.6	5.0	5.3	6.0	151	9	15	30	6	20
USA (Kopp-Hoolihan *et al.,* 1999)	10	13.2	5.5	5.4	6.4	7.1	151	-2	16	29	19	31
Turkey (Cikrikci, Gokbel and Bediz, 1999)	24	12.3		5.2	5.8	6.4	162				12	23
Average[c]		**12.5**	**5.6**	**5.7**	**6.1**	**6.9**	**154**	**5.3**	**11.4**	**25.3**	**8.0**	**19.5**
sd[c]		**0.9**	**0.5**	**0.6**	**0.4**	**0.4**	**24**	**4.0**	**4.0**	**4.3**	**5.8**	**5.8**

[a] Weight gain was extrapolated to 40 weeks of gestation, assuming that the average weight gain during the first ten to 12 weeks of pregnancy is 0.65 kg, and that weight gain increases in the last four to eight weeks by 0.40 kg/week (Hytten and Chamberlain, 1991).
[b] Calculated as cumulative increase throughout pregnancy in relation to pre-pregnancy or early pregnancy values of BMR.
[c] Non-weighted averages and standard deviations of the mean results in the studies shown in this table.

TABLE 6.2
Total energy expenditure measured with DLW in well-nourished non-pregnant and pregnant women

Country, (reference)	No.	Measurement, week of gestation	Weight kg	TEE MJ/d	BMR MJ/d	AEE MJ/d	PAL	Preg TEE/ NP TEE[a] %	Preg AEE/ NP AE[b] %	TEE kJ/kg/d	AEE kJ/kg/d
UK (Goldberg *et al.*, 1991)	10	NP	57.1	9.8	5.9	3.9	1.67			171	69
	10	36	69.0[b]	10.3	7.3	3.0	1.42	5.6	-22.4	150[c]	44[b]
Sweden (Forsum *et al.*, 1992)	19	NP	60.7	10.1	5.6	4.5	1.80			166	74
	19	36	72.7	12.2	7.3	4.9	1.67	20.8	8.9	168	67
	22	NP	61.0	10.4	5.6	4.8	1.86			170	79
	22	30	70.2	12.5	6.9	5.6	1.81	20.2	16.7	178	80
UK (Goldberg *et al.*, 1993)	12	NP	61.7	9.5	6.1	3.5	1.57			154	56
	12	36	73.6	11.3	7.6	3.7	1.49	18.2	6.6	153	50
USA (Kopp-Hoolihan *et al.*, 1999b)	10	NP	63.5	9.2	5.5	3.7	1.68			147	58
	10	34-36	75.1	11.4	7.1	4.4	1.61	23.7	16.6	153	59
USA (Butte *et al.*, 2003)	34	NP	59.3	10.2	5.5	4.7	1.84			172	78
	34	36	72.2	11.3	7.0	4.3	1.61	10.7	-8.2	156	59
Mean non-pregnant			**60.6**	**9.9**	**5.7**	**4.2**	**1.74**			**164**	**69**
sd[d]			**2.2**	**0.4**	**0.2**	**0.5**	**0.11**			**11**	**10**
Mean 30–36 weeks			**72.1**	**11.5**	**7.2**	**4.3**	**1.60**	**16.5**	**3.0**	**160**	**60**
sd			**2.2**	**0.8**	**0.2**	**0.9**	**0.14**	**6.9**	**15.4**	**11**	**13**

[a] Preg = pregnant.
[b] NP = non-pregnant.
[c] Based on estimated mean body weight.
[d] sd = standard deviation of the mean.

TABLE 6.3
Additional energy cost of pregnancy in women with an average gestational weight gain of 12 kg*

A. Rates of tissue deposition					
	1st trimester g/d	**2nd trimester** g/d	**3rd trimester** g/d	**Total deposition** g/280 d	
Weight gain	17	60	54	12 000	
Protein deposition[a]	0	1.3	5.1	597	
Fat deposition[a]	5.2	18.9	16.9	3 741	
B. Energy cost of pregnancy estimated from the increment in BMR and energy deposition					
	1st trimester *kJ/d*	**2nd trimester** *kJ/d*	**3rd trimester** *kJ/d*	**Total energy cost**	
				MJ	*kcal*
Protein deposition[a]	0	30	121	14.1	*3 370*
Fat deposition[a]	202	732	654	144.8	*34 600*
Efficiency of energy utilization[b]	20	76	77	15.9	*3 800*
Basal metabolic rate	199	397	993	147.8	*35 130*
Total energy cost of pregnancy (kJ/d)	**421**	**1 235**	**1 845**	**322.6**	***77 100***
C. Energy cost of pregnancy estimated from the increment in TEE and energy deposition					
	1st trimester *kJ/d*	**2nd trimester** *kJ/d*	**3rd trimester** *kJ/d*	**Total energy cost**	
				MJ	*kcal*
Protein deposition[a]	0	30	121	14.1	*3 370*
Fat deposition[a]	202	732	654	144.8	*34 600*
Total energy expenditure[c]	85	350	1 300	161.4	*38 560*
Total energy cost of pregnancy (kJ/d)	**287**	**1,112**	**2 075**	**320.2**	***76 530***

* Calculated as suggested by Butte and King (2002). Weight gain and tissue deposition in first trimester computed from last menstrual period (i.e. an interval of 79 days). Second and third trimesters computed as 280/3 = 93 days each.
[a] Protein and fat deposition estimated from longitudinal studies of body composition during pregnancy, and an energy value of 23.6 kJ (*5.65 kcal*)/g protein deposited, and 38.7 kJ (*9.25 kcal*)/g fat deposited.
[b] Efficiency of food energy utilization for protein and fat deposition taken as 0.90 (Hytten, 1990).
[c] Efficiency of energy utilization not included in this calculation, as the energy cost of synthesis is included in the measurement of TEE by DLW.

Based on these considerations and averaging the two factorial calculations shown in Table 6.3, the extra energy cost of pregnancy is 321 MJ (77 000 kcal) divided into approximately 0.35 MJ/day, 1.2 MJ/day and 2.0 MJ/day (85 kcal/day, 285 kcal/day and 475 kcal/day) during the first, second and third trimesters, respectively. There are many societies with a high proportion of non-obese women who do not seek prenatal advice before the second or third month of pregnancy. Under these circumstances a practical option to achieve the total additional intake of 321 MJ (77 000 kcal) during pregnancy is to add the extra 0.35 MJ/day required in the first trimester to the 1.2 MJ/day required in the second trimester. Rounding numbers for ease of calculation, this consultation recommends that in such societies pregnant women increase their food intake by 1.5 MJ/day (360 kcal/day) in the second trimester, and by 2.0 MJ/day (475 kcal/day) in the third.

The preceding joint FAO/WHO/UNU expert consultation suggested that the additional energy allowance could be lowered in cases where women reduce their activity level during pregnancy. When such a reduction occurred among the women who participated in the studies listed in Table 6.2, it was built into the 24-hour TEE used to calculate the energy cost of pregnancy in Table 6.3. On the other hand, not all women have the option to reduce physical activity during pregnancy. In particularly, low-income women from developing countries must often continue a strenuous work pattern until shortly before delivery. Furthermore, women who are sedentary prior to pregnancy have little flexibility to reduce their level of physical activity. Consequently, this consultation does not recommend a reduction in the additional energy allowance for pregnancy.

6.4 SPECIAL CONSIDERATIONS FOR MALNOURISHED, OBESE AND ADOLESCENT PREGNANT WOMEN

Undernutrition, whether manifested as underweight or as stunting, and obesity increase the risk of poor maternal and foetal outcomes. Ideally, women should begin pregnancy at a healthy weight, defined as a BMI between 18.5 and 24.9 (WHO, 1995a; March of Dimes, 2002). Adolescent girls who are pregnant must fulfil the dietary requirements imposed by growth associated with their age, in addition to the extra demands of pregnancy.

6.4.1 Pregnancy and undernutrition

A large number of women in many parts of the world enter pregnancy at suboptimal weight and/or height. An analysis of studies in 20 countries (Kelly *et al.,* 1996) showed that in ten countries many women had pre-pregnancy weights of < 50 kg and heights of < 150 cm. These cut-off points were associated with increased risks of maternal complications. In addition, weight below 45 kg or height below 148 cm were associated with poor foetal outcomes. The linear relationship between gestational weight gain and birth weight is influenced by maternal pre-pregnancy BMI, such that women with a BMI < 18.5 must gain more weight than those with a normal BMI in order to have babies with adequate birth weight. It is then particularly important that underweight women increase their energy intake to gain the prescribed 10 to 14 kg during pregnancy, depending on their height (e.g. taller women should strive for a weight gain of 14 kg). Gestational weight gains as high as 18 kg have been suggested for undernourished women (Institute of Medicine/Food and Nutrition Board, 1992).

The association of short stature with increased risk of either delivering a low birth weight infant or requiring special assistance during delivery owing to cephalo-pelvic disproportion (Merchant, Villar and Kestler, 2001) indicates the importance for such women to have adequate prenatal attention and access to appropriate care during labour and delivery. This also reinforces the recommendations for good nutrition and measures to prevent repeated infections during childhood, which may result in stunting and in pregnancy-related problems at a later age.

6.4.2 Pregnancy and obesity

Maternal obesity is also associated with a higher risk of maternal and foetal complications. As for undernutrition, the relative risks of neural tube defects, congenital malformations and pre-term delivery are higher in overweight and obese women (March of Dimes, 2002). Incidences of hypertension, gestational diabetes and the need for caesarean section operations are also higher than in women with normal weight.

Women with a pre-pregnancy BMI > 25 tend to have babies with high birth weights, even when the women have relatively low gestational weight gains (Institute of Medicine/Food and Nutrition Board, 1992; Shapiro, Sutija and Bush, 2000). As this may lead to problems during delivery, it is likely that such women will be better off gaining weight at, or somewhat below, the lower limit of the 10 to 14 kg range recommended for women with normal BMI. It has been suggested that weight gain should be as low as 7 kg for women who enter pregnancy with BMI > 26 (Institute of Medicine/Food and Nutrition Board, 1992).

6.4.3 Pregnancy in adolescence

It is important to satisfy the energy needs of adolescence, when as much as 20 percent of total growth in stature can occur (WHO, 1995b). These needs increase during gestation and must be satisfied by appropriate dietary intakes to satisfy the requirements of both adolescence and pregnancy, in order to allow adequate maternal and foetal growth.

Compared with older women, those under 18 years of age have an increased risk of pre-term delivery, giving birth to infants with low birth weight or small size for gestational age, and requiring special obstetrical assistance (Kumbi and Isehak, 1999; Larsson and Svanberg, 1983; Bwibo, 1985; Gortzak-Uzan *et al.,* 2001). The risks increase with decreasing age (Bwibo, 1985; Bhalerao *et al.,* 1990). Owing to the high incidence of complications associated with an immature body and small size, it is essential that, in addition to a suitable diet, adolescent pregnant girls receive adequate prenatal care and have access to appropriate medical facilities during labour and delivery.

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7. ENERGY REQUIREMENTS OF LACTATION

Exclusive breastfeeding is recommended during the six months after delivery, with introduction of complementary foods and continued breastfeeding thereafter (WHO, 2001). The energy requirement of a lactating woman is defined as the level of energy intake from food that will balance the energy expenditure needed to maintain a body weight and body composition, a level of physical activity and breastmilk production that are consistent with good health for the woman and her child, and that will allow economically necessary and socially desirable activities to be performed. To operationalize this definition, the energy needed to produce an appropriate volume of milk must be added to the woman's habitual energy requirement, assuming that she resumes her usual level of physical activity soon after giving birth.

The mean amount of breastmilk produced daily is similar among population groups with different cultural and socio-economic settings (Prentice *et al.,* 1986; Butte, Lopez-Alarcon and Garza, 2002) (Table 7.1). There may be some variation in milk composition related to maternal nutrition, but the main factors that influence the energy needs of lactating women are the duration of breastfeeding practices and the extent of exclusive breastfeeding. As these vary significantly in different societies, dietary energy recommendations for lactating women should be population-specific. Regardless of the cultural and social environment, the ideal situation is that women be well nourished from the beginning of pregnancy and that they maintain adequate nutritional intake with appropriate weight gain throughout gestation. This will allow them to attain body fat reserves that may act as an energy substrate to cover part of the additional energy needs in preparation for and during lactation.

TABLE 7.1
Average milk production rates (g/d)

Postpartum period (months)	1	2	3	4	5	6	7	8	9	10	11	12
Exclusive breastfeeding												
Industrialized countries	699	731	751	780	796	854						
Traditional countries	562	634	582	768	778	804						
Partial breastfeeding												
Industrialized countries	611	697	730	704	710	612	569	417	497	691	516	497
Traditional countries	568	636	574	634	714	611	688	635	516		565	511

Source: Butte, Lopez-Alarcon and Garza, 2002.

7.1 DETERMINANTS OF THE ENERGY COST OF LACTATION

The energy cost of lactation is determined by the amount of milk that is produced and secreted, its energy content, and the efficiency with which dietary energy is converted to milk energy.

7.1.1 Human milk production

The mean amount of milk ingested by exclusively breastfed infants is similar in industrialized and more traditional societies, according to a WHO-sponsored comprehensive review (Butte, Lopez-Alarcon and Garza, 2002). After six months, variation among individuals and populations increases, owing to the nature and amount of complementary foods provided to the growing infant. From the age of six months onwards, when infants are partially breastfed, milk production is estimated at 550 g/day.

7.1.2 Energy content of human milk

The energy content of human milk depends primarily on milk fat concentration, which shows complex diurnal, within-feed and between-breast fluctuations. Twenty-four-hour milk sampling schemes have been developed that interfere minimally with the secretion of milk flow and capture the diurnal and within-feed variation (Garza and Butte, 1986). Measurements of the gross energy content of representative 24-hour milk samples determined by adiabatic bomb calorimetry or macronutrient analysis in a number of studies of well-nourished women gave a mean value of 2.8 kJ/g (0.67 kcal/g) from 1 to 24 months of lactation (Garza and Butte, 1986; Prentice and Prentice, 1988; Butte and King, 2002; WHO, 1985; Institute of Medicine, 1991; Goldberg *et al.,* 1991; Panter-Brick, 1993).

7.1.3 Efficiency of energy conversion

The efficiency with which food energy and body energy reserves are converted into milk energy has been calculated from theoretical estimates of the biochemical efficiency associated with the synthesis of milk lactose, protein and fat, and from metabolic balance studies (Prentice and Prentice, 1988). Taking into account the energy costs of digestion, absorption, conversion and transport, biochemical efficiency has been estimated at 80 to 85 percent (Butte and King, 2002). Based on that estimate, on the theoretical efficiency used in the 1985 FAO/WHO/UNU report and on the suggestion of the United States Institute of Medicine (1991), an efficiency factor of 80 percent was applied to calculate the energy cost of human milk production.

7.1.4 Energy cost of milk production

Table 7.2 shows the energy cost to produce the mean amounts of milk needed for exclusively breastfed infants. Monthly milk volumes are those reported for well-nourished women with healthy babies in the WHO-sponsored review (Butte, Lopez-Alarcon and Garza, 2002), and gross energy contents are those described in section 7.1.2.

The results were compared with the energy requirements of exclusively breastfed infants from one to six months of age, calculated as described in chapter 3. To do so, human milk intakes that are measured by the test-weighing technique must be corrected for insensible water loss during the course of feeding (5 percent correction factor) and for the digestibility of human milk. The metabolizable energy in human milk was assumed to be 5.3 percent lower than its gross energy content based on proximate analyses and energy factors of 23.6 kJ (5.65 kcal) per gram of protein and free amino acids, 38.7 kJ (9.25 kcal) per gram of fat and 16.5 kJ (3.95 kcal) per gram of lactose. From months one to six the figures are on average within 5 percent, which is remarkable considering that energy requirements of infants were calculated from quite different information (i.e. from predictive equations based on DLW measurements of TEE, plus estimates of growth accretion based on growth velocity and body composition).

TABLE 7.2
Energy cost of human milk production by women who practise exclusive breastfeeding

Months postpartum	Mean milk intake g/day[a]	Human milk intake, corrected for insensible water losses g/day[b]	Gross energy content kJ/g[c]	Daily gross energy secreted kJ/day	Energy cost of milk production kJ/day[d]
1	699	734	2.8	2 055	2 569
2	731	768	2.8	2 149	2 686
3	751	789	2.8	2 208	2 760
4	780	819	2.8	2 293	2 867
5	796	836	2.8	2 340	2 925
6	854	897	2.8	2 511	3 138
Mean	769	807	2.8	2 259	2 824

[a] From Butte, Lopez-Alarcon and Garza, 2002.
[b] Insensible water losses assumed to be equal to 5 percent milk intake.
[c] Gross energy content measured by adiabatic bomb calorimetry or macronutrient analysis.
[d] Based on energetic efficiency of 80 percent.

TABLE 7.3
Comparison of the energy cost of human milk production and energy requirements of exclusively breastfed infants

Months postpartum	Mean milk intake g/day[a]	Human milk intake, corrected for insensible water losses g/day[b]	Gross energy content kJ/g[c]	Daily gross energy secreted kJ/day	Metabolizable energy intake kJ/day[d]	Infant energy requirement kJ/day[e]	Requirement/ME intake
1	699	734	2.8	2 055	1 946	1 922	0.99
2	731	768	2.8	2 149	2 035	2 143	1.05
3	751	789	2.8	2 208	2 091	2 284	1.09
4	780	819	2.8	2 293	2 172	2 219	1.02
5	796	836	2.8	2 340	2 216	2 376	1.07
6	854	897	2.8	2 511	2 378	2 501	1.05
Mean	769	807	2.8	2 259	2 140	2 241	1.05

[a] From Butte, Lopez-Alarcon and Garza, 2002.
[b] Insensible water losses assumed to be equal to 5 percent milk intake.
[c] Gross energy content measured by adiabatic bomb calorimetry or macronutrient analysis.
[d] Metabolizable energy values based on proximate analysis of milk are 5.3 percent lower than bomb calorimetry values.
[e] Mean values of boys and girls, calculated as described in chapter 3 of this report.

7.2 ENERGY REQUIREMENTS FOR LACTATION

Compared with non-pregnant, non-lactating women, during lactation there are no significant changes in BMR, efficiency of work performance, or TEE (Butte and King, 2002), and in most societies women resume their usual level of physical activity in the first month postpartum or shortly thereafter (Goldberg *et al.,* 1991; Panter-Brick, 1993; Roberts *et al.,* 1982; Tuazon *et al.,* 1987; van Raaij *et al.,* 1990). It could be argued that where exclusive breastfeeding is prevalent, lactating mothers may have a lower TEE than non-pregnant, non-lactating women owing to the frequency of breastfeeding, which involves periods of little maternal activity. On the other hand, lactating women often carry their infants while moving around, and this additional workload might balance the lower physical activity associated with breastfeeding. Thus, total energy requirements during lactation are equal to those of the pre-pregnancy period, plus the additional demands imposed by the need for adequate milk production and secretion.

These additional demands correspond to the energy cost of milk production. For women who feed their infants exclusively with breastmilk during the first six months of life, the mean energy cost over the six-month period is: 807 g milk/day × 2.8 kJ/g / 0.80 efficiency = 2.8 MJ/day (675 kcal/day) (Table 7.2). From the age of six months onwards, when infants are partially breastfed and milk production is on average 550 g/day (Table 7.1), the energy cost imposed by lactation is 1.925 MJ/day (460kcal/day).

Fat stores accumulated during pregnancy may cover part of the additional energy needs in the first few months of lactation. Postpartum loss of body weight is usually highest in the first three months, and generally greater among women who practise exclusive breastfeeding, but the extent to which the energy mobilized supports lactation depends on the gestational weight gain and the nutritional status of the mother. A review of 17 studies indicated that, on average, well-nourished women lost 0.8 kg/month, whereas undernourished mothers lost only an average of 0.1 kg/month (Butte and Hopkinson, 1998). Assuming an energy factor of 27.2 MJ/kg (Butte and King, 2002; Butte and Hopkinson, 1998), the rate of weight loss in well-nourished women would correspond to the mobilization of 27.2 × 0.8 kg/month = 21.8 MJ/month, or 0.72 MJ/day (170 kcal/day) from body energy stores. This amount of energy can be deducted from the 2.8 MJ/day (675 kcal)/day needed during the first six months of lactation. The result, 2.1 MJ/day (505 kcal/day), is similar to the additional energy required when infants are partially breastfed after six months of lactation.

On the other hand, undernourished women and those who did not gain adequate body weight during pregnancy must conserve as much energy as possible for their own well-being and that of their infants. Hence, in these women the full energy demands of lactation must be provided by an increment in dietary intake.

In conclusion, well-nourished women with adequate gestational weight gain should increase their food intake by 2.1 MJ/day (505 kcal/day) for the first six months of lactation, while undernourished women and those with insufficient gestational weight gain should add to their personal energy demands 2.8 MJ/day (675 kcal/day) during the first semester of lactation. Energy requirements for milk production in the second six months are dependent on rates of milk production, which are highly variable among women and populations.

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8. RECOMMENDATIONS FOR FUTURE RESEARCH

Expert consultation meetings that are convened to make recommendations on nutrient requirements are sometimes faced with situations in which adequate information is lacking and questions need to be answered before evidence-based recommendations that are applicable to population groups worldwide can be provided. Recognition of the lacunae in the existing knowledge base helps the identification of potential areas for future research and investigation by the wider scientific and academic communities. The deliberations and recommendations of experts in this important sphere carry much weight within the academic community, as well as with research funding bodies, international agencies and bilateral donors.

The following recommendations for future research are based on the topics and issues that were identified during the more focused discussions at the preliminary working group sessions, and that were fed into the expert consultation, as well as on those identified by the experts themselves during the consultation. However, as the present expert consultation acknowledged, it is not enough to come up with a wish list of research topics without prioritizing what needs to be done. With resources becoming increasingly limited, the experts recognized that it would be futile either to outline research needs too broadly or to attempt to include every conceivable topic that may be relevant to the issues raised during their deliberations. The expert consultation recognized the need to make judgements on priorities when they stated: "We need to prioritize our recommendations so as not to dilute the strength of our requests."

The questions and topics that the 2001 expert consultation identified as being in need of further investigation are categorized into two broad groups. The first group consists of those biological questions whose answers will provide better numerical estimates of human requirements. These include conceptual, methodological and data-gathering components. The second group includes epidemiological and community studies aimed at testing the validity of the estimates in populations living in different environmental and social conditions, for which more general, and indeed more realistic, criteria of health and function are required than those that are used in metabolic or clinical investigations. This second group also includes questions that relate to the use of the recommended nutrient requirement estimates and their implications for planners and policy-makers at the national, regional and global levels.

8.1 BIOLOGICAL QUESTIONS: CONCEPTUAL AND METHODOLOGICAL

8.1.1 Basal metabolic rate (BMR) and total energy expenditure (TEE)

1. BMR predictive equations are to be revisited, reviewed and reformulated, if necessary, based on access to a larger, more comprehensive global database that should be expanded and collated with strict and transparent quality and inclusion criteria.
2. There are insufficient data to judge whether either ethnicity or habitation in a tropical environment influences BMR. It is possible that aspects that are attributed to ethnicity may well be responses to early life exposure to suboptimal nutritional environments. It is therefore recommended that when ethnicity is researched and reported, additional information on history of nutritional status and/or environmental exposure in early life also be measured and reported. This phenomenon needs to be better understood, the physiological basis needs to be established and the plausible mechanisms involved need to be clarified.
3. Prospective studies to measure daily TEE by DLW and/or other methods (such as the flex-heart rate method) need to be undertaken in order to provide comparisons for the same subjects with estimates based on the factorial method. Measured BMR and the energy cost of sitting, standing, etc. may be used with the PAL values presented here for calculating daily energy expenditure in an effort to enhance the application of these PAL values. There is accumulating evidence from various laboratories of discrepancies between estimates of TEE by the factorial method using published PAL values compared with estimates using other

methods, such as the flex-heart rate method. This discrepancy becomes more apparent when the intensity of an activity is increased. Studies comparing the two methods using different sources of PAL values suggest that it may be possible to use these data more appropriately and to reconcile the data generated. Given the shortage and inordinate expense of stable isotopes, it is necessary to invest more in accepted methodologies in order to broaden the database. There is also a need for more data on PAL values.

4. There is an urgent need for more TEE and measured BMR studies, coupled with time–motion studies from developing countries that cover prevailing and changing life styles. The use of DLW studies will be essential for the purpose of validating existing methodologies and developing new ones. Support from the International Atomic Energy Agency (IAEA) in making available more isotopes at less cost, in improving the ability to analyse these and in general capacity building to cater to developing country needs is crucial in this area.
5. There is shortage of information on BMR and TEE from elderly groups because this subpopulation is increasing owing to changes in longevity and demographics in developing and developed societies.
6. Further development and validation of techniques for measuring TEE and BMR, as well as energy cost of activity expenditures and patterns, need to be supported. New techniques should be accurate, precise, portable, cheap and appropriate for field-based studies worldwide. Ideally, all new techniques need to be validated against both indirect calorimetry and DLW methods.
7. There is a need to update and expand the data bank on the energy cost of a range of activities undertaken in real-life conditions by children and adults, distinguishing weight-bearing from non-weight-bearing activities, and specifying whether energy cost refers to "net" activity or is integrated over tasks.
8. The number of available DLW studies on infants (and young children) from developing countries is limited and needs to be expanded in normal birth weight infants.
9. Studies with DLW (or other methods) need to be carried out in order to determine TEE of school-going children and adolescents in urban and rural areas of developing countries.
10. The DLW method provides a means of determining the amount of energy expended in physical activity. PALs consistent with normal health and the development of infants and children should be described qualitatively and ethnographically across cultures.
11. Further studies are needed to confirm whether the increased TEE observed in some settings is caused solely by differences in size and body composition or whether other mitigating factors are involved.
12. More information is needed about the influence of habitual physical activity on the growth and development of all children and adolescents, and on the duration, intensity and frequency of the physical activity that is necessary to achieve optimal effects.

8.1.2 Nutritional anthropometry and body composition

1. The use of United States-based reference data for assessing adolescent growth worldwide is a matter of concern, and it is recommended that research be conducted in order to evaluate their universal applicability, specifically the upper percentile elevations and skewness of the NCHS value, especially as they apply to developing countries.
2. More data are needed on variations in body composition of individuals in different population groups. There is a further need to develop methodologies for body size normalization when estimating the energy cost of different activities.

8.1.3 Studies in undernourished subpopulations

1. The effect of the quality of dietary protein, carbohydrate and fat on rates of weight gain, particularly during the recovery period from malnutrition, needs to be understood better. Biological (and behavioural) studies are needed to help establish appropriate levels of energy intake during convalescence from such episodes.
2. Nutrient needs for the rehabilitation of stunted children are also poorly understood. Information is needed on the energy intake and expenditure requirements for catch-up growth

in body mass and stature of stunted and undernourished children. Special nutrient requirements for catch-up growth of bones require further research. Physiological adjustments in physical activity and growth in response to undernutrition should be investigated with newer methodologies such as DLW.

3. There is a need for estimates of BMR and TEE using DLW methodology in undernourished children and adults. This should include an investigation of intra-uterine growth retarded (IUGR) infants, and stunted and undernourished groups of children, compared with children with adequate growth.

8.1.4 Food energy

1. Factors affecting the dietary intake that is necessary to satisfy energy requirements should be explored, including diet digestibility, viscosity, and energy and nutrient density.
2. The validity of metabolizable energy (ME) food energy conversion factors as quantitative equivalents of biologically useful, energy and their relationship to net metabolizable energy (NME) need to be reviewed. It may be necessary to investigate how best NME and energy requirement estimations can be integrated and reconciled.
3. The AOAC (Prosky) method of dietary fibre analysis is now widely used in food analysis. Further research is needed to develop reliable analytical methods for resistant starches.

8.2 EPIDEMIOLOGICAL AND COMMUNITY STUDIES

1. Large numbers of children in developing countries have experienced repeated episodes of infections, which are often accompanied by a negative energy balance owing to decreased appetite and/or increased metabolic activity. Studies on the effects of infection on energy requirements of infants are limited, and should be expanded to cover a broad range of infectious agents of varying severity and duration.
2. More qualitative and quantitative information is needed on the habitual physical activity of children and adolescents in developing societies. This includes physiological, anthropological and behavioural studies. Anthropologists and other social scientists must be invited to participate in this endeavour, as information already exists in reports and monographs in the social sciences literature, and this should be analysed.
3. Currently, there are major gaps in the knowledge regarding estimating the survival level of energy expenditure, and consequently the lower limits of emergency rations and food aid baskets, particularly in refugee settings. This is in need of urgent evaluation. The support of FAO/WHO is essential if the academic community is to obtain funds for such investigations from research organizations.
4. There is a general consensus that the most crucial aspects in understanding the energy requirements in pregnancy and lactation are now known. However, more research with respect to public health-related issues (e.g. low birth weight) should be carried out. There is a need for longitudinal studies on pregnant woman, in order to relate the associated physiological parameters with birth outcomes and risks. More research is needed on the range of issues that affect obese and underweight women during pregnancy and lactation.
5. There is a need to establish the nature, duration, frequency and intensity of physical exercise required to maintain generally good health and to prevent specific pathologies, such as obesity and its related co-morbidities.
6. There is a need to understand better the health risks of people with BMI less than 18.5.
7. Overweight and obesity are closely linked to a positive (i.e. surplus) energy balance. Biological and behavioural investigations are needed to develop and test methods that will guide children and adolescents towards an energy balance that reduces the risk of becoming overweight.
8. Techniques must be developed to stimulate children's and adolescents' interest in performing an appropriate level of physical activity in the context of different geographic, cultural and socio-economic environments.
9. Reliable documentation on life-styles and time use needs to be collected in order to improve the existing energy expenditure estimates using adults, children and the elderly in diverse

contexts, with special efforts to include information from developing country and transitional society contexts.

9. CONCLUSIONS

The primary aim of the expert consultations on nutrient requirements has remained the same: to provide advice on scientific issues related to nutrient requirements and to formulate appropriate recommendations for action. An examination of the historical precedents in this endeavour reveals how the various expert groups have contributed to the principles for determining human energy requirements and their practical applications, which have been adopted worldwide. The recommendations from the resulting reports have not only reflected the state of knowledge at particular points in time, but have also been embraced by the global scientific community, thereby influencing research agendas and methodologies over the years.

Many of the points made by the first committee on calorie requirements, which met in 1949, are still pertinent today. The requirements set by the experts were intended for groups of people rather than individuals, and the committee established the principle, which is often misunderstood, that "an average requirement can never be compared directly with an individual (requirement)" (FAO, 1950). The first committee noted that its recommendations should be adjusted depending on how and for whom they are used, and it cautioned that nutrition and health experts within countries should take into account local conditions in applying the requirements. There is always the need to exercise judgement in interpreting and using requirement values, yet advice in this area is most difficult to impart to users. The first committee on calories offered the very practical rule of thumb that if the person "is in good health and calorie balance, that is, neither over- nor underweight, then he or she is consuming food according to his or her calorie requirements" (FAO, 1950). Subsequent committees also recognized the importance of maintaining an adequate level of energy expenditure, thus acknowledging that non-occupational activities were just as important as occupational ones to the overall health status of many people and that energy requirements did not refer to a minimum level (FAO, 1973).

The 1973 Report of the Joint FAO/WHO Ad Hoc Expert Committee on Energy and Protein Requirements reiterated statements that had been made in past reports that the recommendations for nutrient requirements should be applied to groups and not to individuals. However, the 1973 report also made two additional important points: 1) that estimates of requirements are derived from individuals rather than groups; and 2) that the nutrient requirements of comparable individuals often vary.

The report of the Joint FAO/WHO/UNU Expert Consultation on Energy and Protein Requirements held in 1981 (WHO, 1985) was very clear in its statement that estimates of energy requirements should, as far as possible, be based on estimates of energy expenditure, as the prevailing method of determination – from observed intakes of food energy – was becoming unreliable and served to support a circular argument that access to food determined energy needs. The rationale for this conclusion was that in both developing and developed countries actual energy intakes are not necessarily those that either maintain a desirable body weight or provide for optimal levels of physical activity, and hence health in its broadest sense. The experts at the 1981 consultation were aware of the limited data on energy expenditures, particularly among children. They were also conscious of the fact that no reliable and widely useable method was available to the scientific and academic community for collecting such data from a range of population groups worldwide.

The 1981 expert consultation felt that, except for children, sufficient information was available to approach this issue using data on BMR at the centre of a new conceptual framework to estimate total energy expenditure. Thus the use of BMR became important in determining energy requirements. The experts identified a new methodology for calculating energy requirements, and substantial research that needed to be carried out after the expert consultation. One significant departure of the 1981 expert group from that of the 1971 experts was the rejection of the concept of a single reference man or woman. The 1971 group defined such people as "arbitrarily selected convenient starting points for extrapolation ... and ... not intended to suggest ideal standards. They were originally chosen as being representative of groups of men and women whose food consumption and energy expenditure had been carefully studied" (FAO/WHO, 1973). The 1981 group found this concept too restrictive and not reflective of the wide ranges of both body size and patterns of physical activity.

In keeping with each of its predecessors, the present report has attempted to build on these efforts, while also moving forward in breaking new ground. The 2001 Joint FAO/WHO/UNU Expert Consultation on Human Energy Requirements met after a lapse of nearly 20 years and deliberated only the requirements of energy in the diet, leaving deliberations and debates on protein and amino acid requirements to a separate expert group, which met at WHO in Geneva in 2002. Following up on the recommendations arising from the Energy Consultation, FAO also convened a group of experts to discuss the issue of "food energy", because recommendations for optimal energy requirements become practical only when they are related to foods that provide the energy to meet those requirements. Gains in understanding of the digestion and metabolism of food and the increasing sophistication of analytical techniques meant that the various options available to express the energy value of foods needed to be standardized and harmonized. The recommendations of this group have since been published (FAO, 2002) to complement this report.

When the Expert Consultation on Human Energy Requirements met in 2001, the situation regarding lack of data to arrive at realistic and evidence-based recommendations had changed dramatically. Major technological advances using stable (i.e. non-radioactive) isotopes had by then had a dramatic impact on the measurement of energy expenditures of free-living individuals in real-life situations. Estimates based on these measurements have, to a large extent, replaced estimates using both direct and indirect calorimetry and the associated dependent methodologies such as heart rate monitoring, activity monitoring, pedometers and actometers. It is important to reiterate that these conventional methods continue to be important because the stable isotope technique measures cumulative total energy expenditure over a period but provides no accurate estimate of day-to-day variations, or information relating to the nature and pattern of daily activities. Thus, in this report, almost all of the recommendations made are based on reliable measurements of TEE obtained from infants, children, adolescents, adults and the elderly, as well as from women in special physiological states such as pregnancy and lactation.

A summary of the new concepts and changes in this 2004 expert report include the following:

- The calculation of energy requirements for all ages should be based on measurements and estimates of total daily energy expenditure, including the energy needs for growth.
- New values for energy requirements of infants, children and adolescents were proposed because existing values had been overestimated for children under ten years of age, and underestimated for children over 11 years of age and for adolescents.
- Different requirement levels were proposed for populations with various lifestyles and levels of habitual physical activity, starting at six years of age.
- A comparison and testing of the different BMR databases with varying degrees of ethnic and geographical coverage was carried out to determine whether new equations for estimating BMR from mean age and body weight of population groups were needed (Annex 3).
- New factorial estimates of the additional energy needs imposed by pregnancy and lactation were applied.
- Recommendations for the levels of physical activity required to maintain fitness and health and reduce the risk of developing obesity and diseases associated with sedentary lifestyles were made, and PALs based on the degree of habitual activity recommended for long-term good health were classified.

From the start, most expert groups have sought to address the practical application of the requirements. Time and events have shown that this aspect is as complex as determining the requirements themselves. As in the 1985 report, the section on issues regarding the application of requirements has been omitted from this report. However, in keeping with the recommendation made by the experts, the FAO Secretariat has spent time and effort in developing both a user's manual and a software application (on CD-ROM, see Annex 4), which are released alongside this report so that they might complement each other. Both the scientific content and the recommendations that ensue from this evidence base, as well as the usefulness and appropriateness of the accompanying applications manual and software, will await the judgement of the community of users, who are the best arbiters of the importance of this ongoing exercise by international agencies.

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ANNEXES

ANNEX 1: PARTICIPANTS – JOINT FAO/WHO/UNU EXPERT CONSULTATION ON HUMAN ENERGY REQUIREMENTS, 17 TO 24 OCTOBER 2001, FAO HEADQUARTERS, ROME, ITALY

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ANNEX 2: AUTHORS AND REVIEWERS OF PAPERS FOR EXPERT CONSULTATION WORKING GROUPS, MEETINGS AND FOLLOW-UP

Energy Background Paper No. 1
Andrew Prentice
Macronutrients as sources of food energy
Reviewer: Jean Pierre Flatt

Energy Background Paper No. 2
Geoff Livesey
Analytical issues related to food energy and food composition, energy in food labeling – including regulatory and trade issues
Reviewers: Janis Baines, Janine Lewis, Penelope Warwick

Energy Background Paper No. 3
Anna Ferro-Luzzi
The conceptual framework for estimating food energy requirements
Reviewers: Paul Haggarty, Andreu Palou, Robert Weisell

Energy Background Paper No. 4
Nancy Butte
Energy requirements of infants
Reviewers: Peter Sauer, Jonathan Wells

Energy Background Paper No. 5
Benjamin Torun
Energy requirements of children and adolescents (with addendum)
Reviewers: Margaret Livingstone, Virginia Stallings

Energy Background Paper No. 6
Prakash Shetty
Energy requirements of adults
Reviewers: Michael Goran, Dale Schoeller, Yves Schutz

Energy Background Paper No. 7
7a: Joop van Raaij (Initial draft)
Energy requirements during pregnancy and lactation
Reviewers: Nancy Butte, Janet King
7b: Nancy Butte and Janet King (Final version)
Reviewers: Kathryn Dewey, Elisabet Forsum

Energy Background Paper No. 8
Susan Roberts and Gerry Dallal
Energy requirements and ageing
Reviewers: Elisabet Rothenberg, Jane Wuu

Energy Background Paper No. 9
Marinos Elia
Insights into energy requirements in disease
Reviewers: Bruce Bistrian, Eileen Gibney

Energy Background Paper No. 10
Anura Kurpad, Sumithra Muthayya, Mario Vaz
Consequences of inadequate food energy and negative energy balance in adults
Reviewer: Nick Norgan

Energy Background Paper No. 11
Ricardo Uauy and Erik Diaz
Consequences of food energy excess and positive energy balance
Reviewers: William Dietz, James Hill

Energy Background Paper No. 12
Mario Vaz, Nadine Karaolis, Alizon Draper, Prakash Shetty
A compilation of energy costs of physical activities
Reviewers: Gerald Spurr, K. Satyanarayana, Angela Polito

Energy Background Paper No. 13
Jeya Henry
Basal metabolic rate studies in humans: measurement and application
Reviewers: Anna Ferro-Luzzi, Kevin Acheson, Philip James, George Bray

Energy Background Paper No. 14
Nick Norgan
Laboratory and field measures of body composition
Reviewers: Paul Deurenberg, Tim Lohman, Cameron Chumelea

Energy Background Paper No. 15
Ingrid Coles-Rutishauser
Laboratory and field measures of dietary intake
Reviewers: Elisabet Wirfaelt, Wija van Staveren

Energy Background Paper No. 16
James Levine
Measurement of energy expenditure
Reviewers: Anna Ferro-Luzzi, Klaas Westerterp, Eric Ravussin, Catherine Geissler

Opinion Paper No. 1
Michael Goran
Estimating energy requirements: regression based prediction equations or multiples of resting metabolic rate

Opinion Paper No. 2
Penelope Warwick and Janis Baines
Point of view: Energy factors for food labelling and other purposes should be derived in a consistent fashion for all food components

Opinion Paper No. 3
Cutberto Garza
Effect of infection on energy requirements of infants and children

POST-CONSULTATION SOLICITED DOCUMENTS

Document No. 1
Sally Grantham-McGregor and Helen Heningham-Baker
Review of the evidence linking protein and energy to mental development

Document No. 2
Tim Cole and Jeya Henry
The Oxford Brookes BMR database—a reanalysis

Document No. 3
Manuel Ramirez-Zea
Validation of three predictive equations for basal metabolic rate

Document No. 4
Anna Ferro-Luzzi
A review of Tim Cole and Manuel Ramirez-Zea's reports on BMR predictive equations

ANNEX 3: UPDATE ON PREDICTIVE EQUATIONS TO ESTIMATE BASAL METABOLIC RATE

The Joint FAO/WHO/UNU Expert Consultation on Energy and Protein Requirements, which met at FAO in Rome in 1981, concluded that – wherever possible – estimates of energy requirements should be based on measurements of energy expenditures rather than on energy intakes. It also decided that there would be many advantages in expressing the various components of total energy expenditure (TEE) as multiples of the basal metabolic rate (BMR). BMR is the most dominant component of TEE, and this is the primary reason for expressing the energy requirement (primarily BMR plus energy requirements for physical activity) as a multiple of the BMR. As a result, measurements of BMR and the methods to predict BMR have gained increased significance in estimating human energy requirements.

Dr J. Durnin of Glasgow University, the United Kingdom, made an extensive examination of the scientific literature and produced a background document for the 1981 expert consultation, which laid the foundations for the use of the BMR factorial approach to estimate TEE and energy requirements. It was noted that, while attempts had been made to carry out post hoc analysis of the existing data on BMRs in the past at the express request of FAO (Quenouille *et al.,* 1951), subsequent FAO and FAO/WHO committees had not followed up on this approach of using BMR as the starting point to assess human energy requirements. On the recommendation of the 1981 expert consultation, it was decided to undertake a more comprehensive analysis of the available data on BMRs worldwide in order to generate predictive equations that could be used in the report. In a relatively short period following the 1981 expert consultation, FAO initiated a thorough research of the available literature for robust BMR data in order to construct a series of regression equations by sex and age groups. These equations and the related scientific papers appeared as a supplement of *Human Nutrition: Clinical Nutrition* (Volume 39C, Supplement 1, 1985). The new database contained 7 173 data points drawn from 114 published studies. Shortcomings in the data sets were duly noted, predominantly the over- or underprediction of BMR, and these were viewed primarily as the result of a lack of ethnic and geographical representation in the data.

The BMR predictive equations were used for the first time in the 1985 Joint FAO/WHO/UNU Expert Report on Energy and Protein Requirements and have gained considerable popularity since then. They were also used by several national expert groups that deliberated on energy requirements. Since then, however, questions have frequently been raised in the literature about the adequacy and accuracy of these predictive equations for universal use. In the 1990s, based on the recommendations made at a workshop organized by the International Dietary Energy Consultative Group (IDECG)[*] in London (Scrimshaw, Waterlow and Schurch, 1996) and supported by FAO and the Nestle Foundation, Dr C.J.K. Henry (in collaboration with Dr Durnin) was commissioned to conduct a review of the literature of BMR data, in order to expand and refine the earlier database and to derive new equations based on selective criteria using more geographically representative data. This work resulted in the creation of a new database that has been referred to as the "Oxford database". It also resulted in an increased number of data points and included additional data from several developing countries. The findings of this review were presented at an IDECG meeting in December 1997 in Rome. The results were reviewed and found to be inconclusive in furthering the need to produce new, representative and internationally useable BMR predictive equations for future use.

In preparation for the 2001 Joint FAO/WHO/UNU Expert Consultation on Human Energy Requirements, Dr Henry prepared a background paper that constituted the final analysis of this complete data set, taking into account the feedback provided on his original findings. Concurrently, a subcommittee was formed to guide the expert consultation regarding the appropriateness of the

[*] Created in 1986, IDECG studies the effects of varying levels of dietary energy intake on the health and welfare of individuals and societies. Its objectives include the compilation and interpretation of relevant research data on functional and other consequences of deficiency, change or excess of dietary energy; the identification and promotion of related research needs and priorities; the publication of scientific and policy statements and other information on the significance of chronic deficiencies and excesses of dietary energy; and the identification and promotion of appropriate and practical means of corrective action.

methods used to measure BMR and its related issues. The final conclusion of the subcommittee was to conduct a more in-depth analysis of the Oxford database.

In December 2001, following the 2001 Joint Expert Consultation on Human Energy Requirements, FAO assigned Dr T. Cole the task of reanalysing both the earlier Schofield database and the more recent Oxford data sets on BMR. This analysis was expected to provide information on the influence of ethnicity on BMR, to reveal any possible methodological biases, and to help develop new BMR predictive equations that would replace the currently used international equations in the 1985 report, if their predictive performance was better. Dr Cole carried out an elegant and sophisticated analysis in two stages using the Oxford database consisting of 13 910 BMR data points. The thrust of the first analysis was to develop a single unified and seamless predictive equation that would apply to all ages, i.e. through the life cycle from infancy to old age. The expectation was that a seamless, continuous equation could eliminate the split of the predictive curves at the joining points of the various age groups. This analysis showed that cleaning the data sets by exclusion increased their inefficiency, and hence the inclusion of all data irrespective of the methodology used, the date of publication or the geographical region was the favoured approach. Two major factors that seemed to affect BMR were age and weight, with height having far less effect than weight. The inclusion of both weight and height in the model ensured that variations in body composition were adjusted for. Following a presentation of the first analysis of the data sets, Dr Cole was persuaded to carry out a supplementary analysis to develop predictive equations from subsets of the original database. These were meant to consider adults only, within normal ranges of body mass index (18.5 to 25.0) and were further separated to observe the effect of the time period when the data were collected (i.e. pre- and post-1950), as well as the effect of excluding any data based on close circuit calorimetry. This analysis showed that all four models examined among adults produced very similar results, and comparison with the earlier predictive equations indicated the absence of any significant improvement from the equations generated for the 1985 report.

Following the reanalysis, Dr M. Ramirez-Zea was asked to validate the equations developed by Dr Cole and compare their predictive performance with that of other BMR predictive equations generally used. Dr Ramirez-Zea then researched the recent literature for additional data sets that had not been included in the 1980s and in the Oxford data sets, but that fulfilled the established criteria for selecting data for those databases, and then tested the various equations against these data. Following this process, a careful review of all findings to date was undertaken by Dr A. Ferro-Luzzi, who suggested that this lengthy post-consultation exercise may not result in providing the experts with a new set of BMR predictive equations to be presented in the report.

In conclusion, the enhanced precision and robustness of the earlier equations, many of them in the published literature since the 1985 report, and the seamlessness of the Cole equation proved to be inadequate to persuade the expert consultation to warrant discontinuing the use of the international equations presented in the1985 report and widely used since then. Thus, for the current energy report, the experts decided to follow the advice of the FAO Secretariat and continue to use the Schofield BMR predictive equations. However, it was agreed that it was necessary to pursue an aggressive review of all the work that had been done to see whether the BMR equation question could be resolved more satisfactorily, both as a follow-up and in preparation for the next energy review, which it is hoped will take place within the next five years. Additional details as to how this decision was reached, along with Dr Henry's background document on this topic, Dr Cole's analysis and the review by Drs Ramirez-Zea and Ferro-Luzzi, will be published alongside all the background documentation related to this expert consultation as a supplement to the *Public Health Nutrition* journal in 2005.

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Scrimshaw, S., Waterlow, J.C. & Schurch, B. (eds). 1996. Energy and protein requirements. Proceedings of an IDECG Workshop 31 October to 4 November 1994. *Eur. J. Clin. Nutr.,* 50: S1–S197.

ANNEX 4: SOFTWARE APPLICATION FOR CALCULATING POPULATIONS' ENERGY REQUIREMENTS AND FOOD NEEDS

This software application is an interactive program that allows the user great flexibility in customizing input parameters and population statistics. It is composed of a series of modules with the following functions:

- calculation of average daily energy requirements for populations;
- estimation of corresponding quantities of food commodities (cereals, pulses, roots and tubers, fish, meat, and fruits and vegetables) needed to meet the energy needs of the population;
- display of results in report and graphical formats.

The software allows users to base calculations on default data provided for countries and UN-defined regions, or to customize data for sub-country-level populations.

A. CONTENT OF THE CD-ROM: CALCULATING POPULATION ENERGY REQUIREMENTS AND FOOD NEEDS

- Installation instructions.
- Setup.exe.
- Read me first.txt.
- *Calculating population energy requirements and food needs: user's manual.* This is a PDF file of the user's manual, which includes background information for the estimation of population energy requirements, a description of the data needed for the calculations, a description of the calculations for single age groups, an explanation of the values obtained from the software application, advice on maximizing information obtained from the software application, and annexes that demonstrate how the calculations are made. **The user is advised to read this manual to get the most out of the software application.**
- Manual annexes with formulas and application databases in MS Excel format.
- Application files.

B. CALCULATION OF ENERGY REQUIREMENTS USED BY THE SOFTWARE APPLICATION

There are four options available for calculating energy requirements, as summarized in Annex Table 1.

ANNEX TABLE 1
Options in the energy requirement module

Default data, average daily energy requirements for populations	Customized data, average daily energy requirements for populations
Default data, daily energy requirements for special groups	Customized data, daily energy requirements for special groups

The default data option is chosen when the user wishes to calculate energy requirements for a UN-defined region or a country using default data provided with the application. The data provided include population structure by age and sex, crude birth rate and percent urban population for five-year periods from 2000 to 2025, as well as average body weight by age and sex. When choosing the default data option, a screen appears with the default data, any of which may be modified on screen if more recent information is available. This profile can be saved with a unique name and used again at a later date.

ANNEX TABLE 2

Summary of age-specific calculations of average energy requirements

Age group	Default body weight[a]	Additional energy allowances	Average daily energy requirements[b]	Adjustments
Infants: 0–5.99 months	Reference weight-for-age by sex, 6-month average	Energy deposition in normal growth	TEE for *breastfed* infants + energy needed for growth	For calculation of the average per capita energy requirement for a country, the sum of average daily energy requirements across age groups does not include breastfed infants aged 0.0–5.9 months, whereas the additional allowance for breastmilk production is included for the adult age group of 18–29 years
Infants: 6–11.99 months	Reference weight-for-age by sex, 6 month average	Energy deposition in normal growth	TEE for *mixed diet* infants + energy needed for growth	
Children: 1–4.99 years	Reference weight-for-age, 1year average	Energy deposition in normal growth	TEE + energy needed for growth	TEE is reduced by 7% for age 1.0–1.9 years[c]
Children: 5–17.99 years	Weight for given height corresponding to median reference BMI for age-sex	Energy deposition in normal growth	TEE + energy needed for growth	
Adults: 18–29.99 years	Weight for given height corresponding to BMI of 22.0 (body weight is held constant across adult age groups)	*Pregnancy:* increase of 1.168 MJ per day averaged over entire pregnancy, or 0.870 MJ per day averaged over a year *Lactation:* increase of 2.100 MJ per day averaged over 6 months after birth of child, or 1.050 MJ per day averaged over a year	BMR × PAL (location-specific PAL as determined by mix of rural and urban percent and physical activity, or fixed in case of minimum requirement)	
Adults: 30–59.99 years	Weight for given height corresponding to BMI of 22.0		BMR × PAL (as above)	
Adults: 60+ years	Weight for given height corresponding to BMI of 22.0		BMR × PAL (as above)	

[a] Median weight-for-age (infants and children 1–4.99 years) and median weight-for-height from NCHS/WHO international reference population growth for infants and children (WHO, 1983) (Annex 1 of user's manual). The given heights used to calculate average age-specific body weights come from the growth curves provided in the 1985 James and Schofield manual (James, W.P.T. & Schofield, E.C. 1990. *Human energy requirements. A manual for planners and nutritionists*. Oxford, UK, Oxford Medical Publications under arrangement with FAO).

[b] Equations for TEE and BMR used in the calculations are given in Annex 3 of the user's manual.

[c] For age 1.0–1.9 years, the predicted values of TEE were about 7% higher than actual TEE measurements, so in the current program the TEE for the year 1.0–1.9 is adjusted down by 7% to account for the discrepancy (see Chapter 4 of this report).

The customized data option allows the user to supply data for a subnational area for which default data are not available, or for a country for which more recent information is available, using a template provided by the application. This profile can be saved with a unique name and used again at a later date.

The average daily energy requirements for populations option calculates energy requirements for healthy populations with a full range of physical activity lifestyles among adults and a mix of urban and rural residence. This option is indicated for food and nutrition planning under normal conditions. Average requirements may be calculated for both default and customized data. The user will be asked to make an educated guess of the PAL based on lifestyle patterns of urban and rural populations in order to calculate the location-specific PAL.

The daily energy requirements for special groups option calculates energy requirements for groups of people with more homogeneous activity lifestyles and residence (i.e. either urban or rural) using a fixed PAL value. Examples of special groups include settlements for refugees or internally displaced persons. This option is indicated for users who have a good knowledge of appropriate PAL values and who are concerned with food planning for special groups, such as rations for emergency use.

Annex Table 2 summarizes the protocols used by the software application to calculate age-specific average daily energy requirements.

C. PRESENTATION OF THE RESULTS

The energy requirement results are presented in two forms. First, per capita requirements for specific age and sex groups and the entire population are calculated, i.e. the average daily energy requirement for an average person of that group. Per capita requirements are then converted to *population daily energy needs*, i.e. the total number of joules or kilocalories needed to meet the daily energy needs of everyone in that group or in the population as a whole.

Food quantities corresponding to the percentages of the national food supply accounted for by six commodities that meet the population energy needs are reported in metric tonnes (1 000 kg) on a daily, monthly, semi-annual or annual basis for the population under consideration.

ANNEX 5: ENERGY COSTS OF ACTIVITIES

ACTIVITY	MALES		FEMALES	
	Average PAR	PAR Range	Average PAR	PAR Range
General personal activities				
Sleeping[a]	1.0		1.0	
Lying[a]	1.2		1.2	
Sitting quietly[a]	1.2		1.2	
Standing[a]	1.4		1.5	
Dressing	2.4	1.6–3.3	3.3	
Washing hands/ face and hair	2.3			
Plaiting hair			1.8	
Eating and drinking	1.4		1.6	
Means of transport				
Walking around/ strolling	2.1	2.0–2.2	2.5	2.1–2.9
Walking slowly	2.8	2.6–3.0	3.0	
Walking quickly	3.8			
Walking uphill	7.1	5.5–8.6	5.4	4.8–6.1
Walking downhill	3.5	3.1–4.0	3.2	
Climbing stairs	5.0			
Sitting on a bus/train	1.2			
Cycling	5.6	3.8–8.6	3.6	
Cycling on a dirt road	7.0	5.0–9.0		
Driving a motor cycle	2.7	2.4–3.0		
Driving a car/truck	2.0			
Paddling a canoe	3.0			
Pulling a rickshaw (one person/no load)	5.3	4.0–6.6		
Pulling a rickshaw (2 persons)	7.2	6.7–7.8		
Horseback riding (slow)	3.6			
Horseback riding (trotting)	5.2	4.8–5.5		
Activities involving weight bearing				
Walking with 15–20 kg load			3.5	3.4–3.5
Walking with 25–30 kg load			3.9	3.8–4.1
Carrying 20–30 kg load on head	3.5	2.4–4.2		
Carrying 35–60 kg load on head	5.8	5.0–7.0		
Carrying 27 kg load with shoulder straps – varying gradients	5.0	2.3–7.7		
Carrying 27 kg load with forehead strap – varying gradients	5.32	2.4–8.0		
Loading 9 kg sack on to a truck	5.78			
Loading 16 kg sack on to a truck	9.65			
Pulling hand cart – unloaded	4.82			
Pulling hand cart with 185–370 kg load	8.3	7.0–9.6		
Domestic chores				
Cooking/preparing food				
Collecting wood (for fuel)	3.3			
Collecting water (from well)			4.5	
Chopping wood (for fuel)	4.2	2.3–6.5		
Kneading dough			3.4	
Making tortillas			2.4	
Peeling vegetables	1.9	1.3–2.4	1.5	
Pounding grain			5.6	5.0–6.3

ACTIVITY	MALES		FEMALES	
	Average PAR	PAR Range	Average PAR	PAR Range
Cooking/preparing food *(cont.)*				
Shopping			4.6	
Squeezing coconut			2.4	
Washing dishes			1.7	1.6–1.9
Child care				
Child care (unspecified)			2.5	
Bathing child (standing)			3.5	
Carrying child			1.9	
House cleaning				
Housework (unspecified)			2.8	2.5–3.0
Beating mats/carpets			6.2	5.1–7.4
Bed making (tropical climate)			3.4	
Bed making (cold climate)			4.9	4.6–5.1
Mopping/washing floor			4.4	3.4–6.5
Polishing floor			4.4	
Sweeping			2.3	2.0–2.5
Vacuuming			3.9	
Window cleaning	3.0	2.8–3.3		
Laundry				
Washing clothes (sitting/squatting)			2.8	2.6–3.0
Hanging washing out to dry			4.4	4.3–4.6
Ironing clothes	3.5		1.7	
Sewing/knitting	1.6		1.5	1.3–1.8
Care of the yard/garden				
Cleaning/sweeping yard	3.7	2.9–4.5	3.6	
Weeding garden	3.3	2.4–5.1	2.9	2.7–3.6
Shovelling snow from driveway	7.9			
Agricultural activities				
General activities				
Digging	5.6		5.7	
Driving a tractor	2.1	1.9–2.3		
Fertilizing (spreading manure)	5.2	4.9–5.4		
Gleaning			4.5	
Grinding grain using a mill stone			4.6	
Hoeing	4.2	3.6–4.6	5.3	4.7–6.5
Loading sacks on to a truck	6.6			
Ploughing with horse	4.8			
Ploughing with tractor	3.4			
Ploughing with buffalo			3.6	
Spraying crops	4.3			
Weeding	4.0	2.6–4.7	3.7	3.7–3.8
Cocoa crop				
Collecting cocoa			2.9	
Pruning	2.4			
Splitting cocoa			2.0	
Activities for coconut crop				
Collecting (climbing trees)	4.2			
Husking	5.6			
Bagging and splitting	3.9			

ACTIVITY	MALES		FEMALES	
	Average PAR	PAR Range	Average PAR	PAR Range
Fruit crops (apple, orange)				
Picking (with pole)			3.8	
Picking by hand	3.4			
Pruning trees	3.6			
Groundnut crop				
Harvesting	4.7			
Planting	3.1			
Shelling	1.6			
Sorting	1.9			
Weeding	3.2			
Maize crop				
Harvesting	5.1			
Planting	4.1			
Rice crop				
Bundling rice	3.7		3.0	
Fertilizing	3.1			
Harvesting	3.5	2.4–4.2	3.8	3.5–4.4
Planting	3.7	3.5–4.0	3.6	2.6–4.7
Spraying	5.2			
Threshing	5.4	4.6–5.0	5.1	4.8–5.4
Transplanting seedlings	3.3	3.1–3.4	3.7	3.5–4.0
Winnowing	2.9	2.3–3.6	2.7	2.5–2.9
Sugar cane crop				
Cutting	7.0	6.6–7.9		
Loading on to wagon	5.6			
Tying cane	3.0			
Tuber crops				
Harvesting	4.4	3.5–5.7	3.0	2.8–3.4
Planting	5.0		3.9	3.6–5.0
Sorting (kneeling)	2.2	1.6–2.7		
Animal husbandry				
Carrying straw	3.1			
Cleaning equipment	4.0			
Cutting straw	5.0			
Feeding animals	3.6			
Grooming horses	5.5	3.8–7.1		
Milking by hand	3.6	3.1–4.1		
Milking by machine	3.2			
Tending animals (feeding, watering, cleaning stable)	4.6			
Hunting/fishing				
Crabbing			4.51	
Fishing with a line[b]	1.9			
Fishing with a spear	2.3			
Fishing with hands			3.94	
Hunting (bats, birds, pigs)[b]	3.2			
Occupational categories				
Bakery work			2.5	
Brewery work			2.9	

ACTIVITY	MALES		FEMALES	
	Average PAR	PAR Range	Average PAR	PAR Range
Brickmaker				
Earth cutting	5.6	5.5–5.7		
Making mud bricks (squatting)	3.0			
Builder				
Carrying wood	6.6			
Cement mixing with shovel	5.3			
Chipping cement walls	3.3			
Chiselling	5.0			
Nailing	3.0			
Planing softwood	5.7	4.4–7.1		
Planing hardwood	8.0			
Roofing	2.9			
Sandpapering	2.9			
Sawing softwood	5.3	5.0–5.6		
Sawing hardwood	6.6			
Painting	3.6			
Firefighter				
Dragging fire hose	9.8			
Climbing steps with full gear	12.2			
Flight attendant (serving food, beverages and galley work) [b]	3.0		3.1	
Forester				
Tree cutting	6.9	5.4–8.0		
Sawing	5.7			
Planting trees	4.1			
Nursery work	3.6			
Military training				
Digging trenches	6.4	4.6–7.9		
Drill	4.5	4.1–4.8		
March (slow)	3.18			
March 2–4 m/h (3.2–6.4 km/h) with 27 kg load[b]	4.9			
Obstacle course	5.7	5.0–6.3		
Miner				
Drilling with jackhammer	3.9			
Loading operations	3.2			
Shovelling	4.6			
Office worker				
Filing	1.3		1.5	
Reading	1.3		1.5	
Sitting at desk[a]	1.3			
Standing/moving around[a]	1.6			
Typing	1.8		1.8	
Writing	1.4		1.4	
Postal worker				
Climbing stairs	8.9	7.7–10.7		
Sorting parcels (habitual)	5.4			
Shoemaker	2.6		2.2	
Tailor[b]	2.5			
Textile factory worker (average of spinning, weaving, dyeing) [b]	3.1		2.2	

ACTIVITY	MALES		FEMALES	
	Average PAR	PAR Range	Average PAR	PAR Range
Sports activities				
Aerobic dancing – low-intensity	3.51		4.24	
Aerobic dancing – high-intensity	7.93		8.31	
Basketball	6.95		7.74	
Batting	4.85			
Bowling	4.21			
Callisthenics	5.44			
Circuit training	6.96		6.29	
Football	8.0	7.5–8.5		
Golf	4.38			
Rowing	6.7		5.34	
Running – long distance[b]	6.34		6.55	
Running – sprinting	8.21		8.28	
Sailing	1.42		1.54	
Swimming	9	8.5–9.4		
Tennis	5.8		5.92	
Volleyball	6.06		6.06	
Miscellaneous recreational activities				
Dancing	5.0		5.09	
Listening to radio/music[b]	1.57	1.45–1.9	1.43	
Painting	1.25		1.27	
Playing cards/board games[b]	1.5	1.4–1.8	1.75	
Playing the drums	3.71			
Playing the piano	2.25			
Playing the trumpet	1.77			
Reading	1.22		1.25	
Watching TV	1.64		1.72	

Notes: This annex has been compiled from the background document provided to the expert consultation by M. Vaz *et al.* and also from the values referred in WHO. 1985. *Energy and protein requirements: report of a joint FAO/WHO/UNU expert consultation.* WHO Technical Report Series No. 724. Geneva.
The average PAR is the average PAR reported from multiple studies, when such data exist. PAR range refers to the minimum and maximum PAR reported across studies for a particular activity.
[a] These entries come from the WHO, 1985 report.
[b] These activities are averages of two or more categories.