
UNIT 2 HUMAN ENERGY REQUIREMENTS

Structure

- 2.1 Introduction
- 2.2 Energy: Some Basic Concepts
- 2.3 Definition and Components of Energy Requirement
- 2.4 Factors Affecting Energy Expenditure and Requirement
 - 2.4.1 Factors Affecting the BMR
 - 2.4.2 Factors Affecting the Thermic Effect of Food
 - 2.4.3 Factors Affecting the Energy Expended in Physical Activity
- 2.5 Methods of Estimation of Energy Expenditure and Requirements
 - 2.5.1 Direct Calorimetry
 - 2.5.2 Indirect Calorimetry
 - 2.5.3 Double Labeled Water (DLW) Technique
 - 2.5.4 Heart Rate Monitoring (HRM) Method
 - 2.5.5 Factorial Estimation of Total Energy Expenditure
- 2.6 Energy Requirements and Dietary Energy Recommendations
 - 2.6.1 Energy Requirements of Infants (from Birth to 12 Months)
 - 2.6.2 Energy Requirement for Children and Adolescents
 - 2.6.3 Energy Requirement of Adults
 - 2.6.4 Energy Requirement during Pregnancy
 - 2.6.5 Energy Requirement during Lactation
- 2.7 Energy Imbalance: An Overview
- 2.8 Let Us Sum Up
- 2.9 Glossary
- 2.10 Answers to Check Your Progress Exercises

2.1 INTRODUCTION

This unit focuses on the human energy requirements. The nutrient requirement for Indian population, you may recall studying in the last unit, are computed by the Indian Council of Medical Research (ICMR) and published in its recent document “Recommended Dietary Allowances and Estimated Average Requirement – Nutrient Requirements for Indians”. The energy requirements have been computed on the basis of recommendations made by a Joint Expert Consultation of the World Health Organization (WHO)/Food and Agricultural Organization (FAO)/United Nations University (UNU) in 2004 and by an Expert Committee constituted by ICMR (2020).

A Joint FAO/WHO/UNU Expert Consultation on Human Energy Requirements, convened in October 2001 at FAO headquarters in Rome, Italy has formulated recommendations for human energy requirements published in 2004. The levels of energy intake recommended by this expert consultation are based on estimates of the requirements of *healthy, well-nourished individuals*. The recommendations that have resulted from this consultation are important guidelines on energy in human nutrition for the academia, 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.

What are the components of energy requirement? Which are the factors which influence the energy expenditure and requirements of individuals? What are the old and new methods we can use for measuring the energy expenditure and requirement? What are the problems associated with high and low energy intakes? These are some of the issues covered in this unit.

Objectives

After studying this unit, you will be able to:

- define the units of energy and physiological fuel value of foods,
- discuss the components of energy requirements,
- describe the methods of estimation of energy requirements,
- define and explain the basis for formulating the energy requirements of different physiological groups, and
- critically analyze the regulation of energy metabolism— problems associated with high and low energy intake.

2.2 ENERGY: SOME BASIC CONCEPTS

Energy in simple terms may be defined as the ability, or power, to do work. As a student of dietetics and nutrition, you already know that the physiological sources of energy are carbohydrates, protein, fats – the macronutrients present in food. Energy is released by the metabolism of food and the potential energy value of foods is expressed in terms of the kilocalorie (Kcal). *A kilocalorie is defined as the amount of heat required to raise the temperature of 1 kg of water through 1° Celsius (centigrade).* Internationally, you may notice that the unit of energy measurement commonly used is the Joule (J). It expresses the amount of energy expended when 1 kg of a substance is moved 1 meter by a force of 1 newton. The conversion factor for changing kilocalories to kilojoules is 1 kilocalorie = 4.184 kilojoules.

The amount of heat energy (kilocalorie) per gram that can be made available to the body by each of the energy-yielding macronutrients – carbohydrate, protein, fat – must be known to you. Yes, 1 g of carbohydrates yields 4 Kcal, 1 g of fat yields 9 Kcal, and 1 g protein yields 4 Kcal. These values are known as the physiological *fuel factors*.

Do you know how the energy in various foods is generally measured? The amount of energy available in a food is precisely determined by a laboratory technique known as *calorimetry*. In this process, a weighed amount of food is placed inside a metal container called a *bomb calorimeter*, which is immersed in water. The food is then ignited in the presence of oxygen and burned. The increase in temperature of the surrounding water is measured and used in calculating the number of kilocalories given off by the oxidation of the food.

An alternate method of measuring food energy is to use the macronutrient composition of foods in the food composition tables and by using the physiological fuel factors referred to earlier. The Indian Council of Medical Research (ICMR), India has published food value tables in a book titled 'Nutritive Value of Indian Foods'. Certainly, as a student of nutrition or dietetics, you may have referred to this book some time or other.

With this basic understanding of the measurement of energy, let us move on to studying the energy requirements. But before we move on to the requirements we must give a definition of what we understand by energy requirements and also know about the components of energy requirements. These are described next.

2.3 DEFINITION AND COMPONENTS OF ENERGY REQUIREMENT

We shall begin our study in this section by first understanding what we mean by energy requirement. *Energy requirement (ER)* is defined as 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 also 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* (TEE). There are additional energy needs to support growth in children and in women during pregnancy, and for milk production during lactation.

Total energy expenditure (TEE), may be defined as *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.

The energy needs vary widely among individuals in a group. You will find it impossible to compute an individual's energy need without knowing something about the personal lifestyle and metabolism. Consider the following situations:

Situation 1: A 30 year old woman who bikes, and swims each day, would require more energy than a 30 year old who does a desk job.

Situation 2: In a group of 20 odd people, with similar body weight and activity levels, some individuals may require more energy per day than others.

Why do you think the energy requirements are different in these situations?

Well the requirement is dependent on the ways in which the body spends energy. For example in the first case the intensity of work or voluntary activity i.e. intentional activities (such as cycling, swimming) conducted by voluntary muscles affects the amount of energy used, hence the variation in the requirement. On the other hand, think of all the involuntary activities of our body that are necessary to sustain life, including circulation, respiration, temperature maintenance, hormone secretion, nerve activity, new tissue synthesis etc. All these involuntary activities of the body, which continue day in and day out without our conscious awareness, require energy. Further, as the food is chewed, digested, absorbed, these metabolic responses to food increase total energy expenditure. Therefore, 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)*. BMR is measured under standard conditions that include being awake in the supine position after 10 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 the total daily energy expenditure, and it is determined mainly by the individual's age, gender, as well as, body size and body composition. We will learn more about these factors which influence the BMR in the next section.

BMR is commonly extrapolated to 24 h to be more meaningful, it is then referred to as *Basal Energy Expenditure (BEE)* and is expressed as Kilocalories per 24 hours. The basal metabolic rate, as defined originally by *Boothby* and *Sandiford* was measured in the morning upon awakening, before any physical activity and 12-18 h after a meal. A closely related term used now is *Resting Metabolic Rate (RMR)*. RMR is measured with the subject in a supine or sitting position in a comfortable environment several hours after a meal and without any significant activity. RMR is slightly higher than BMR but the difference is small. RMR when extrapolated to 24 hours is the *resting energy*

expenditure (REE).

- *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*’ (TEF). 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 “occupational” was used earlier in the WHO/FAO/UNU 1985 report but the preferred term now is *obligatory* as it is more comprehensive. In addition to occupational work, obligatory activities include daily activities such as going to school, attending 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. We will dwell further on this aspect later in this unit; however, we need to look at two concepts in the context of physical activity namely physical activity level (PAL) and physical activity ratio (PAR), which find extensive use in calculating the total energy requirement of healthy, well-nourished adults.

Physical activity level (PAL) is defined as the total energy required over 24 hours divided by the energy needed for basal metabolism over 24 hours. In simple terms, 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 multiplied by PAL is equal to TEE or the daily energy requirement.

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.

- *Growth.* The energy cost of growth has two components: 1) the energy needed to synthesize growing tissues; and 2) the energy deposited in these 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.

From our discussion above, it is evident that the total energy expenditure over a 24-hour period is the sum of BMR, TEF, and energy for physical activities as also highlighted in Figure 2.1. 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. Energy balance is achieved when input (i.e. dietary energy intake) is equal to the 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.

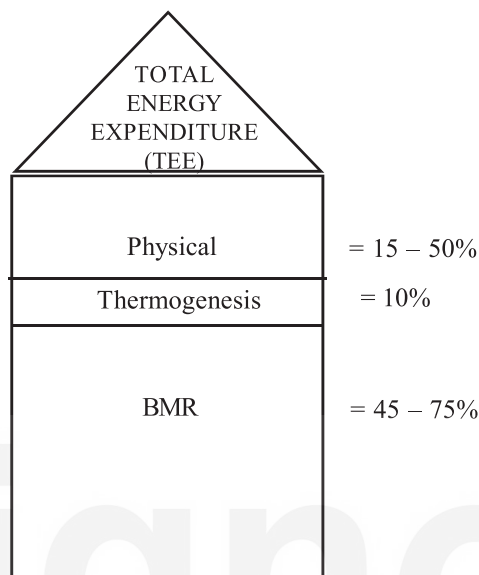


Figure 2.1: Components of total energy expenditure

In the next section, we shall review the factors which influence the energy expenditure and requirements.

2.4 FACTORS AFFECTING ENERGY EXPENDITURE AND REQUIREMENT

As mentioned earlier, the energy needs vary widely among individuals in a group. Why? A number of factors cause the RMR or more appropriately the REE to vary among individuals. Major determinants are the body size, composition, age, sex, growth etc. Similarly, there are factors affecting the thermic effect of food and energy expended in physical activity. A brief review on these factors follows.

2.4.1 Factors Affecting the BMR

Basal metabolic rate, we know, is the largest component of the daily energy demand representing *45 to 70 percent* of daily total energy expenditure. It is highly variable and the causes of this variation include factors such as fat free mass (FFM), fat mass (FM), age, sex, hormonal status, growth, disease/infections etc. Let us learn about these factors starting with body size and composition.

Body size and composition: Basal and resting energy expenditures are related to body size, being most closely correlated with the size of the *fat-free mass (FFM)*, which is the weight of the body less the weight of its fat mass. The size of the FFM generally explains about 70 to 80 percent of the variance in RMR. FFM is the metabolically active tissue in the body; what we also call as the lean body mass (LBM) and so most of the variation in BMR between people can be accounted for by the variation in their FFM. For example, athletes with greater muscular development have approximately a 5% higher basal metabolism than non-athletic individuals. Thus, exercise can help maintain a higher lean body mass and hence a higher metabolic rate. Similarly, the lower basal metabolic energy requirement of women is primarily

related to their generally lower amount of lean muscle mass (more of fat mass) as compared to men. The decline in BMR with increasing age is also to some extent the consequence of changes in the relative size of organs and tissues. Further larger people (big size) have higher metabolic rates than people of smaller size. In fact, individuals with greater surface area have higher metabolic rate. To illustrate, if two people of different heights weigh the same, the taller individual with the larger body surface area will have a higher metabolic rate. In adults with higher percentages of body fat composition, mechanical hindrances can also increase the energy expenditure associated with certain types of activity.

Age: The BMR per unit weight also varies with age, being higher in children and lower in the elderly. The loss of FFM with ageing is associated with a decline in the metabolic rate, amounting to about 1-2% decline per decade after early adulthood. The REE is highest during the periods of rapid growth, chiefly during the first and second year of life, and reaches a lesser peak through the periods of puberty and adolescence in both sexes.

Gender: We have already emphasized earlier that sex difference in metabolic rates are primarily attributable to difference in body size and composition. Women who have generally more fat in proportion to muscle than men, have metabolic rates which are 5-10% lower than men of the same weight and height. Thus, differences in BMR between genders are due to the greater level of body fatness in women.

Hormonal Status: Thyroid status may be most important factor and can make differences of up to plus or minus 50% for hyperthyroidism or hypothyroidism, respectively. Hyperthyroidism increases the resting metabolic rate, whereas hypothyroidism decreases the RMR. Stimulation of the sympathetic nervous system (e.g. during the period of stress or emotional excitement or fear, anxiety) causes the release of epinephrine, which directly promotes glycogenolysis and increases cellular activity. This too is associated with increased metabolic rate. In adult premenopausal women, the metabolic rate fluctuates with the menstrual cycle. An average of 359 Kcal/ day difference in the BMR has been measured between the low point, about 1 week before ovulation on day 14, and the high point, just before the onset of menstruation.

Environmental Conditions: Extremes in environmental temperatures also affect the metabolic rate. Energy expenditure will be increased if extra heat production is needed to maintain body temperature in a cold climate. The extent to which the energy metabolism increases in extremely cold environment depends on the insulation available from body fat and protective clothing. Conversely, there is some evidence that the basal metabolic rate is reduced in hot climates. For example, BMR is on an average 10% lower in Indians than in North Europeans. Further exercise undertaken in temperatures greater than 86°F also imposes an additional metabolic load of about 5% from increased sweat gland activity.

Besides climatic conditions, altitude too has been shown to affect metabolic rates. Hypoxia (lack of oxygen in tissues) of high altitude increases BMR. Hypoxia increases glucose utilization, which might affect the metabolic rate. However, these are temporary effects, which disappear with acclimatization. We learn more about this aspect later in Unit 18 at the end of this course.

Pregnancy and Lactation: These periods of physiological stress also have an impact on the metabolic rate. Earlier, we studied that REE is highest during the periods of rapid growth, i.e. chiefly during the first and second year of life. In pregnancy too, which is the foetal growth period, the metabolic rate increases, particularly later in pregnancy because of uterine, placental and foetal growth and the mother's increased cardiac work load.

Fever/Illness/Infections/Injury: Any illness or fever caused by an illness influences the metabolic rate. Fevers increase the metabolic rate by about 7% for each degree increase in body temperature above 98.6°F or in other words 13% for each degree above 37°C.

During injury or infections there is an increased BMR, and this increase is dependent on the severity of the injury. For example, the BMR may even double with burns of more than 40% of the body surface, in severe sepsis, multiple traumas, whereas it may only increase by about 25% in patients with long bone fractures and even less after surgery. But we need to understand that in sick patients who are likely to be in bed, the increase in the BMR due to the stress imposed by the disease may be offset by the decrease in physical activity, such that the total daily energy expenditure may not change drastically.

Nutritional status: Undernutrition and starvation are the factors which require consideration. Prolonged undernutrition or starvation causes a reduction of about 10-20% in BMR. In semi-starvation studies, data suggest that the subjects BMR decrease by about 25% when expressed per kilogram of their free fat mass (FFM) (or metabolic active tissue). Reduction in BMR are partly mediated through weight loss itself, in which metabolically demanding tissue of the body (the FFM i.e. the lean body tissue) are reduced in size, and partly through reduction in the metabolic activity of these tissues. We will learn more about this aspect later in section 2.6 in this unit.

Other Factors: Smoking is one variable thought to influence the metabolic rate. Smoking increases BMR, cessation of smoking lowers BMR. The BMR in sleep is about 5% less than in the basal condition.

Thus, there is an exhaustive list of factors which influence BMR and hence the total energy requirements, under different conditions. Next, we shall move on to the study of the factors affecting the thermic effect of food.

2.4.2 Factors Affecting the Thermic Effect of Food

The thermic effect of food, as we learnt earlier, is the increase in energy expenditure associated with the consumption of food and it accounts for approximately 10% of TEE (Total Energy Expenditure). The intensity and duration of meal induced TEF (Thermic effect of food) is, however, determined primarily by the amount and composition of the foods consumed. TEF, for example, *is greater after consumption of carbohydrate and protein than after fat*. The increments in energy expenditure during digestion above baseline rates, divided by the energy content of the food consumed, vary from 5 to 10 percent for carbohydrate, 0 to 5 percent for fat, and 20 to 30 percent for protein. The high TEF for protein reflects the relatively high metabolic cost involved in processing the amino acids yielded by absorption of dietary protein, for protein synthesis, or for the synthesis of urea and glucose. Activation of the sympathetic nervous system elicited by dietary carbohydrate and by sensory stimulation causes an increase in energy expenditure.

Consumption of the usual mixture of nutrients (i.e. a mixed diet) is generally considered to elicit increases in energy expenditure equivalent to 10 percent of the food's energy content. Spicy foods enhance and prolong the effect of TEF. Meals with chili and mustard may increase the metabolic rate as much as 33% more than unspicied meal, and this affect may last for more than 3 hours. Caffeine and nicotine also stimulate TEF.

Next, we shall review the factors influencing the energy expended on physical activity.

2.4.3 Factors Affecting the Energy Expended in Physical Activity

Physical activity as we learnt earlier, is the second largest component of daily energy expenditure, after BMR. However, the energy expended in physical activity is most variable as it may range from 10% in a person who is bedridden to as much as 50%

of TEE in an athlete. In fact, *different lifestyles* have different levels of energy demands. The examples of lifestyles with different levels of energy demands as given by FAO/WHO/UNU 2004 are enumerated herewith.

- *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/female teachers, office workers (executives, clerks, typists etc.) in urban areas, who only occasionally engage in physically demanding activities during or outside working hours. Another example are housewives living in urban areas with access to energy saving devices and domestic help to carry out most of the manual chores and other moderate energy activities.
- *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. Other examples of moderately active lifestyles are associated with occupations such as servants, house cleaners, 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 fuel wood.
- *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. Other examples of vigorously active occupations include rickshaw pullers, mine workers, coolies etc.

Now that we have classified the different lifestyles, it is important to note that the energy expended will vary not only with the different types of activity undertaken by an individual (both occupational and discretionary physical activity), *but also by the time spent in each activity/task and the energy cost of each activity throughout a theoretical 24-hour period*. The classification of lifestyles in relation to the energy cost of each activity or the intensity of habitual physical activity, or physical activity level (PAL) is given in Table 2.1. You would notice a reduction in PAL value for Indian population is proposed by ICMR (2020). *Physical activity level (PAL)*, we learnt earlier, is defined as the total energy required over 24 hours divided by the basal metabolic rate over 24 hours. In adult men and non-pregnant, non-lactating women, BMR times PAL is equal to TEE or the daily energy requirement.

Table 2.1: Classification of lifestyles in relation to the intensity of habitual physical activity, or PAL

Category	PAL value (FAO/WHO/UNU(2004))	PAL value ICMR (2020)
Sedentary or light activity lifestyle	1.40 - 1.69	1.40
Active or moderately active lifestyle	1.70 - 1.99	1.80
Vigorous or vigorously active lifestyle	2.00 - 2.40*	2.30

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

You would realize that the energy expended in physical activity tends to decrease with *age*, a trend that as you may already be aware is associated with a decline in FFM and an increase in fat mass which influences the energy requirement.

In addition to the immediate energy cost of individual activities, physical activity also affects energy expenditure in the *post-exercise period*. Excess post-exercise oxygen consumption (EPOC) depends on exercise intensity and duration, as well as, other factors, such as environmental temperatures, state of hydration, and degree of trauma, demonstrable sometimes up to 24 hours after exercise. The increase in daily energy expenditure is somewhat greater, however, because exercise induces an additional small increase in expenditure for some time after the exertion itself has been completed. This excess post-exercise oxygen consumption (EPOC), as mentioned above, depends on exercise intensity and duration and has been estimated at some 15 percent of the increment in expenditure that occurs during exertions like walking/jogging.

There may also be chronic changes in energy expenditure associated with regular physical activity as a result of changes in body composition and alterations in the metabolic rate of muscle tissue, neuroendocrine status, and changes in spontaneous physical activity associated with altered levels of fitness. Habitual exercise does not cause a significant prolonged increase in metabolic rate per unit of active tissue, but it does cause an 8-14% higher metabolic rate in men who are moderately and highly active because of their increased fat free mass i.e. lean body tissue. Since FFM is the major predictor of BMR and RMR, increases in FFM due to increased physical activity would be expected to increase BMR or RMR. The level of fitness also affects the energy expenditure of voluntary activity, probably because of variation in muscle mass.

To conclude, *intensity, duration and frequency of the activity, the body mass of the person, efficiency at performing the activity and age* influences the energy expended in physical activity.

Next, we shall move to a review the methods/means to calculate the energy expenditure and/or requirements. But before that let us recapitulate what we have learnt so far by answering the questions in the check your progress exercise 1.

Check Your Progress Exercise 1

1) Define the following

Energy:.....

Kilocalorie:.....

Physiological fuel factor:

TEF:.....

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2) List the different components of energy requirements.

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3) Define BMR? Give the factors which influence BMR.

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4) Give the different lifestyle classifications with their PAL value.

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Now let us learn about the methods we can use to measure energy expenditure and requirements.

2.5 METHODS OF ESTIMATION OF ENERGY EXPENDITURE AND REQUIREMENTS

There are a variety of methods available to measure human energy expenditure. Knowledge of these methods will help us in calculating the expenditure either in the practical sessions or in the research setting. Some of these methods covered in this section include:

- Direct calorimetry
- Indirect calorimetry
- Factorial estimation
- The doubly labelled water (DLW) technique
- Heart rate monitoring (HRM)

Let us get to know about these techniques.

2.5.1 Direct Calorimetry

Calorimetry refers to the measurement of the amount of heat evolved or absorbed in a chemical reaction, change of state, or formation of a solution. *Direct calorimetry* is the method, which monitors the amount of heat produced by a subject placed inside a structure large enough to permit moderate amount of activity. These structures are referred to as whole room calorimeters. This method provides a measure of energy expended in form of heat, but provides no information on the kind of fuel being oxidized. Further, this method is limited by the high cost and by the confined nature of the testing conditions i.e. the physical activity within the chamber is limited and therefore not representative of free-living environment.

Another method to be considered is the use of a respiration chamber or of a direct calorimeter. To obtain reliable data with either of these techniques involves an experimental set-up which is both expensive and technically complex. Relatively few of these chambers exist and their usefulness in the present context is restricted to specific basic problems which do not require a natural free-living environment

2.5.2 Indirect Calorimetry

This method estimates energy expenditure by determining the oxygen consumption and carbon dioxide production of the body or a cell over a given period of time. Data so obtained from this method permits calculation of the respiratory quotient (RQ) which is expressed as:

$$\text{RQ} = \frac{\text{moles CO}_2 \text{ expired}}{\text{moles O}_2 \text{ consumed}}$$

The RQ indicates the source of metabolic energy. It ranges from 1.0 (carbohydrate oxidation) to 0.7 (fat oxidation). On a mixed diet the RQ is about 0.85.

This determination is converted into kilocalories of heat produced per square meter of body surface area per hour and is extrapolated to energy expenditure in 24 hours.

2.5.3 Double Labeled Water (DLW) Technique

DLW is currently considered the most accurate technique for measuring TEE in free-living individuals. It is the 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 ^2H and ^{18}O . The use of the doubly labeled water (DLW) ($^2\text{H}_2^{18}\text{O}$) 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 and its application was later validated in humans. 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.

2.5.4 Heart Rate Monitoring (HRM) Method

HRM is 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.

Extrapolating from heart rate to energy expenditure is a method which has been widely believed to be valuable and reasonably valid. The technique is fairly practicable, there are several instruments on the market which are not very expensive, and it is probably the method of choice in some population groups, such as young children, old people, and ill people. This is not the place to give a detailed critique of the methodology, other than to say that it must be used with circumspection and an awareness of the variable relationships of heart rate and energy expenditure.

Finally, let us learn about the factorial estimation of total energy expenditure which is most practical and provides a good indication of total requirements.

2.5.5 Factorial Estimation of Total Energy Expenditure

The wide variations observed in the physical activity patterns of adults from different geographic, social and economic groups combined with the variations observed in body size and composition of adults, do not allow the universal application of TEE measured by DLW technique, described above, to be used directly for estimating the energy requirements for adults. Therefore, the factorial estimate is used which combines the time allocated to different habitual activities and the energy cost of these activities expressed in multiples of BMR per unit of time, i.e. either per minute or per hour. Total energy expenditure can, therefore, be estimated by a factorial approach involving summation of all the expected components of energy expenditure, including BMR and taking into account the energy costs of different activities and their durations. Table 2.2 shows examples of these calculations. To account for differences in body size and composition, the energy cost of activities is calculated as a multiple of BMR per

minute also referred to as the physical activity ratio (PAR) (refer to Table 2.2). The PAL values can be calculated as the aggregated PAR over 24 hrs. Then the PAL value is multiplied with calculated BMR to derive at energy expenditure for a day.

It must be noted here that the factorial approach should be used only for adults. It should not be used in the case of infants and children.

Table 2.2 : Computation of energy expenditure of adult Indian Population using factorial approach

Main Daily Activities	Time Allocation Hours	Energy Cost PAR	Time × Energy Cost	Mean PAL Multiple of 24-hour BMR
Sedentary or Light Activity Lifestyle				
a) Sleeping	8	1.0	8.0	
b) Occupational Activity [Sitting (office work, selling produce, tending shop)]	8	1.3	10.4	
c) Non-Occupational Activity	8	1.9	15.2	
Personal Care (dressing, showering)	1	1.6	1.6	
Eating	1	1.2	1.2	
Commuting to work by bus/car/walk	1	2.0	2.0	
General household or other activities as cooking etc.	2	2.0	4.0	
Walking at various speeds without load	1	3.4	3.4	
Light leisure activity (watching TV, chatting)	2	1.4	2.8	
	24		33.6	33.6/24=1.4
Men: Body wt. (65 kg), BMR (1506 kcal)		2123		
Women: Body wt. (55 kg), BMR (1184 kcal)		2711		
Active Or Moderately Activity Lifestyle				
a) Sleeping	8	1.0	8.0	
b) Occupational Activity [Sitting (office work, selling produce, tending shop)]	8	2.5	20	
c) Non-Occupational Activity	8	1.9	15.2	
Personal Care (dressing, showering)	1	1.6	1.6	
Eating	1	2.0	2.0	
Commuting to work by bus/car/walk	1	2.0	2.0	
General household or other activities as cooking etc.	2	3.4	6.8	
Walking at various speeds without load	1	1.4	1.4	
Light leisure activity (watching TV, chatting)	2	1.9	3.8	
	24		43.2	43.2/24=1.8
Men: Body wt. (65 Kg), BMR (1506 Kcal)		2711		
Women: Body wt. (55 Kg), BMR (1184 Kcal)		2131		
Vigorous Or Vigorously Activity Lifestyle				
a) Sleeping	8	1.0	8.0	
b) Occupational Activity [Sitting (office work, selling produce, tending shop)]	8	4.1	32.8	
c) Non-Occupational Activity				
Personal Care (dressing, showering)				
Eating				
Commuting to work by bus/car/walk				
General household or other activities as cooking etc.				
Walking at various speeds without load				
Light leisure activity (watching TV, chatting)				
	24		56	56/24=2.33
Men: Body wt. (65 Kg), BMR (1506 Kcal)		3509		
Women: Body wt. (55 Kg), BMR (1184 Kcal)		2759		

Source: Adapted from RDA and EAR- Nutrient Requirements for Indians, ICMR (2020), NIN

Let us understand this calculation with the help of an example. However, we shall first learn about the use of predictive equations to measure BMR.

We already know that 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 as described above. But, BMR, can be measured only under laboratory conditions and in small groups of representative individuals by these methods. 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. The report from the 1985 FAO/WHO/UNU expert consultation used a set of equations proposed in 1985 by *Schofield* derived mostly from studies in Western Europe and North America. Table 2.3 present these equations.

Table 2.3: Equations for estimating BMR from body weight*

Age Years	No.	BMR: MJ/day	see	BMR: Kcal/day	see
Males					
< 3	162	$0.249 \text{ kg} - 0.127$	0.292	$59.5 \times \text{BW (kg)} - 30.4$	70
3 - 10	338	$0.095 \text{ kg} + 2.110$	0.280	$22.7 \times \text{BW (kg)} + 504.3$	67
10 - 18	734	$0.074 \text{ kg} + 2.754$	0.441	$17.7 \times \text{BW (kg)} + 658.2$	105
18 - 30	2879	$0.063 \text{ kg} + 2.896$	0.641	$15.1 \times \text{BW (kg)} + 692.2$	153
30 - 60	646	$0.048 \text{ kg} + 3.653$	0.700	$11.5 \times \text{BW (kg)} + 873.1$	167
> 60	50	$0.049 \text{ kg} + 2.459$	0.686	$11.7 \times \text{BW (kg)} + 587.7$	164
Females					
< 3	137	$0.244 \text{ kg} - 0.130$	0.246	$58.3 \times \text{BW (kg)} - 31.1$	59
3 - 10	413	$0.085 \text{ kg} + 2.033$	0.292	$20.3 \times \text{BW (kg)} + 485.9$	70
10 - 18	575	$0.056 \text{ kg} + 2.898$	0.466	$13.4 \times \text{BW (kg)} + 692.6$	111
18 - 30	829	$0.062 \text{ kg} + 2.036$	0.497	$14.8 \times \text{BW (kg)} + 486.6$	119
30 - 60	372	$0.034 \text{ kg} + 3.538$	0.465	$8.1 \times \text{BW (kg)} + 845.6$	111
> 60	38	$0.038 \text{ kg} + 2.755$	0.451	$9.1 \times \text{BW (kg)} + 658.5$	108

* Weight is expressed in kg. Predictive equations for children and adolescents are presented for the sake of completeness.
see = standard error of estimate.

Source: Schofield, 1985; FAO/WHO/UNU (2004). ICMR (2020).

We can use these equations to estimate BMR from body weight. Multiplying the PAL by the BMR then gives the actual energy requirements. The PAL values as given in Table 2.1 for different lifestyles may be considered.

Now, let us understand the factorial calculation of total energy expenditure using the predictive equations to estimate BMR and using the PAL values with the help of an example.

Example: Manju is a female, 25 years of age, with a moderately active lifestyle and a mean body weight of 55 kg. Now let us calculate her energy requirements.

Calculations:

- From the Table 2.3, *BMR calculated from the predictive equation* is: $14.8 \times \text{BW} + 486.6$ (i.e. $14.8 \times 55 + 486.6 = 1300.6$ kcal/day)
- *PAL* of the moderately active lifestyle ICMR 2020 in Table 2.1 is 1.80.
- *TEE or Energy requirement:* $1300.6 \times 1.80 = (2341 \text{ Kcal/day})$, or $2341/55 = 43 \text{ Kcal/kg/day}$.

We hope that with this example you have understood the factorial estimation of total energy requirement. In this manner, with the help of the BMR predictive equation and the PAL value you can calculate the total energy expenditure (TEE) which will be the energy requirement for the individual.

Few other examples specific to different lifestyles are presented next, to help you understand the concept better.

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 (1290 Kcal/day), $TEE = 1.4 \times 5.40 = 7.56 \text{ MJ (1806 Kcal)}$, or (33 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 (1338 Kcal/day), $TEE = 1.80 \times 1338 = 2408 \text{ Kcal}$, or (42 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 (1745 Kcal/day), $TEE = 2.30 \times 1745 = 4014 \text{ Kcal}$, or (57 Kcal)/kg/d.

Next, let us study about the energy requirements for different age groups.

2.6 ENERGY REQUIREMENTS AND DIETARY ENERGY RECOMMENDATIONS

Energy requirement, as you may recall studying earlier, 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.

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 this amount of energy must be consumed every day or that the requirement and the recommended intake remain constant day after day. A convenient time frame of one week has been often used in practice for defining the number of days over which the requirement and the recommended energy intake may be averaged, although there is no biological basis for this or any other time frame. Considering that habitual physical activities may vary on some days of the week a seven day period appears reasonable for averaging the requirement and the recommended intakes.

Remember, 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*.

The ICMR expert group (2020) recommends the use of factorial approach in computation of energy requirement for Indian adults. They have recommended a 10%

and 9% reduction in Basal Metabolic Rate (BMR) for males and females, respectively from FAO/WHO/UNU equations with simultaneous reduction in physical activity level (PAL) values. The ICMR Expert group (2020) recommends the use of the lower range of PAL reported by FAO/WHO/UNU (Refer to Table 2.1)

2.6.1 Energy Requirements of Infants (from Birth to 12 Months)

Energy requirements during infancy are very high because this is one of the periods of very rapid growth. Energy requirement for infants and children of all age group are based on the principle of calculating energy requirements from total energy expenditure (TEE) plus the energy needs for growth. Energy needs for growth have two components: 1) the energy used to synthesize growing tissues, which is part of the total energy expenditure, and 2) the energy deposited in those tissues, basically as fat and protein, because carbohydrate content is insignificant. This has to be taken into account along with the basal energy needs and energy needs for activity in infants and children.

Available data suggest that energy needs are highest during the first three months and then fall over the next six months when the growth rates are lower. It rises again after nine months as the child becomes physically more active. The RDA for infants drawn by ICMR (2020), as given in Table 2.4 takes this phenomenon into account. Using WHO child growth standard data for body weight of infants, they recommend 1 kcal/kg body weight/day increment of requirement for infants age 0-6 months. The requirements are categorized into two groups: 0-6 months and 6-12 months, and are calculated as energy units per kilogram of body weight.

Table 2.4: Estimated Energy Requirement for infants

	Energy per kg Body Weight	Net Energy (Kcal/d)	Body Weight (kg)
0 - 6 months	~98/Kcal/kg/d	530	5.8
6 - 12 months	80/Kcal/kg/d	680	8.5

Source: Recommended Dietary Allowances and EAR. Nutrient Requirement for Indian-2020, ICMR, NIN

Breastmilk is the best food for infants, and exclusive breastfeeding is strongly recommended during the first six months of life which is sufficient to meet the energy requirements. Thereafter, a combination of breastmilk and complementary foods throughout infancy is recommended to meet the requirements. We will learn more about the requirements and how to meet these requirements later in Unit 14.

Table 2.5 presents the FAO/WHO/UNU 2004 recommended average energy requirements of infants from one to 12 months of age, combining the needs of breastfed and formula-fed infants. TEE is calculated with the predictive linear equations described later in this section. 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.

The TEE is lower among breastfed than formula-fed infants during the first year of life; hence the energy requirements of breastfed infants are also lower as you may have noticed in Table 2.5.

Table 2.5: Energy requirement of breastfed, formula-fed and all infants

Age Months	Breast-fed			Formula-fed			All breast&formula-fed		
	Boys	Girls	Mean	Boys	Girls	Mean	Boys	Girls	Mean
MJ/kg/d									
1	445	415	430	510	490	500	475	445	400
2	410	395	405	400	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	81	79	78
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

The equations to predict TEE from body weight of infants are as follows:

$$\text{TEE (MJ/d)} = -0.416 + 0.371 \times \text{BW (kg)}$$

$$n = 320, r = 0.085 \text{ and}$$

$$\text{Standard error g estimate} = 0456/\text{MJ/d}$$

$$\text{TEE (Kcal/d)} = -99.4 + 88.6 \times \text{BW (kg)}$$

$$\text{Standard error of estimate} = 109 \text{ (Kcal/d)}$$

In populations around the world, and particularly in India, we 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. Therefore, 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 the quantitative energy requirements for catch up growth and it is best done on individual basis. Some tentative estimates as proposed by the FAO/WHO/UNU expert Consultation of 2001 are given in Table 2.6.

Table 2.6: 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	% 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.

Next, let us learn about the requirements of older children and adolescents.

2.6.2 Energy Requirement for Children and Adolescent

The preschool years represent the age from approximately 1 to 6 years. Marked variability exists between requirements during the preschool years because of variation in growth and physical activity. 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. Dietary energy recommendations also include recommendations for physical activity compatible with maintenance of health and optimal growth and maturation. The WHO/FAO/UNU and the ICMR Expert Committee took note of the fact that Indian children are smaller at birth, infancy, childhood and adolescence but suggested that it is desirable that the growth potential of children should be fully expressed and that the estimates of energy and protein requirement should allow for this. However, as the normal Indian children are smaller and they weigh less, the actual energy requirements may be substantially lower. The dietary intakes thus recommended by ICMR for Indian children are presented in Table 2.7. You would have noticed that the energy needs for preschoolers is given in two categories: 1-3 years and 4-6 years.

Table 2.7: Energy requirement for Indian children and adolescent

Group	Particulars	Body Weight (kg)	Net Energy (Kcal/d)	
Children	1-3 years	11.7	1110	
	4-6 years	18.3	1360	
	7-9 Years	25.3	1700	
Adoloscent				
	Boys	10-12 years	34.9	2220
	Girls	10-12 years	36.4	2060
	Boys	13-15 years	50.5	2860
	Girls	13-15 years	49.6	2400
	Boys	16-18 years	64.4	3320
	Girls	16-18 years	55.7	2500

Source: Recommended Dietary Allowances and EAR, Nutrient Requirement for Indians-2020, ICMR, NIN

Marked variability exists for boys and girls in the energy requirements after 9 years of age because of variations in growth rate and physical activity levels. Marked gender differences in intensity and duration of the adolescent growth spurt in fat free mass (FFM) dictates higher energy needs in boys than girls. Hence energy requirements are specified separately for boys and girls after the age of 9 years as you see in Table 2.7.

The energy requirements for children and adolescents are based on estimates of energy expenditure and requirements for growth based on tissue deposition based on predictive quadratic equation proposed by FAO/WHO/UNU 2004. Dietary energy recommendations also include recommendations for physical activity compatible with health, prevention of obesity, and appropriate social and psychological development. In adolescents, growth is relatively slow except around the adolescent growth spurt, which varies considerably in timing and magnitude among individuals between 10 and 19 years. Adolescents gain 30 percent of their adult weight and more than 20 percent of their adult height between 10 and 19 years. Taking into account, the desirability of achieving full potential for growth, ICMR has used WHO growth standard data for body weight for computing RDA for adolescents as given in Table 2.7.

The FAO/WHO/UNU 2004 proposed predictive quadratic equation to predict TEE from body weight include:

Boys:

TEE kcal/day : $310.2 + 63.3 \cdot BW \text{ (kg)} - 0.263 \cdot BW^2 \text{ (kg}^2\text{)}$

TEE MJ/day : $1.298 + 0.265 \cdot BW \text{ (kg)} - 0.0011 \cdot BW^2 \text{ (kg}^2\text{)}$

n: 801, $r = 0.982$, $r^2 = 0.964$

Girls:

TEE kcal/day : $263.4 + 65.3 \cdot BW \text{ (kg)} - 0.454 \cdot BW^2 \text{ (kg}^2\text{)}$

TEE MJ/day : $1.102 + 0.273 \cdot BW \text{ (kg)} - 0.0019 \cdot BW^2 \text{ (kg}^2\text{)}$

n: 808, $r = 0.955$, $r^2 = 0.913$

Occupational and recreational activities variably affect energy requirements. ICMR recommendations, have taken this into consideration and energy requirements are calculated for children over five years of age and for adolescents with lifestyles involving different levels of habitual physical activity as enumerated herewith:

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 practice 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 walk long distances every day 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.

Table 2.8 : Energy requirements and PAL of Indian Boys at different activity levels*

		Sedentary Activity			Moderate Activity			Vigorous Activity		
Age(y)	Weight (kg)	Total energy requirement (kcal/d)	Total Energy requirement (kcal/kg/d)	PAL	Total energy requirement (kcal/d)	Total Energy requirement (kcal/kg/d)	PAL	Total energy requirement (kcal/d)	Total Energy requirement (kcal/kg/d)	PAL
5-6	18.5	1210	65	1.3	1403	76	1.51	1680	90	1.8
6-7	20.5	1270	60	1.3	1508	74	1.54	1760	90	1.8
7-8	22.9	1350	60	1.3	1635	71	1.58	1860	80	1.8
8-9	25.4	1530	60	1.4	1762	69	1.62	2070	80	1.9
9-10	28.1	1610	60	1.4	1896	67	1.65	2190	80	1.9
10-11	31.2	1710	55	1.4	2046	66	1.68	2320	75	1.9
11-12	34.6	1920	55	1.5	2205	64	1.72	2560	75	2.0
12-13	38.9	2040	55	1.5	2398	62	1.76	2720	70	2.0
13-14	44.3	2190	50	1.5	2627	59	1.80	3060	70	2.1
14-15	50.6	2370	50	1.5	2875	57	1.83	3300	65	2.1
15-16	56.6	2690	50	1.6	3081	54	1.84	3520	60	2.1
16-17	61.3	2810	45	1.6	3228	53	1.84	3680	60	2.1
17-18	64.8	2910	45	1.6	3326	51	1.83	3810	60	2.1
18-19	67.3	2970	45	1.6	3393	50	1.83	3890	60	2.1

Source: RDA and EAR- Nutrient Requirements for Indians, ICMR (2020), NIN

Table 2.9 : Energy requirements and PAL of Indian Girls at different activity levels*

		Sedentary Activity			Moderate Activity			Vigorous Activity		
Age(y)	Weight (kg)	Total energy requirement (kcal/d)	Total Energy requirement (kcal/kg/d)	PAL	Total energy requirement (kcal/d)	Total Energy requirement (kcal/kg/d)	PAL	Total energy requirement (kcal/d)	Total Energy requirement (kcal/kg/d)	PAL
5-6	18.3	1130	60	1.3	1318	72	1.52	1560	85	1.8
6-7	20.2	1180	60	1.3	1408	70	1.56	1620	80	1.8
7-8	22.4	1330	60	1.4	1510	67	1.59	1710	75	1.8
8-9	25.0	1410	55	1.4	1626	65	1.62	1900	75	1.9
9-10	28.2	1500	50	1.4	1761	62	1.65	2030	70	1.9
10-11	31.9	1590	50	1.4	1905	60	1.68	2150	70	1.9
11-12	36.2	1790	50	1.5	2054	57	1.73	2380	65	2.0
12-13	41.2	1890	50	1.5	2209	54	1.75	2510	60	2.0
13-14	46.0	1990	45	1.5	2333	51	1.76	2640	60	2.0
14-15	50.1	2070	40	1.5	2417	48	1.76	2750	55	2.0
15-16	52.8	2110	40	1.5	2461	47	1.75	2810	55	2.0
16-17	54.7	2150	40	1.5	2486	45	1.74	2860	50	2.0
17-18	55.7	2160	40	1.5	2498	45	1.73	3030	55	2.1
18-19	56.7	2180	40	1.5	2511	44	1.73	3050	55	2.1

Source: RDA and EAR- Nutrient Requirements for Indians, ICMR (2020), NIN

Next, we move on to the energy requirement for the adults.

2.6.3 Energy Requirement of Adults

The energy needs of Indian men and women for different activity levels computed on the basis of recommendations made by ICMR (2020) Expert Group are shown in Table 2.10.

For computing RDA, the ICMR has taken body weight of ‘reference man’ as 65 kg and that of woman’ as 55 kg. In view of these, it is likely that the energy requirement of Indians is likely to be substantially lower. ICMR (2020) recommend a 10% and 9% reduction in BMR for males and females, respectively from FAO/WHO/UNU equations. Special consideration is given for the population >60 yrs as BMR in this population decrease by nearly 200 kcal, assuming the same reference body weight in both men and women is maintained.

Table 2.10: ICMR’s RDA for energy (reference body weight and actual body weight)

Sex	Ref.Body Weight	Energy (EAR)	
		Activity Category	For Ref. Body Weight
Man	65.0	Sedentary	2320
		Moderate	2710
		Heavy	3470
Woman	55.0	Sedentary	1660
		Moderate	2130
		Heavy	2720

Source: Recommended Dietary allowances and estimated average requirements: Nutrient requirements for Indians - 2020; ICMR, NIN.

With increasing age, there are metabolic changes and also reduction in physical activity and, as a result, the energy requirement of older adults and elderly is substantially lower than younger adults as highlighted in Figure 2.2(a) and 2.2(b). The energy requirement for the population >60 years of age has been provided as requirements decrease due to a reduction in BMR.

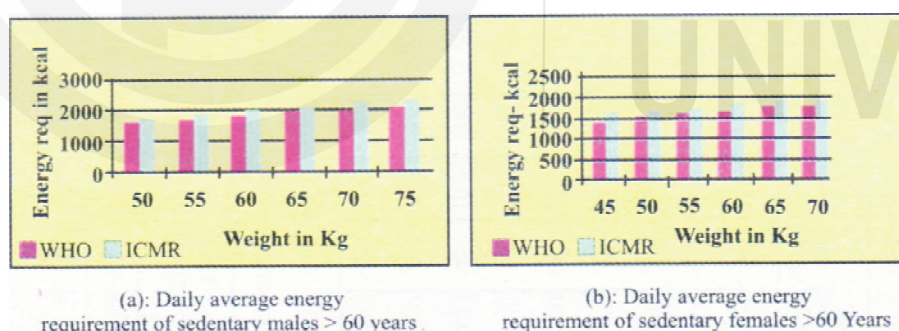


Figure 2.2: Daily average energy requirement of sedentary adults

Source: 10th Five Year Plan (2002-2007), Planning Commission, Government of India.

The new recommendations base the factorial estimates of energy requirements on the energy expenditure associated with lifestyles that combine occupational and discretionary physical activities. Multiplying the PAL value (as given in Table 2.1 by ICMR (2020) Expert group for different lifestyles) by the BMR gives the actual energy requirements. Table 2.11 gives the energy requirement as recommended by ICMR (2020) for men and women aged 19-30y, 30-60y and >60y, at the three levels of activity and at different body weights.

The practice of regular physical activity is associated with the maintenance of adequate body weight, cardiovascular and respiratory health, and fitness and a lower risk of developing chronic non communicable diseases associated with diet and lifestyle. Consequently, dietary energy recommendations to satisfy requirements should be

Table 2.11: Current estimated energy Requirement of Indian Men and Women at Different Ages, Body Weights and activities

Sex	Body weight (kg)	19-30 y				30-60 y				>60 y			
		BMR (kcal /d) ^a	Sedentary Work TEE (kcal/d) ^b	Moderate Work TEE (kcal/d) ^b	Heavy Work TEE (kcal/d) ^b	BMR (kcal /d) ^a	Sedentary Work TEE (kcal/d) ^b	Moderate Work TEE (kcal/d) ^b	Heavy Work TEE (kcal/d) ^b	BMR (kcal /d) ^a	Sedentary Work TEE (kcal/d) ^b	Moderate Work TEE (kcal/d) ^b	Heavy Work TEE (kcal/d) ^b
	45	1235	1728	2222	2839	1251	1752	2253	2878	1003	1404	1805	2306
	50	1302	1823	2344	2996	1303	1824	2346	2997	1055	1478	1900	2427
Males	55	1370	1919	2467	3152	1355	1897	2439	3116	1108	1551	1995	2549
	60	1438	2014	2589	3308	1407	1969	2532	3235	1161	1625	2089	2670
	65	1506	2109	2711	3465	1458	2042	2625	3354	1213	1699	2184	2791
	70	1574	2204	2834	3621	1510	2114	2718	3473	1266	1772	2279	2912
	75	1642	2299	2956	3777	1562	2187	2812	3592	1319	1846	2374	3033
	40	982	1374	1767	2258	1064	1490	1916	2448	930	1303	1675	2140
	45	1049	1468	1888	2412	1101	1542	1982	2533	972	1361	1749	2235
Females	50	1116	1563	2009	2567	1138	1593	2048	2618	1013	1419	1824	2331
	55	1184	1657	2130	2722	1175	1645	2115	2702	1055	1477	1898	2426
	60	1251	1751	2252	2877	1212	1696	2181	2787	1096	1535	1973	2521
	65	1318	1846	2373	3032	1249	1748	2247	2872	1138	1593	2048	2616
	70	1386	1940	2494	3187	1285	1800	2314	2957	1179	1650	2122	2711

Source: RDA and EAR- Nutrient Requirements for Indians, ICMR (2020), NIN

^aBMR calculated using FAO/WHO/UNU, 2004 equation and adjusted to 10% and 9% lower value for males and females, respectively^bPAL Values: Sedentary – 1.40, Moderate – 1.80; Heavy 2.30

accompanied by recommendations to perform adequate amounts of physical activity regularly has been strongly advocated by the ICMR (2020) recommendation.

2.6.4 Energy Requirement During Pregnancy

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. Basal metabolism, we learnt, increases during pregnancy as a result of accelerated tissue synthesis, increased active tissue mass, and increased cardiovascular and respiratory work. Based on these considerations the ICMR recommendation during pregnancy is given in Table 2.17. As you may have noticed the extra energy cost of pregnancy is 350 Kcal during the second and third trimester of pregnancy for an Indian women of 55 kg body weight and pregnancy weight gain between 10-12 kg. This is over and above the women's habitual energy requirement before pregnancy. The additional energy allowance could be lowered in cases where women reduce their activity level during pregnancy.

Table 2.17: Additional energy cost of pregnancy

	Energy(Kcal)	
	ICMR (2020)	FAO/WHO/UNU 2004
1 st Trimester	—	+85
2 nd Trimester	+350	+285
3 rd Trimester	+350	+475

Now let us look at the FAO/WHO/UNU 2004 recommendations. The FAO/WHO/UNU 2004 recommendation for the extra energy cost of pregnancy is 85 Kcal/day, 285 Kcal/day and 475 Kcal/day during the first, second and third trimesters, respectively as highlighted in Table 2.17. 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, this consultation recommends that in such societies pregnant women increase their food intake by 360 Kcal/day in the second trimester and by 475 Kcal/day in the third. Further, not all women have the option to reduce physical activity during pregnancy. In particular, women belonging to low-income group 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. In fact, appropriate adjustments can be made to compute the requirements of average women with pre-pregnant weight of 4-7 kg, gestational weight gain of 7-8 kg, and birth weight of 2.8 kg in food supplementation programmes intended to bridge the gap between the requirement and intake in pregnant women.

Finally let us get to know about the requirement during lactation.

2.6.5 Energy Requirement During Lactation

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 (assuming that she resumes her usual level of physical activity soon after giving birth). Table 2.18 presents the energy requirement for lactation. The ICMR has recommended an additional intake of 600 Kcal during the first six months of lactation and 520 Kcal during 7-12 months of lactation.

Table 2.18: RDA's for lactation

Energy (Kcal)/day		
	ICMR (2020)	FAO/WHO/UNU (2004)
0-6 months	+ 600	+ 600
6-12 months	+ 520	+ 450

Exclusive breastfeeding is recommended during the six months after delivery, with introduction of complementary foods and continued breastfeeding thereafter. For women who feed their infants exclusively with breastmilk during the first six months of life, the mean energy cost as recommended by FAO/WHO/UNU 2004 over the six-month period is 600 Kcal/day (refer to Table 2.18). From the age of six months onwards, when infants are partially breastfed and milk production is on average 550 g/day, the energy cost imposed by lactation is 450 Kcal/day.

It further suggests that *well-nourished women* with adequate gestational weight gain should increase their food intake by 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 675 Kcal/day during the first six months 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.

With a review of the energy requirement during the different ages and physiological stages we end our discussion on the requirements here. Finally, we shall look at the energy imbalance problems.

2.7 ENERGY IMBALANCE: AN OVERVIEW

Energy balance, we have learnt from our discussion so far, is achieved when input (i.e. dietary energy intake) is equal to output (i.e. total energy expenditure). When energy balance is maintained over a prolonged period, an individual is considered to be in a steady state.

The recommended intake of energy of a group is equal to the average energy requirement of individuals of the group because both lower and higher energy intakes are associated with health hazards. Too much deviation on either side from the appropriate range of body weight increases our risk of health problems. Just as overweight is the result of positive energy balance, underweight results when the energy balance is negative.

A growing literature supports the use of the body mass index (BMI) as a predictor of the impact of body weight on morbidity and mortality risks. BMI, *defined as weight in kilograms divided by the square of height in meters*, is also termed the Quetelet's index. It is used in preference to other weight/height indices, including the weight/height ratio, the Ponderal Index and the Benn's Index as highlighted in Table 2.19.

Table 2.19: Indices for weight relative to height

Index	Formula
Weight/Height ratio	wt/ht
Body Mass Index (BMI)	wt/ (ht) ²
Ponderal Index	ht ³ vwt
Benn's Index	wt/(ht) ^p

The power P in Benn's index is calculated to minimize the direct relationship with height. Weight in all indices is in kg and height in meters.

BMI, although only an indirect indicator of body composition, is now used to classify underweight and overweight individuals. Table 2.20 presents the WHO classification of underweight, overweight and obesity in adults according to BMI.

Table 2.20: Classification of underweight, overweight and obesity in adults according to body mass index (BMI)

Classification	BMI Classification (kg/m ²)		Risk of Comorbidity
	For General Population ⁺	For Asian Population [#]	
Underweight	<18.5	<18.5	Low*
Normal Range	18.5-24.9	18.5-22.9	Average
Overweight	25-29.9	23-24.9	Increased
Obesity	≥30.0	≥25	
Class I	30.0-34.9	-	Moderate
Class II	34.9-39.9	-	Severe
Class III (Morbid)	≥40.0	-	Very Severe

* Low for the non-communicable diseases associated with obesity, but increased mortality due to cancer and infectious diseases

Source: ⁺WHO (1998), [#]Misra et al. 2009

As both underweight and obesity are associated with adverse health consequences, it has been suggested that each country should develop its own BMI and cut-off points indicative of various degrees of undernutrition and overnutrition based on their own data on health problems in persons with varying BMI levels. It has been found that for a given BMI, Indians have more body fat than other ethnic groups, both within and outside Asia. This relative increase in adiposity in Indians has led to the suggestion that the BMI cut-off for non-communicable diseases such as obesity should be reduced for Indians to *about 23 kg/m²* or lower. In other words, we can refer to it as a public health action point at a BMI of 23 kg/m². The point at which low BMI poses a health risk is poorly defined. The ability to identify persons with low BMIs who are at increased risk for morbidity and mortality is highly nonspecific.

Weight status in children can be classified based on percentile curves for BMI for age. Table 12.21 presents the weight status based on percentile BMI for age. The latest BMI for age percentile for boys and girls, aged 2-20 years have been published by the United States Centre for Health Statistics (NCHS) in collaboration with the National Centre for Chronic Diseases Prevention and Health Promotion in the Year 2000 which may be applied to health of well-nourished Indian children also.

Table 2.21: WHO classification of weight status in children based on percentile curves for BMI for age

Weight Status	BMI for Age
Underweight	< 5 th percentile
At risk of overweight	≥ 85 th to < 95 th percentile

Source: WHO Technical Report (1995).

From our discussion above it is clear that the common way to assess undernutrition or overnutrition (obesity) is in terms of body weight. Undernutrition is caused by a less than adequate intake of nutrient, most of which are related to the energy intake. In adults, this has led to the term '*energy deficiency*'. *Obesity* on the other hand is energy imbalance where energy intake exceeds energy expenditure. Let us review these two conditions, linked to energy imbalance, briefly here.

Energy deficiency we have seen refers to less than adequate intake of energy. It is further sub classified into acute and chronic energy deficiency. *Acute energy deficiency* is suspected when an involuntary weight loss of greater than 10% of body weight occurs over the preceding 3-6 months. We can say it is sudden and associated with a declining body weight. *Chronic energy deficiency (CED)*, on the other hand, occurs over a long period of time, such that body weight over the preceding few months may be low, but stable. It is characterized by low body mass index in weight-stable individuals.

In 1994, FAO adopted the term 'chronic energy deficiency' for underweight. They categorized three degrees of underweight on the basis of BMI as presented in Table 2.22. WHO has adopted the same cut-off as presented in Table 2.22 to define three grades of low BMI, referred to as 'underweight' (refer to Table 2.22) rather than 'chronic energy deficiency'.

Table 2.22: FAO/WHO classification for chronic energy deficiency and/or underweight

Chronic Energy Deficiency Grade (FAO)	Underweight Grade (WHO)	BMI (kg/m ²)
Normal	Normal	> 18.5
Grade I	Mild Underweight	17.0 - 18.4
Grade II	Moderate Underweight	16.0 - 16.9
Grade III	Severe Underweight	< 16.0

Energy deficiency is associated with body weight loss along with changes in body composition (both body fat and the fat free mass are decreased), as well as, a reduced BMR and physical activity. Figure 2.3 illustrates how these factors interact with each other to attain lower energy expenditure when an acute negative energy balance exists.

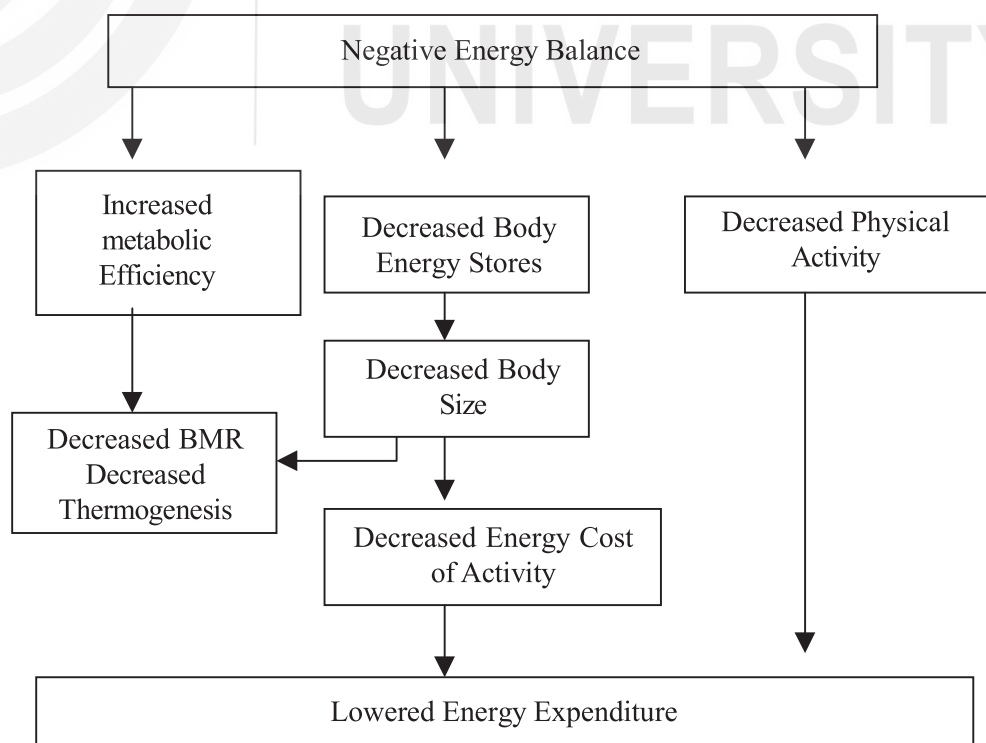


Figure 2.3: Factors leading to lowered energy expenditure

Now if the lowered energy expenditure (as illustrated in Figure 2.3) is adequate to compensate the lowered or decreased energy intake (which was the cause of negative energy balance in the first place) a new energy balance is achieved which allows a person to survive, albeit at a lower plane of nutrition and this is what is referred to as *chronic energy deficiency*. Thus, you would notice, it is a weight-stable condition, in the presence of lower than normal energy intake. It is characterized by low body weight and fat stores, but the individual's health is normal and the body's physiological function is also not compromised and therefore the individual's ability to lead an economically productive life is maintained.

However, the consequences of inadequate energy intake during the childhood and adolescence of an individual is a reduced body size and a low BMI. In the presence of concomitant repeated infections in childhood and adolescence, an individual with CED, will also show stunting. Both the body fat and the fat free mass are decreased as compared to a normally nourished individual. Reduction in muscle mass leads to reduced skeletal muscle performance, which may also be partly due to functional changes in skeletal muscles. Further adults with CED have lowered handgrip strength and they also fatigue faster when subjected to standard exercise protocols. Statistics suggest that nearly 25-50% of adults from developing countries, including India may be described as having CED. *Low values of BMI in adults have been consistently associated with a decline in work output, productivity, and income-generating ability, as well as, a compromised ability to respond to stressful conditions.*

Eight percent (8%) of Indians do not get two square meals a day and there are pockets where severe undernutrition takes its toll even today. Every third child born is underweight. Around half of the preschool children suffer from undernutrition problem low birth weight is associated not only with higher infant mortality but also long-term health consequences including increased risk of non-communicable diseases such as obesity, diabetes mellitus, coronary heart diseases etc.

Chronic energy deficiency and undernutrition is a public health problem in India. The contributory factors include:

- low dietary intake because of poverty and low purchasing power;
- high prevalence of infection because of poor access to safe-drinking water, sanitation and health care;
- poor utilization of available health and other facilities due to low literacy and lack of awareness.

Next, let us review another energy imbalance condition viz. obesity which is a state of excess energy intake over expenditure.

Obesity

The World Health Organization has declared obesity as the largest global chronic health problem in adults, which by 2025 will emerge as a more serious world problem than undernutrition.

Recent data from National Nutrition Monitoring Bureau (NNMB) repeat surveys indicate that there has been some reduction in undernutrition and alarmingly some increase in obesity over the last two decades in India. Data from National Family Health Survey-4 (NFHS) confirms that currently both undernutrition and overnutrition are problems in women (Table 2.23)

Table 2.23: Nutritional status of ever married women aged 15-49 years

	BMI < 18.5 (kg/m²)	BMI > 25 (kg/m²)
All India	23%	21%

Source: NFHS-4 (2015-16).

Alterations in lifestyles and dietary intake have led to the increasing incidence of obesity and associated non-communicable diseases. Obesity results from an imbalance between energy intake and energy expenditure. The health risks associated with obesity include increased mortality, hypertension, cardiovascular disease, diabetes mellitus, gallbladder disease, some cancers, and changes in endocrine function and metabolism. The risk factors for becoming obese are not entirely understood but are thought to include genetics, food intake, physical inactivity, and some rare metabolic disorders. Obesity rates in all age groups are increasing also mainly because of the reduction in physical activity without concomitant reduction in energy intake.

Energy expenditure by physical activity varies considerably between individuals, affecting the energy balance and the body composition by which energy balance and weight maintenance are achieved. Indeed, physical inactivity is a major risk factor for development of obesity in children and adults. Therefore, 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. There is consensus (FAO/WHO/UNU 2004) 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.

In view of the known adverse health consequences of both excess and deficient energy intake, it is essential that appropriate recommendation for the RDA for Indians is evolved. This is important as the country is entering an era of dual disease burden of CED and infections on the one hand and that of obesity and non-communicable diseases on the other.

Check Your Progress Exercise 2

- 1) What does the factorial estimation of energy expenditure involve? Rani is a female, 25 years of age, with a moderately active lifestyle and a mean body weight of 50 kg. Calculate her energy requirements using the factorial approach.

.....

- 2) Give the energy requirement as recommended by ICMR and FAO/WHO/UNU 2004 for the following:

Lactating Mothers:.....

.....

Adults:

.....

.....

- 3) Compared with the values in the FAO/WHO/UNU 1985 report, how are the energy requirements for infants proposed by FAO/WHO/UNU 2004 consultation different.

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- 4) List two conditions arising due to energy imbalance. What are the consequences of these conditions?

.....

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.....

2.7 LET US SUM UP

In this unit we learnt about the human energy requirements. Energy requirement we learnt 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, 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 (TEE). The total energy expenditure over a 24-hour period is the sum of basal metabolic rate (BMR), thermic effect of feeding (TEF), physical activity and the energy cost of tissue synthesis.

Further, we studied that the energy needs vary widely among individuals in a group. A number of factors cause the BMR to vary among individuals. Major determinants are the body size, composition, age, sex, growth etc. Similarly, there are factors affecting the thermic effect of food and energy expended in physical activity which influence energy requirements.

When energy balance is maintained over a prolonged period, an individual is considered to be in a steady state. However, too much deviation on either side from the appropriate range of body weight, either due to intakes in excess of requirements or intakes lower than requirements, increases our risk of health problems. Just as overweight (obesity) is the result of positive energy balance, undernutrition (chronic energy deficiency) results when the energy balance is negative.

2.8 GLOSSARY

Glycogenolysis	:	catabolism of glycogen leading to glucose availability.
Sepsis	:	serious medical condition, resulting from the immune response to a severe infection.

2.9 ANSWERS TO CHECK YOUR PROGRESS EXERCISES

Check Your Progress Exercise 1

- 1) Energy in simple terms may be defined as the ability, or power, to do work.

A kilocalorie is defined as the amount of heat required to raise the temperature of 1 kg of water through 1° Celsius (centigrade).

The amount of heat energy (kilocalorie) per gram that can be made available to the body by each of the energy-yielding macronutrients – carbohydrate (1 g yields 4 Kcal), protein (1 g yields 4 Kcal), fat (1 g yields 9 Kcal) is known as the physiological *fuel factor*.

The metabolic processes (such as ingestion and digestion of food, the absorption, transport, interconversion, oxidation and deposition of nutrients) increase heat production and oxygen consumption, and are known as by term 'thermic effect of feeding' (TEF).

- 2) The total energy expenditure over a 24-hour period is the sum of BMR, TEF, and energy for physical activities. 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.

- 3) The amount of energy used for basal metabolism, which includes 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, in a period of time is called the basal metabolic rate (BMR). The factors which influence BMR include fat free mass (FFM), fat mass (FM), age, sex, hormonal status, nutritional status, growth, disease/infections etc.

- 4) The different lifestyle classifications with their PAL values are as follows:

Category	PAL Value
Sedentary or light activity lifestyle	1.40 - 1.69
Active or moderate activity lifestyle	1.70 - 1.99
Vigorous or heavy activity lifestyle	2.00 - 2.40

Check Your Progress Exercise 2

- 1) The factorial estimation of energy expenditure involve summation of all the expected components of energy expenditure, including BMR and taking into account the energy costs of different activities and their durations.

- Energy requirement for Rani can be calculated as:
- From the Table 2.3, BMR calculated from the predictive equation is: 1227.5 Kcal/day) (i.e. $14.818 \times 50 + 486.6 = 1227.5$).
- PAL from mid-point of the moderately active lifestyle in Table 2.1 is: 1.85.
- TEE or Energy requirement: $1227.5 \times 1.85 = 2271$ Kcal/day), or $2271/50 = 45$ Kcal/kg/day).

- 2) The energy requirements for lactation as given by ICMR and FAO/WHO are presented in Table 2.18. Look up the values and write on your own.

The energy requirements for adults as given by ICMR and FAO/WHO are presented in Table 2.10, 2.11, 2.12, 2.13 and 2.14. Look up the values and write on your own.

- 3) Compared with the values in the FAO/WHO/UNU 1985 report, energy requirements proposed by FAO/WHO/UNU 2004 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. 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.
- 4) The two conditions arising due to energy imbalance are chronic energy deficiency and obesity. Consequences of inadequate energy intake during the childhood and adolescence of an individual result in a reduced body size and a low BMI. In the presence of concomitant repeated infections in childhood and adolescence, an individual with CED, will also show stunting, reduction in muscle mass leading to reduced skeletal muscle performance. The health risks associated with obesity include increased mortality, hypertension, cardiovascular disease, diabetes mellitus, gallbladder disease, some cancers, and changes in endocrine function and metabolism.



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