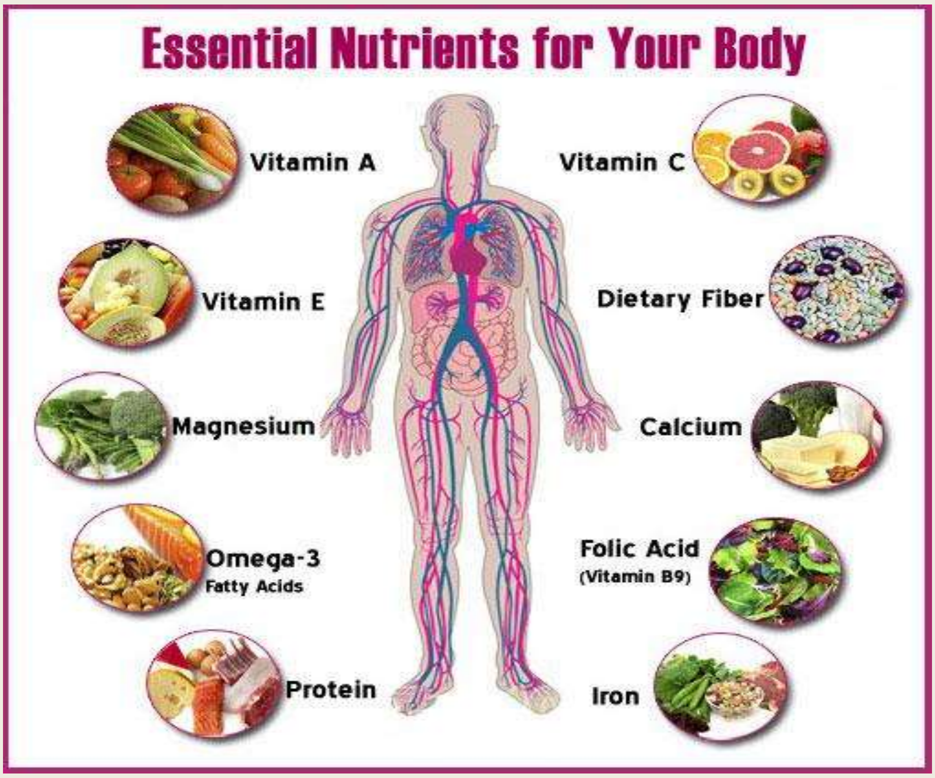
KARNATAKA STATE OPEN UNIVERSITY

Mukthagangothri, Mysuru – 570 006

M.Sc. in Clinical Nutrition and Dietetics

CBCS Scheme

I Semester



MCNDDSE-1.5: Human Nutrition

M. Sc.

CLINICAL NUTRITION AND DIETETICS

CBCS Mode

FIRST SEMESTER

MCNDDSE 1.5: HUMAN NUTRITION

(Blocks -I, II and III)

MCNDDSE 1.5: HUMAN NUTRITION

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Unit 1: Techniques for measuring body composition

1.1. OBJECTIVES

After studying this unit, you will be able to

- Describe the different techniques used measuring body composition
- Describe the applications of different instruments used for measuring body composition

1.2. INTRODUCTION

Body composition is the proportion of fat and non-fat mass in the body. A healthy body composition is one that includes a lower percentage of body fat and a higher percentage of non-fat mass including muscle, bones, and organs. Body is composed of two types of mass, body fat, and non-fat mass. Body fat is found in muscle tissue, under the skin (subcutaneous fat), or around organs (visceral fat). Fat helps for overall health. "Essential fat" helps protect internal organs, stores fuel for energy, and regulates important body hormones. Non-fat mass includes bone, water, muscle, organs, and tissues and is also called lean tissue. Non-fat mass tissues are metabolically active helping in burning calories for energy. Body composition can be assessed at the atomic level with the basic elements of carbon, calcium, potassium, and hydrogen; at the molecular level by amounts of water, protein, and fat; at the cellular level with extracellular fluid and body cell mass; and at the tissue level for amounts and distributions of adipose, skeletal, and muscle tissues. Body composition methodologies are based on assumptions regarding the density of body tissues, concentrations of water and electrolytes, and/or biological interrelationships between body components and body tissues and their distributions among healthy individuals. Similar assumptions do not exist for obese persons or those with chronic disease, whose metabolic and hormonal problems, together with associated comorbid conditions, alter the underlying assumptions, interrelationships, and validity of body composition methods. In addition, the application of body composition technology is limited among most obese adults and many older obese children because their bodies exceed the limitations of the available equipment.

1.3. INDIRECT METHODS

1.3.1. Anthropometry

Anthropometric measurements are the most basic method of assessing body composition. Anthropometric measurements describe body mass, size, shape, and level of fatness. Because body size changes with weight gain, anthropometry gives the researcher or clinician an adequate assessment of the overall adiposity of an individual. However, the associative power among anthropometric measures and indices is altered as weight is gained or lost. Standardized anthropometric techniques are necessary for comparisons between clinical and research studies.

1.3.1.1. Weight, Stature, and Body Mass Index (BMI):

Body weight is the most frequently used measure of obesity. In general, persons with high body weights typically have higher amounts of body fat. A variety of scales are available for measuring weight, and these should be calibrated regularly for accurate assessments of weight. Changes in weight correspond to changes in body water, fat, and/or lean tissue. Weight also changes with age in children as they grow and in adults as they accumulate fat. However, body weight taken without other measures of body size is misleading because a person's weight is highly related to stature (i.e., tall people are generally heavier than short people). Stature is measured easily with a variety of wall-mounted equipment. Additional methods have been developed for predicting stature when it cannot be measured directly, e.g., for the handicapped or mobility impaired. One way to overcome the lack of specificity in body weight is to use the body mass index.

BMI is a descriptive index of body habitus that encompasses both the lean and the obese and is expressed as weight divided by stature squared (kg/m^2). A significant advantage of BMI is the availability of extensive national reference data and its established relationships with levels of body fatness, morbidity, and mortality in adults. BMI is particularly useful in monitoring the treatment of obesity, with a weight change of about 3.5 kg needed to produce a unit change in BMI. In adults, BMI levels above 25 are associated with an increased risk of morbidity and mortality, 17 with BMI levels of 30 and greater indicating obesity. In children, BMI is not a straightforward index because of growth. However, high BMI percentile levels based on Centers for Disease Control and Prevention (CDC) BMI growth charts and changes in parameters of BMI curves in children are linked to significant levels of risk for adult obesity at corresponding high percentile levels. The use of BMI alone is also cautioned in athletes and persons with certain medical conditions (e.g., sarcopenia) where body weight may be altered significantly by changing proportions of muscle and fat masses.

The BMI is a convenient rule of thumb used to broadly categorize a person as underweight, normal weight, overweight, or obese based on tissue mass (muscle, fat, and bone) and height. Major adult BMI classifications are underweight (under 18.5 kg/m2), normal weight (18.5 to 24.9), overweight (25 to 29.9), and obese (30 or more). When used to predict an individual's health, rather than as a statistical measurement for groups, the BMI has limitations that can make it less useful than some of the alternatives, especially when applied to individuals with abdominal obesity, short stature, or unusually high muscle mass. BMIs under 20 and over 25 have been associated with higher all-causes mortality, with the risk increasing with distance from the 20–25 range

The BMI is generally used as a means of correlation between groups related by general mass and can serve as a vague means of estimating adiposity. The duality of the BMI is that, while it is easy to use as a general calculation, it is limited as to how accurate and pertinent the data obtained from it can be. Generally, the index is suitable for recognizing trends within sedentary or overweight individuals because there is a smaller margin of error. The BMI has been used by the WHO as the standard for recording obesity statistics since the early 1980s.

This general correlation is particularly useful for consensus data regarding obesity or various other conditions because it can be used to build a semi-accurate presentation from which a solution can be stipulated, or the RDA for a group can be calculated. Similarly, this is becoming more and more pertinent to the growth of children, since the majority of children are sedentary. Cross-sectional studies indicated that sedentary people can decrease BMI by becoming more physically active. Smaller effects are seen in prospective cohort studies which lend to support active mobility as a means to prevent a further increase in BMI. BMI categories are generally regarded as a satisfactory tool for measuring whether sedentary individuals are underweight, overweight, or obese with various exceptions, such as athletes, children, the elderly, and the infirm. Also, the growth of a child is documented against a BMI-measured growth chart. Obesity trends can then be calculated from the difference between the child's BMI and the BMI on the chart.

1.3.1.2. Abdominal Circumference:

Obesity is commonly associated with increased amounts of intra-abdominal fat. A centralized fat pattern is associated with the deposition of both intra-abdominal and subcutaneous abdominal adipose tissue. Abdominal circumference is an imperfect indicator of intra-abdominal adipose tissue, as it also includes subcutaneous fat deposition, as well as visceral adipose tissue. Persons in the upper percentiles for abdominal circumference are considered obese and at increased risk for morbidity, specifically type 2 diabetes and the metabolic syndrome, and mortality. The calculation of fat and muscle areas of the arm is not accurate or valid in the obese. The ratio of abdominal circumference (often referred to incorrectly as “waist” circumference) to hip circumference is a rudimentary index for describing adipose tissue distribution or fat patterning. Abdomen-to-hip ratios greater than 0.85 represent a centralized distribution of fat.

1.3.1.3. Skinfolds

Skinfold measurements are used to characterize subcutaneous fat thickness at various regions of the body, however, they have limited utility in the overweight or obese adult. The primary limitation is that most skinfold calipers have an upper measurement limit of 45 to 55 mm, which restricts the use to subjects who are moderately overweight or thinner. A few skinfold calipers take large measurements, but this is not a significant improvement because of the difficulty of grasping and holding a large skinfold while reading the caliper dial. The triceps skinfold varies considerably by sex and can reflect changes in the underlying triceps muscle rather than an actual change in body fatness. Skinfolds are particularly useful in monitoring changes in fatness in children because of their small body size, and the majority of fat is subcutaneous even in obese children. However, the statistical relationships between skinfolds and percent or total body fat in children and adults are often not as strong as that of BMI. Also, the true upper distribution of subcutaneous fat measurements remains unknown because most obese children and adults have not had their skinfolds measured.

To estimate the total amount of body fat, four skinfolds are measured:

- Biceps skinfold (front side middle upper arm)
- Triceps skinfold (back side middle upper arm)
- Subscapular skinfold (under the lowest point of the shoulder blade)
- Suprailiac skinfold (above the upper bone of the hip)

a. The biceps skinfold is the exact opposite of the triceps skinfold, being on the anterior aspect of the arm and at the same mid-point level as previously described for triceps skinfold. It is picked up with the subject facing the observer and the left arm hanging relaxed but with the palm facing forwards. The middle finger and thumb sweep together at a point 1 cm above the marked mid-point level, coming together at the vertical axis joining the center of the anticubital fossa and the head of the humerus. It is unusual for the movement of the dial to present any problem with this skinfold measurement, as it is not a site for major fat deposits.
b. The triceps skinfold is necessary for calculating the upper arm muscle circumference. Its thickness gives information about the fat reserves of the body, whereas the calculated muscle mass gives information about the protein reserves. It's better to repeat the measurements for a good indication of changes in nutritional status and body fat mass.
c. The mid distance was marked on the skin anteriorly to measure the biceps skinfold and posteriorly to measure the triceps skinfold with the arm by the side of the body. Subscapular skinfold thickness (SBS) is measured 1-2 cm below the inferior angle of the scapular.
d. Suprailiac skinfold (above the upper bone of the hip), A diagonal fold just above the front forward protrusion of the hip bone (just above the iliac crest at the midaxillary line).

1.4. DIRECT METHODS

1.4.1. Total Body Water:

Water is the most abundant molecule in the body, and total body water volume is measured by isotope dilution. Water maintains a relatively stable relationship to fat free mass, hence, measured water/isotope-dilution volumes allow prediction of fat free mass and fat (i.e., body weight minus fat free mass) in normal weight individuals. As with the other methods mentioned earlier, the total body water method is limited in the obese. The major assumption is that fat free mass is estimated from total body water based on an assumed average proportion of total body water in fat free ma of 73%, but this proportion ranges from 67 to 80%.

In addition, about 15 to 30% of total body water is present in adipose tissue as extracellular fluid, and this proportion increases with the degree of adiposity. These proportions tend to be higher in women than in men, higher in the obese, and therefore produce underestimates of fat free ma and overestimates of fatness. Importantly, variation in the distribution of total body water as a result of disease associated with obesity, such as diabetes and renal failure, affects estimates of fat free ma and total body fluid further. Total body water is a potentially useful method applicable to the obese but there are details that need to be considered. The several analytical chemical methods used to quantify the concentration of total body water (and extracellular fluid) have errors of almost a liter. Equilibration times for isotope dilution in relation to levels of body fatness are unknown because, theoretically, it might (and should) take longer for the dilution dose to equilibrate in an obese person as compared with a normal weight individual. Also, a measure of extracellular space is necessary to correct the amount of fat free mass in an obese person.

1.4.2. Total Body Counting and Neutron Activation:

In addition to total body water, two other direct methods of body composition assessment are available to the researcher/clinician: total body counting and neutron activation. Total body counting (also called whole body counting) measures the amount of naturally radioactive potassium 40 (40K) in the body. Because potassium is found almost entirely within cell bodies, measuring potassium can provide an estimate of body cell mass. Fat-free mass can then be estimated once total body potassium is known, assuming a constant concentration of potassium in fat free mass. Neutron activation techniques have been reported to be highly accurate for tissue-specific body composition, with a typical body scan occupying up to 1 hour. After subject exposure to a neutron field, gamma output can be measured as the cell nucleus relaxes and goes back to its pre-exposed state. Gamma output can be measured immediately upon activation (“prompt gamma neutron activation”) or at a somewhat delayed period (“delayed gamma neutron activation”). Using this technique, many elements in the body can be measured, including carbon, nitrogen, sodium, and calcium. Body nitrogen quantified by this method has been used to predict the amount of protein in the body to further analyze components of fat free mass. A significant concern with this technique is that it involves high levels of neutron radiation exposure and therefore has not been used in large-scale population research

CHECK YOUR PROGRESS - 1

1. What is BMI?
2. Write the different skinfolds measured?

Fill in the blanks

1. BMI classifications for normal weight is _______________, overweight is ____________, and obese is _____________.
2. Total body counting measures the amount of naturally radioactive ________________ in the body

1.5. CRITERION METHODS

1.5.1. Body Density:

Hydro densitometry (commonly called "underwater weighing") is a technique that estimates body composition using measures of body weight, body volume, and residual lung volume. Historically, body density was converted to the percentage of body weight as fat using the two-compartment models but more recently, a multi-compartment model is used to calculate body fatness. The multi-compartment models combine body density with measures of bone density and total body water to calculate body fatness and are more accurate than two-compartment models. Hydro densitometry is highly reliant upon subject performance. This is particularly problematic in children or obese subjects because it is difficult, if not impossible, for them to submerge completely under water. Weight belts reduce buoyancy, but cannot compensate for all aspects of performance problems.

Air displacement plethysmography works under many of the same assumptions as hydro densitometry and affords some advantages over it (e.g., subject compliance does not involve breath holding or aversions to being under water). Air displacement devices do make assumptions regarding tissue density, much like other methods of body composition assessment.

1.5.2. Dual-Energy X-ray Absorptiometry

Dual Energy X-ray absorptiometry is the most popular method for quantifying fat, lean, and bone tissues. The two low-energy levels used in DXA and their differential attenuation through the body allow the discrimination of total body adipose and soft tissue, in addition to bone mineral content and bone mineral density. DXA is fast and user-friendly for the subject and the operator. A typical whole body scan takes approximately 10 to 20 minutes and exposes the subject to <5 mrem of radiation. Mathematical algorithms allow calculation of the separation components using various physical and biological models. The estimation of fat and lean tissue from DXA software is based on inherent

assumptions regarding levels of hydration, potassium content, or tissue density, and these assumptions vary by manufacturer.

Dual energy X-ray absorptiometry estimates of body composition are also affected by differences among manufacturers in the technology, models, and software employed, methodological problems, and intra- and intermachine differences.56,58 There are physical limitations of body weight, length, thickness and width, and the type of DXA machine, i.e., pencil or fan beam. Most obese adults and many obese children are often too wide, too thick, and too heavy to receive a whole body DXA scan, although some innovative adaptations have been reported. Additionally, some studies indicate that DXA may not be as reliable in extreme populations, including the obese. Although specific manufactures and models have been tested and found to have certain biases that may overestimate fat free mass. DXA is a convenient method for measuring body composition in much of the population and is currently included in the ongoing National Health and Nutrition Examination Survey (NHANES).

1.5.3. Computed Tomography and Magnetic Resonance Imaging:

The other imaging modalities, such as Computed Tomography and Magnetic Resonance Imaging, are gaining in popularity and represent important new techniques for body composition assessment. Unfortunately, these methods are often not practical for obese individuals. CT is able to accommodate large body sizes but has high radiation exposures and, as such, is inappropriate for whole body assessments, but it has been used to measure intra-abdominal fat. In many instances, MRI is not able to accommodate large body sizes but can be used for whole body assessments in normal weight or moderately overweight individuals. Both these methods require additional time and software to provide whole body quantities of fat and lean tissue. In addition to its imaging capabilities, CT can also distinguish body tissues based on signal attenuation.

1.6. BIOIMPEDANCE ANALYSIS

Bioimpedance analysis is a broadly applied approach used in body composition measurements and healthcare assessment systems. The essential fundamentals of bioimpedance measurement in the human body and a variety of methods are used to interpret the obtained information. In addition, there is a wide spectrum of utilization of bioimpedance in healthcare facilities such as disease prognosis and monitoring of body vital status.

1.6.1. Whole Body Bioimpedance Measurement

Measurement of total body bioimpedance is the most commonly used method for estimating whole body compartments. Many of the whole body bioimpedance instruments apply three approaches for impedance measurement: hand to foot method, foot to foot method and hand to hand method. The hand to foot is the most commonly used method. Tetra polar hand to foot measurements are performed on a supine subject for 15 min, placing electrodes filled with gel to minimize gap impedance on the dorsal surfaces of the right hand and foot, distal (current) ones being respectively proximal to the metacarpal and metatarsal phalangeal joints, in accordance with standard tetra polar electrode placement. In leg to leg bioimpedance measurements, the subject stands vertically, with uncovered feet, on four stainless steel footpads' electrodes and divided for each foot into frontal and back portion for current injecting and voltage measurement.

1.6.2. Body Segment Bioimpedance Measurement

Segmental bioimpedance analysis achieves better estimation of skeletal muscle mass than whole body bioimpedance analysis, with a reported standard error of 6.1% in reference to MRI measurements. Segmental bioimpedance analysis detects the fluctuation in extra cellular fluid due to differences in posture and is more precise than the ankle foot method, and gives a better estimation of total body water than total body measurements with reference to dilution method.

Measurement of segmental bio impedance can be achieved through four types of protocols. The first approach, uses dual current injection electrodes on the proximal area of the right forearm and lower leg, and quad voltage electrodes placed on the right proximal forearm, shoulder, upper thigh and lower leg. The second approach is through the sum of segments technique, that uses dual current injection electrodes on the right wrist and foot, and quad voltage electrodes placed on the right wrist, shoulder, upper iliac spine and foot. A third approach is the use of dual current injection electrodes on the right wrist and foot, and quad voltage electrodes, two placed on the right wrist and foot, and two on the left wrist and foot. The fourth approach is through the use of quad current injection electrodes located on the right and left wrist and foot, and quad voltage electrodes located at the same place.

1.6.3. Body Composition Prediction Using Bioimpedance Analysis

Body composition assessment is considered a key factor for the evaluation of general health status of humans. Several methods use different assumptions to estimate body composition based on the number of compartments. Fat free mass is composed of bone minerals and body cell mass that includes skeletal muscle mass. Body cell mass contains proteins and total body water that represents 73% of lean mass in normal hydrated subjects. Total Body Water is composed of Intra cellular fluid and Extra cellular fluid.

Fat Mass and Fat free mass estimations are considered one of the main objectives of body composition assessment techniques. Variations in Fat Mass among the reference population are due to several factors, but are believed to follow aging factors in addition to gradual changes in lifestyle. Anthropometric and skin fold thickness measurements are traditional, simple and inexpensive methods for body fat estimation to assess the size of specific subcutaneous fat depots compared with other methods such as underwater weighing, dilution method and dual-energy x-ray absorptiometry that requires a trained practitioner to perform it. Bioimpedance analysis has been shown in recent studies to be more precise for determining lean or fat mass in humans. In comparison with BMI, anthropometric and skin fold methods, BIA offers trustable results in the estimation of fatness across human tissues.

CHECK YOUR PROGRESS - 2

1.What is Bioimpedance analysis?

2.What does Segmental bioimpedance analysis detects?

Fill in the blanks

1. _____________ is a technique that estimates body composition using measures of body weight, body volume, and residual lung volume.
2. ___________________ is the most popular method for quantifying fat, lean, and bone tissues.
3. ___________________ can also distinguish body tissues based on signal attenuation.

1.7. SUMMARY

Increasing demands for accurate, cost effective and non-invasive systems for clinical status monitoring and diagnosis of diseases in healthcare, has accelerated the research endeavors to provide new methods and technologies to evaluate the health condition of human body. Body composition assessment tools has been considered a promising approach for the quantitative measurement of tissues characteristic over time, in addition to direct relativity between fluctuations in body composition equivalences and survival rate, clinical condition, illness and quality of life. Bioimpedance analysis is a growing method for body compartments estimation in nutrition studies, sport medicine and evaluation of hydration rate, fat mass and fat free mass between healthy and diseased populations. Fat mass, fat free mass including skeletal muscle mass, bone minerals, and total body water, which is composed of intercellular fluid and extracellular fluid, are compartments that can be predicted and analyzed using suitable bioimpedance measurements techniques, procedures and population, age, ethnic groups or disease-dedicated bioimpedance analysis equations. Further studies are needed to evaluate the correlations between variations in bioimpedance parameters, especially in ECF and ICF, and the deviation from health to disease.

1.8. GLOSSARY

Essential fat: Essential fatty acids, or EFAs, are fatty acids that must be ingested because the body requires them for good health but cannot synthesize them.

Adipose tissue: Adipose tissue, body fat, or simply fat is a loose connective tissue composed mostly of adipocytes

Isotope: Isotopes are members of a family of an element that all have the same number of protons but different numbers of neutrons

Mathematical algorithms: A procedure for solving a mathematical problem (as of finding the greatest common divisor) in a finite number of steps that frequently involves repetition of an operation

Tetrapolar: Having four poles certain abnormal mitotic figures are tetrapolar.

1.9. FURTHER SUGGESTED READING

1. Davis P.S.W. & Cole T.L. (1995) Body Composition Techniques in Health and Disease, Cambridge University Press

2. Lohman, T, Wang Z & Going, S.B. (2005) Human Body Composition, Human Kinetics

3. Lusuki H.C. (2017) Body Composition: Health and Performance in Exercise and Sport, CRC Press

1.10. ANSWERS TO CHECK YOUR PROGRESS - 1

1. BMI is a descriptive index of body habitus that encompasses both the lean and the obese and is expressed as weight divided by stature squared (kg/m2).

2. Four skinfolds are measured are Biceps skinfold, Triceps skinfold, Subscapular skinfold and Suprailiac skinfold

Fill in the blanks

1. BMI classifications for normal weight is 18.5 to 24.9, overweight is 25 to 29.9, and obese is 30 or more.

2. Total body counting measures the amount of naturally radioactive potassium 40 (40K) in the body

1.11. ANSWERS FOR CHECK YOUR PROGRESS -2

1. Bioimpedance analysis is a broadly applied approach used in body composition measurements and healthcare assessment systems.

2. Segmental bioimpedance analysis detects the fluctuation in extra cellular fluid due to differences in posture

Fill in the blanks

1. Hydro densitometry is a technique that estimates body composition using measures of body weight, body volume, and residual lung volume.

2. Dual Energy X-ray absorptiometry is the most popular method for quantifying fat, lean, and bone tissues.

3. Computer Tomography can also distinguish body tissues based on signal attenuation.

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Unit 2: Body compositional changes in life cycle

Unit 2: Body compositional changes in life cycle

2.1. OBJECTIVES

After studying this unit, you will be able to

- Understand the pattern of changes that ensue during stages of life
- Know importance of body compartments affecting maturation
- Know the factors affecting body composition

2.2. INTRODUCTION

The process of growth and development is experienced by every human being. We see others growing, an infant grow into a toddler, a school age child, an adolescent and a young adult, this period is referred to anabolic stage where the individual is constantly changing his/ her linear height, width and mass. The changes in the body's shape and size etc. At the same time, the adults exhibit different type of bodily changes, although there is no linear growth occurring. The changes that occur are obviously because there are steady changes in body tissues affecting bodily appearance. It is also a common understanding that people who are less active put on weight and become obese, on the other hand people who eat less or fast frequently loses weight. Therefore, understanding about the changes that ensue due to age, gender or the health status is essential for appreciating healthy and sick people. Especially this information is required for effective handling patients in the clinical setup.

2.3. CHANGES IN BODY COMPOSITION DURING LIFE CYCLE

2.3.1. Growing years' infancy to post adolescence

Human body composition and the degree of biological variability seen in the healthy population with regard to gender, ethnicity, age, and sexual maturation is well known that there are two distinct phases of metabolism that occur throughout life at different stages- they are anabolic phase and the catabolic phase.

The first half of life span roughly is an anabolic phase and the second half is considered to be the catabolic stage. Starting from conception till a man reaches the age of 30 years is the young adult. The body undergoes a positive development and exhibits the highest level of functional capacities. There upon the capacities slowly decrease ultimately reaches a stage wherein there is a frank decrease in their functional capacities. Since the major component of the body weight are water, fat and body cell mass, weight change can be attributed to any one or all of these.

Infancy is a period of rapid growth, substantial changes body composition occurs in and is very different from that of an adult body. The mineral, protein, water, and lipid contents of the body increase with age during early life, each at markedly different rates. There is also a significant redistribution of body water between its extracellular and intracellular fluid volumes during early life. Limited body composition data exist for children in the toddler years (age range, 1–4 yr).

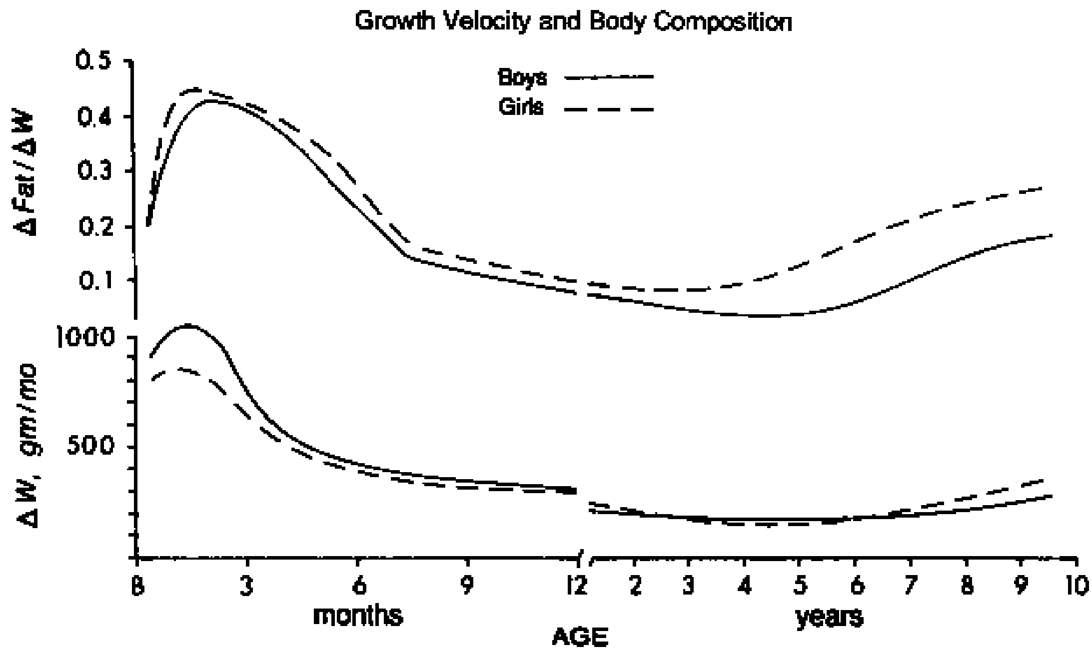

Figure 1: Body compositional changes from 0 to 10 years

Source: https://archive.unu.edu/unupress/food2/UID09E/UID09E09.HTM

Body water: Body Water being the largest component exhibits marked changes. Body of full term neonates is highly hydrated with total body water ranging from 75 to 83%. Body water decrease from birth up to pre pubertal age and thereby becomes more stable. Moulton in1923 introduced a concept of "chemical maturity". He defined chemical maturity as "the point at which the concentration of water, proteins & salts becomes comparatively constant in the fat – free body. He showed that there was a rapid decrease in the water content of fat – free mammalian tissue & an increase in protein & ash content from conception to the time of chemical maturity, when the change suddenly becomes less & a practically constant concentration is reached, this state is also referred to ‘matured hydration’. This also helps to explain why infants are not able to stand on their feet, physical movement and ability to stand and hold the body weight is possible only when body is less hydrated or chemically mature.

The distribution of body water into extra cellular and intra cellular compartment also vary, infants and young children have higher proportion of Extra cellular water (ECW) than intra cellular water (ICW) which gets closer to the adult type by end of fifth year. Body water measured as a percentage of body weight is 70% at birth, dropping to 61% at 12 months. This change is fundamentally due to a decrease in ECF from 45% to 28% of body weight. ICF stays relatively constant. After age 12 months, there is a slow and variable fall in ECF to adult levels of about 20% and a rise in ICF to adult levels of about 40%. The relatively larger amount of body water, its high turnover rate, and the comparatively high surface losses (due to a proportionately large surface area) make infants more susceptible to fluid deprivation than older children and adults. Around the time of preadolescence, a temporary increase in body water is seen, which decreases eventually by end of the preadolescence age.

Body fat: Fat is the most variable component because it varies enormously during the stages of life, differences also occur due to gender, lifestyle and genetic factors. At birth 13% of body weight is fat that increase to 20 to 25% by 12 months, accounting for the chubby appearance of most infants. In the third year, there is a fat loss which is apparent in boys than girls called as, “preschool loss”. This is the first difference in body composition due to gender. Subsequently, a slow fall occurs until preadolescence, when body fat returns to about 13%. There is a slow rise again until the onset of puberty; a sharp increase is seen in girls, while body fat again falls in boys. After puberty, the percentage generally stays stable in girls, whereas in boys there tends to be a slight decline making boys appear more masculine. The figure given below indicates the pattern gain during childhood and adolescence. Children who are overweight at age 5 years and during adolescence tend to become obese throughout their adult life. Also fat is an important compartment that varies with gender, females have higher body fat than those of men and this difference is attributed to the sex steroids.

The lean body mass (LBM) increase linearly and forms 87% of total body mass by 10th year. However, in absolute terms increase in LBM is very high, i.e, a mean weight of LBM is 2.9 Kg in a full term baby with birth weight 3.4 kgs, this increase to 27 and 26 kg at age 10 in boys and girls respectively. The increase is rapid in both boys and girls during the preadolescence and adolescence coinciding with peak growth velocity. Nearly two third of the adult LBM is gained by age of 15 years. Increase in muscle mass is significantly higher during adolescence; especially in boys, proportion of LBM gain exceeds over other components because of the concomitant decrease in fat. LBM accretion and peak height velocity have parallel developments, hence as height velocity declines, fat accumulation resumes in both sexes but twice as rapid in girls. At the end of post adolescence, boys would have gained 15% of LBM of an average female and twice the number of cell mass. The increase in skeletal size and muscle mass leads to increased strength in males. Attaining maturity does not mean cession of change and alteration in relative and absolute LBM, but the changes continue to occur at a slower rate as individual ages.

Bone minerals: At birth bone density is negligible. Calcium content is approximately 8g/kilogram body weight, no difference due to gender. Accretion of calcium in bone is constant from birth to 18 years, when the mean calcium content increases to 19.0 g/kg. Mean daily accretion of the major mineral in the bone is believed to be 200mg Ca, 107 mg P and 4.0 mg Magnesium, therefore the total bone calcium accretion is a linear function to age. Both androgens and estrogen promote deposition of bone mineral and more than 90% of peak skeletal mass is present by age 18 years in adolescents who have undergone normal pubertal development at the usual time. Therefore, the Peak bone mass is reached by 30 years of age, while genetic differences are very high. Relative amount of calcium remains constant while absolute quantities of bone mineral mass vary with stage of development. A marked increase in the width of bone in adolescent boys are noted by increase in muscle and a simultaneous loss of fat. Skeletal size is related to height of an individual and this is directly proportional to calcium content, regression slope for bone calcium is 20g/cm height of normal and healthy bone. Nevertheless, bone mineral mass is related to dietary calcium intakes. Hence a man 175 cm tall has a calcium content of 1300g and a woman of 150 cm will contain approximately 710g. Exercise is an important modulator of body composition; although it brings about muscle development it also exerts strong influence on bone mineral mass. Individuals who exercise or engaged in moderate to heavy activity tend to deposit higher quantity of bone mineral than less active individuals. The bone mineral mass is referred as 'bone density', bones with higher densities are strong and healthy, they withstand heavy loads and exercises

Body Weight: Normal term neonates generally lose 5 to 8% of birth weight in the days soon after delivery but regain their birth weight within 2 wk. They then gain 14 to 28 g/day until 3 months, between 3 to 12 months the infants gain an additional 4000 g. a rough estimate of the weight changes is that, the infants double their birth weight by 5 months and triple by 12 months, and almost quadrupling by 2 yr. Between age 2 years and puberty the weight increase by 2 kg/year. The recent epidemic of childhood obesity has involved markedly greater weight gains, even among very young children. In general, boys are heavier and taller than girls when growth is complete because boys have a longer pre-pubertal growth period, increased peak velocity during the pubertal growth spurt, and a longer adolescent growth spurt. Boys and girls gain approximately fifty percent of their adult weight. In the young adult life, both men and women generally maintain constant body weights.

2.4. ADULTS AND THE ELDERLY

Adulthood encompasses age between 20 to 60 years, wherein a further classification is introduced as young adults that is the age between 20 and 30 for males and 18 to 30 years in females. This classification is applicable for convenience, however, there is a fact that the young adults are highly functional and enjoy complete health. The physiological and functional capacities are at its maximum level. They can take up endurance exercises with convenience and reach for the highest output order, which tends to decline as age advances. The elderly group include individuals who are more than 60 years of age.

2.4.1. Fat Free Mass (FFM)

Aging is associated with considerable changes in body composition, redistribution of both body fat and FFM occurs throughout the age of 30 years. People aged 20 to 30 years if maintaining ideal body weight carries maximum proportion of muscle mass, which is generally 75 – 80% in females and males respectively. The muscle capacity during the young adulthood is maximum this is also reflected in the functional capacity of important organs such as heart and kidney, and has maximum Resting Metabolic Rate (RMR). After 30 years, fat-free mass (FFM) progressively decreases without any changes in body weight. Most often the decrease in FFM is replaced by fat mass there by concomitant increase and decrease of fat and fat free mass occurs after 30y of age. FFM (primarily skeletal muscle) decreases up to 40% from 20 to 70 years of age. Maximal FFM is usually reached at 20 y of age, and maximal fat mass is usually reached at 60–70 years of age; further both the components subsequently decline thereafter. Therefore, both FFM and fat mass decrease during old age (70 y) therefore elderly people in 80+ are seen shrunken.

2.4.2. Fat Mass

Increase in fat mass is a normal process, with aging there is a greater relative increase in intra-abdominal fat than in subcutaneous or total body fat. There is a greater relative decrease in peripheral than in central FFM because of the loss of skeletal muscle. In addition, there is also increase in intramuscular and intra-hepatic fat in older persons, this is found to associate with insulin resistance. A recent cross-sectional study from the Adelaide on male subjects determined that the increase in percent FM was mostly due to reduced lean mass, whereas the increase in abdominal percent FM was due to more FM deposited in the abdominal region.

2.4.3. Body water

Although percent body water does not change with age, the absolute total body water including both ECW and ICW decreases with age. The major cause for the decline in body water is the loss of active cell mass. The component that has highest proportion of water in the body is the FFM that is 70%. This results in decrease in body water and reaches a measurable level only after 60 years of age; eventually with increasing age, shrinking of the body becomes apparent, wrinkled skin is the indication. Also body surface area is reduced. Old age is known for the changes in certain physiological cues, importantly is the sense of thirst in response to water deprivation or thermal dehydration. This reduction combined with decreased renal function is considered to predispose the elderly to dangerous levels of dehydration during illness.

2.4.4. Bone Minerals

Bone mass continues to accrue at higher proportion till age 30 years in both males and females, and then with advancing age bone mineral content decrease potentially resulting in osteoporosis. After 40 years of age, bone mass decrease in both sexes at the rate of 1-2% every decade, this process is referred as ‘bone resorption’. The regions from where bone loss occurs are spine, radius, femoral neck, trochanter region, wards triangle and hip bone. Bone loss from each region varies from 1% in radius to spine at 3-6% and highest losses are encountered from hip bone variations are also influenced by the gender, women tend to lose at an early age and at higher rates as compared to men. This explains why the elderly people are prone for fractures.

2.5. PREGNANCY

This is the time in a women’s life when a variety of alterations take place, nature has so accommodated that fetal development continue uninterrupted. Gestation period in humans is 9 to 10 months; however, 12 months’ pregnancy also is reported in rare cases. A progressive change in weight and other maternal tissues takes place along with development of fetus. There is expansion of blood volume, adipose tissues and body water content. Weight gain in healthy young women during pregnancy is estimated to be approximately 12.5 kg at term. Although vast variations in weight gains are reported from population studies, the desirable gain is considered to be 10 to 12 kg, as this reduces complications and childbirth stress on both mother and the fetus.

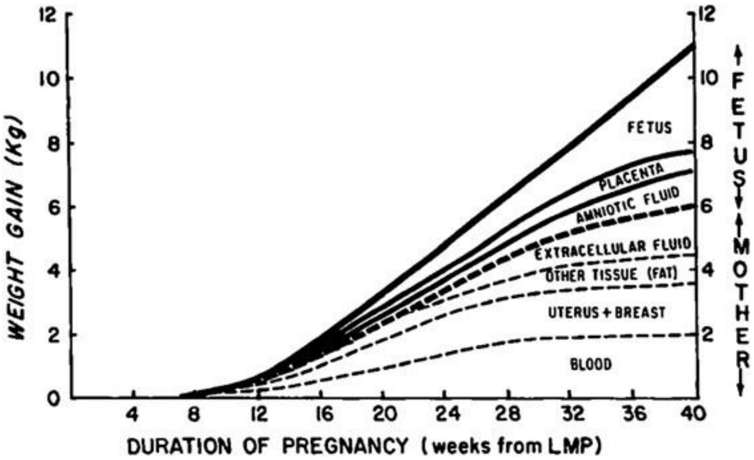

Figure 2: Weight gain during Pregnancy

Source: https://www.nature.com/articles/ejcn201440

The first trimester accounts for a small change in weight, with a further increase in second trimester. The maximum weight occurs between 2nd and the mid of 3rd trimester. The maximum tissue that accumulates is fat, on an average 4 kg of maternal tissues deposited accounts for fat, and one kilogram of cell mass. the fat deposition is localized subcutaneously, of the total fat deposited, 46% deposit in the lower trunk, 32% in the upper trunk, 16% in the thighs, 1% in the calves, 4% in the upper arms and 1% in the forearms The other component which is most important is body fluid, a gradual increase in body water occurs over the course of pregnancy; a mean increase of 2.5 kg is reported. The extra fluid accounts for expansion of blood volume and hydration of connective tissues. The hydrated status during pregnancy is considered to facilitate most of the physiological functions such as diffusion of nutrients across tissues, and elimination of waste material. Hydrated tissues give rise to visible edema in certain cases referred to physiological edema this is regard as a normal physiological phenomenon for easy parturition.

2.5.1. Human Fetal Development

Development in the fetus begins from the time of fertilization causing a series of developments leading to formation of a ‘conceptus’ or the product of conception. This includes formation of a cellular mass called ‘blastocyst’, which implants into the endometrium and eventually generate extra-embryonic structures, such as the placenta and the membranes, all these together is referred to conceptus. Rapid growth occurs and the fetus main external features begin to take form. As the fetus grows and develops, total body water which is the largest contributor to weight, falls from approximately 92% to 70 – 72% at term. This change is accompanied by an increase in fat content. The relative amounts of nitrogen and fat exhibits an inverse relation to the water content of the fetus. Deposition of protein far exceeds that of fat until the last two months of gestation, when relatively large amounts of fat are accumulated.

The fat free mass in a full term infant is negligible and fat mass comprise 14% that is minimum proportion of the body weight. Total body water is 70 to 72%; this restricts body movements of the fetus. In preterm and the Low Birth Weight (LBW) fetus, the composition is different affecting the post-natal developments. The preterm babies, body fat is low, the subcutaneous fat is negligible this make the fetus look wrinkled and scrawny. Poor subcutaneous fat leads to intolerance to atmospheric temperature. On the other hand, the LBW babies have low deposit of nitrogen and fat and relatively higher proportion of body water.

CHECK YOUR PROGRESS - 1

Fill in the blanks

1. The __________, __________, ___________, and ________ contents of the body increase with age during early life
2. Moulton in1923 introduced a concept of "______________".
3. Infants and young children have higher proportion of ______________________ than intra cellular water (ICW)
4. After puberty, the fat percentage generally stays stable in ________, whereas in ________ there tends to be a slight decline making boys appear more masculine.
5. The ________________ increase linearly and forms 87% of total body mass by 10th year
6. Calcium content is approximately __________ body weight, no difference due to gender.
7. Normal term neonates generally lose _________of birth weight in the days soon after delivery but regain their birth weight within 2 wk.
8. After 30 years, _______________ progressively decreases without any changes in body weight.
9. Bone mass continues to accrue at higher proportion till age 30 years in both males and females, and then with advancing age bone mineral content decrease potentially resulting in ________________.
10. Weight gain in healthy young women during pregnancy is estimated to be approximately ___________ at term.
11. Development in the fetus begins from the time of fertilization causing a series of developments including formation of a cellular mass called ____________

2.6. LACTATION

Lactation is only one phase of a woman´s reproductive cycle, together with pre-pregnancy, pregnancy, and post-weaning. During pregnancy and lactation, a series of metabolic changes assure the growth of the fetus, maternal health and postpartum breast-milk production. Mean weight, height and BMI at day 15 and at months 3, 6, and 12 of follow-up. Weight loss, FM loss and decreased BMI were statistically significant from 3 months onwards postpartum. An approximate fat loss of 26.3 to 32.9 % in the first 6 months postpartum is observed; where in maximum loss i.e., up to 28.0% occurs in 1 to 4 months, providing 137 kcal/d. FM loss could be explained by the increase in resting energetic expenditure in well-nourished lactating women.

In healthy, well-nourished women with a mean age of 21 and 38 years who breastfed for at least 6 months, it has been shown that maintenance of LBM during lactation is possible with an adequate protein intake, since protein stores during pregnancy and their subsequent mobilization would partially meet the increased needs for maternal milk-production. Blood volume expansion noted in pregnancy is more or less sustained or even slightly increased in early lactation. Increased tissue hydration during pregnancy, due primarily to an increase in extracellular fluid, can persist into lactation in humans. Also a small increase in hydration of fat-free mass (FFM) in lactating women compared with non-lactating women at 15 days postpartum occurs.

2.7. FACTORS AFFECTING BODY COMPOSITION

Under this the most important influencing factor is the weight change. Since the major components of body are body water, fat and body cell mass, any change in body weight would reflect an alteration in one or more of these components. The reasons for the body change may vary so also the composition for example, dehydration, malnutrition etc.

2.7.1. Obesity:

Increase in body weight more than what is desirable is more often involve fat mass. Women and men are considered obese if they possess greater than 32 ± 2% body fat, respectively. However, in adults gain in weight indicates an increase in both absolute and relative amounts of body fat, but always does include fat mass alone. The extra weight may also comprise of water, body cell mass and cell solids.

Increase in body weight, with the major component being fat mass but a relative amount of total body water and body cell mass also increase. The increase in cell mass comprised in the connective tissues, vascular system, since regardless of the type of tissue expanded, vascular system should form in order to provide nutrition, oxygen and other exchange accommodated through blood circulation. Water also is increased in terms of expansion of blood volume and the moisture associated with increased cell mass. However, when one individual has put on weight, the proportion of change in the components suggests the function of body metabolic state. Effect of gender is very obvious, since the percent fat mass accumulated is markedly higher in females as compared to male counterparts. Further, the composition differs in individuals engaged in regular exercise.

In sports personnel and the exercising people, the FFM predominates; therefore, one can predict the proportions only if the detail of the life style is assessed or is actually determined using instruments. Weight Loss Reduction in body weight is the first manifestation of lack of food or starvation. Loss of body weight during energy restriction involves loss of variable proportions of body fat and other tissue materials, including proteins and minerals along with changes in extracellular and intracellular fluid compartments in the body. Semi starvation in human adults has exhibited a mean loss of 24% of initial body weight in 24 weeks this was accompanied with a relatively more body hydration. The plasma volume reduced in absolute terms from 5.8 to 5.3L around 23 weeks of semi starvation. The plasma volume increased by approximately 9% while the ICF decreased. This caused a mean increase in plasma volume per kg body weight by 40%, and the total blood volume increased by 19%. The semi starvation seems to be associated with a large and dramatic increase in relative hydration of the body. The body fat is altered by semi starvation, on a 24-day semi starvation, a mean reduction in body fat reported was approximately 8.5 %, an initial fat at 14% reduced to 5.5%. An adult body has 20 – 25 kg of muscle mass and provides enormous stores of energy, with prolonged starvation 2/3rd of muscle mass is utilized for energy purpose thereby creates a total disturbances of water balance

2.7.2. Physical Activity

The body composition of any two individuals with different activity profile but similar height and body weight, vary enormously. The physically active always have a higher body density indicating a greater proportion of lean body mass. The total body fat is reduced markedly with exercise with a concurrent increase in muscle mass and Lean mass develop. These changes appear to be more prominent during training period and become stable thereafter. However, once the exercise is interrupted changes occur in the opposite direction. Studies have demonstrated that the changes have a clear, dose-response relationship between the amount of weekly exercise and the amount of weight change in overweight individuals. Both male and females exhibit similar response to exercise.

2.8. NUTRITIONAL DISORDERS AND EFFECTS ON BODY COMPOSITION

Malnutrition resulted in a loss of body cell mass, accompanied by an expansion of the extracellular mass. In the patients with clinically obvious malnutrition, the size of the body cell mass was reduced to 60 per cent normal, while the extracellular mass was 24 per cent more than normal.

2.8.1. Body compositional changes in protein energy malnutrition

With regard to body composition it is known that total body water (TBW) is increased in malnourished children, and that the extracellular water (ECW) is also increased. Body water composition in the various manifestations of protein-calorie malnutrition an increase of TBW as a percentage of body weight was found in kwashiorkor, marasmus and children who were underweight for age but asymptomatic. The increase of TBW appears to correlate well with the degree of weight deficit, being highest in the marasmus cases. The presence of oedema appeared to bear no relation to the TBW. ECW was also increased in protein-calorie malnutrition and bore a close relation to the weight deficit. However, in edematous cases ECW was still further expanded. Children with protein-calorie malnutrition thus have an abnormal or immature body composition for their age in addition to their growth failure.

2.8.2. Body compositional changes in cancer

Cancer patients experience a significant depletion of lean body mass, fat-free mass, and skeletal muscle, accompanied by body fat mass, while undergoing (chemo)radiotherapy. This can be demonstrated either by triceps skinfold thickness, bioelectrical impedance analysis, dual-energy x-ray absorptiometry, or computed tomography. This loss has a remarkable impact on their survival, on their quality of life, and on the risk for post-operative complications and may result in a reduced response to cancer treatment.

2.8.3. Body compositional changes in Renal Failure

Body composition is frequently altered among patients with chronic kidney disorders, with obesity and muscle wasting common and sometimes occurring simultaneously. BMI does not accurately reflect overall adiposity and does not distinguish visceral fat, which is associated with adverse outcomes, from subcutaneous fat, which may be protective against wasting and catabolism in the setting of End-Stage Renal Disease, particularly when intercurrent illnesses occur. Exercise and anabolic steroids have been shown to have potentially beneficial effects on body composition and to positively impact physical performance.

2.8.4. Body compositional changes in thyroid related disorders

Hyperthyroidism is primarily accompanied by quantitative as well as qualitative changes in the lean body while considerable fat increase is the most important feature of hypothyroidism. Severity of body composition derangement cannot be predicted from the degree of thyroid dysfunction.

CHECK YOUR PROGRESS - 2

Fill in the blanks

1. During pregnancy and lactation, a series of metabolic changes assure the growth of the __________, _________________ and postpartum breast-milk production.
2. Women and men are considered obese if they possess greater than _________ body fat,
3. ___________ resulted in a loss of body cell mass, accompanied by an expansion of the extracellular mass.

4. With regard to body composition it is known that ______________ is increased in malnourished children,.

2.9. SUMMARY

Changes in body composition are synonym with growth and development in humans starting from conception till the older age. The major components of the body that is the body water, fat mass, Fat free Mass and bone mineral constantly change in both the absolute quantities and their relative quantity in human body with age and gender. The physiological state and pathological conditions also affect body composition.

2.10. GLOSSARY

Hypertrophic - increase in size of a tissue or a cell.

Hyperplasia - increase in number of cells in a tissue.

Accretion - deposition/ accumulation.

Quadrupling - increase by four times the volume

2.11. FURTHER SUGGESTED READING

1. Davis P.S.W. & Cole T.L. (1995) Body Composition Techniques in Health and Disease, Cambridge University Press

2. Lohman, T, Wang Z & Going, S.B. (2005) Human Body Composition, Human Kinetics

3. Lusuki H.C. (2017) Body Composition: Health and Performance in Exercise and Sport, CRC Press

2.12. ANSWERS TO CHECK YOUR PROGRESS - 1

Fill in the blanks

1. minerals, protein, water, and lipid

2. chemical maturity.

3. Extra cellular water (ECW)

4. girls, whereas in boys

5. lean body mass (LBM)
6. 8g/kilogram
7. 5 to 8%
8. fat-free mass (FFM)
9. Osteoporosis.
10. 12.5 kg.
11. ‘blastocyst’

2.13. ANSWERS FOR CHECK YOUR PROGRESS -2

Fill in the blanks

1. fetus, maternal health.
2. 32 ± 2% body fat,
3. Malnutrition
4. total body water (TBW)

Unit 3: Energy requirement

Unit 3: Energy requirement

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3.1. OBJECTIVES

After reading this chapter you will be able to:

- Understand about source of energy and the process of energy transfer
- Understand thermogenesis and its physiological importance
- Discuss the methods to measure energy expenditure
- Explain Basal Metabolism and factors influencing Basal Metabolic Rate

3.2. INTRODUCTION

Energy is the driving force for the universe; it is generally defined as the capacity to do work. Energy is required not only to perform voluntary activities but is crucial for the cellular activities to continue uninterrupted. Energy metabolism is therefore defined as the entirety of an organism’s chemical processes that includes complex metabolic reactions, principally concerned with how macromolecules such as fats, proteins, and carbohydrate break down to provide usable energy for growth, repair, and physical activity.

3.3. BASIC PRINCIPLES

Energy in any system exhibits its quantitative property and the status. There are many different forms of energy; one form of energy gets transferred to another form following certain laws of thermodynamics. Understanding about the basic laws of energy is important in order to appreciate energy metabolism and associated factors. There are three laws of thermodynamics. The first law is about the conservation of energy, according to this the total amount of energy in the universe is constant, and that the energy ends either in the original form or in a different from. This has wide application in physical and biophysical systems, and its end product of energy metabolism. The most important property of energy is that it cannot be created or destroyed. Energy exists in universe in different forms such as electrical energy; mechanical energy; thermal energy; and chemical energy. The ultimate source of energy is sun, called reservoir of nuclear energy. Humans and animals get energy from food. The food energy, especially from plant source that is carbohydrates is formed from carbon dioxide and water in presence of solar energy by a process called photosynthesis. When carbohydrate from plants is metabolized, releases in turn carbon dioxide, water and energy, where energy is used for physiological functions. This entire process of change in the form of energy is a natural phenomenon explaining the unique character of energy, referred to 'energy cycle'. In a physiological system, energy occurs in two forms, that is, Free energy and Potential energy.

Free energy: It is an unbound energy freely available and in motion. In a system this energy is involved at any given moment in performance of tasks.

Potential energy: This is the stored and bound form of energy as in food energy. This occurs in chemical compounds bound in the form of chemical bondages. The chemical bond that holds elements of compounds together consists of energy, the covalent bonds that holds C-C atoms; hydrogen bonds are weak bonds than the covalent bonds but they are highly significant because they occur in abundance. The phosphate bonds are unique because it stores energy in cells. This energy is available for conversion into free energy whenever required.

In physiological system, energy is changed from one form into other till the work is done, and large quantity of heat is liberated. During the course free energy is used and so gets reduced first then the potential energy is mobilized and secondarily diminished. In human body, the food energy is converted into chemical energy and stored, as presented below

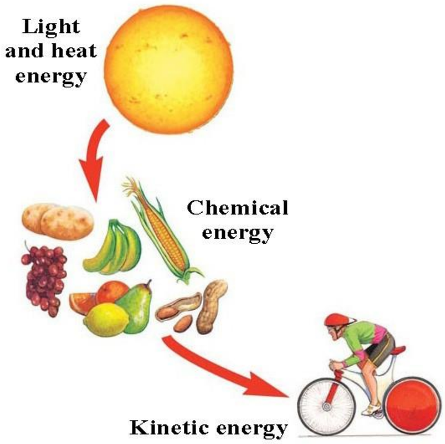

Figure 1: Explicit of Energy

Source: https://www.toppr.com/ask/content/story/amp/energy-transformation-68509/

Currency of energy: Adenosine Tri Phosphate...... ATP

Unit of measure:

Kilo calorie (Kcal): amount of energy required to raise the temperature of 1000ml water by one degree Celsius, i.e., from 15 to 16 °C.

Joule: is a measure of energy in terms of mechanical work. It is derived unit of energy in the International System of Units. It is equal to the energy expended to move a mass of one kg to a distance of one meter using one Newton force.

1 Joule = 4.185 Kcals

1 Mega joules = 239 Kcals

Newton force: force needed to accelerate one kg mass by one meter/sec.

3.4. ENERGY REQUIREMENTS

The energy needs or energy requirements of the body to maintain energy balance must be equal to total daily energy expenditure. Total daily energy expenditure is the sum of the individual components of energy expenditure and represents the total energy requirements of an individual that are required to maintain energy balance. The doubly labelled water (DLW) technique has provided a truly noninvasive means to measure accurately total daily energy expenditure, and thus energy needs, in free living humans. Before DLW, energy requirements were usually assessed by measurement or prediction of Resting Metabolic rate (RMR), the largest component of energy requirements. However, since the relationship between RMR and total energy expenditure is highly variable because of differences in physical activity, the estimation of energy needs from knowledge of RMR is not that accurate and requires a crude estimate of physical activity level. Nevertheless, reasonable estimates can be made to estimate daily energy budgets for individuals.

Following the validation of DLW in humans, this technique has been applied to many different populations. Total energy expenditure is often compared across groups or individuals using the ratio of one's total energy expenditure to RMR, or physical activity level (PAL). Thus, for example, if the total energy expenditure was 12.6 MJ/day and the RMR was 6.3 MJ/day, the PAL factor would be 2.0. This value indicates that total energy expenditure is twice the RMR. The PAL factor has been assessed in a variety of types of individual. A low PAL indicates a sedentary lifestyle, whereas a high PAL represents a highly active lifestyle.

Factors such as body weight, FFM, and RMR account for 40–60% of the variation in total energy expenditure. Total energy expenditure is similar between lean and obese individuals after taking into account differences in FFM. Thus, fatness has small, but important, additional effects on total energy expenditure, partly through RMR, but also by increasing the energetic cost of any physical activity. With regard to age, some studies suggest that only a limited change in total energy expenditure (relative to RMR) occurs from childhood to adulthood, but that a decline occurs in the elderly. Recent data also suggest a gender-related difference in total energy expenditure, in addition to that previously described for RMR. In a meta-analysis that examined data from a variety of published studies, absolute total energy expenditure was significantly higher in males than in females by 3.1 MJ/day (10.2 ± 2.1 MJ/day in females, 13.3 ± 3.1 MJ/day in males), and nonrusting energy expenditure remained higher in men by 1.1 MJ/day

Table 1: Typical Daily Energy Nudges for a sedentary and a physical active individual of identical occupation, body weight, and resting metabolic rate of 6.0 mJ/day (4.2 kJ/min)

		Minutes per day		Mj per day	
Activity	Activity Index	Sedentary	Active	Sedentary	Active
Sleep	1.0	480	480	2.0	2.0
Daily needs	1.06	120	120	5.3	5.3
Occupational	1.5	480	480	3.0	3.0
Passive recreation	2.0	360	360	3.0	2.5
Exercise	12.0	0	0	0	3.0
Total		1440	1440	8.6	11.1
				PAL=1.4	PAL=1.8

Thus, the sedentary individual would need to perform 60 min of vigorous activity each day at an intensity of 12.0 to increase the physical activity level (PAL) from a sedentary 1.4 to an active and healthy 1.8.

Individuals who have sedentary occupations and do not participate frequently in leisure pursuits that require physical activity probably have a PAL factor in the region of 1.4. Those who have occupations requiring light activity and participate in light physical activities in leisure time probably have a PAL around 1.6 (this is a typical value for sedentary people living in an urban environment). Individuals who have physically active occupations and lifestyles probably have a PAL greater than 1.75. It has been suggested that the optimal PAL that protects against the development of obesity is around 1.8 or higher. Increasing one's physical activity index from 1.6 to 1.8 requires 30 min of daily vigorous activity, or 60 min of light activity.

CHECK YOUR PROGRESS - 1

Fill in the blanks

1. _________________ is chemical processes that include complex metabolic reactions.
2. Energy exists in universe in different forms such as _______ energy; __________ energy; ________ energy; and __________ energy.
3. The food energy is formed from carbon dioxide and water in presence of solar energy by a process called _____________.
4. ___________ is an unbound energy freely available and in motion.
5. ______________ is the stored and bound form of energy as in food energy
6. _______________ is the amount of energy required to raise the temperature of 1000ml water by one degree Celsius.

Answer the Following

1. How many laws of thermodynamics are there?
2. What is the currency of energy?
3. Define Total daily energy expenditure

3.5. DETERMINATION OF FOOD ENERGY

The principle of measuring energy from food is combustion reactions which are exothermic. Bomb calorimeter is the instrument that is a type of constant-volume calorimeter used in measuring the heat of combustion of a reaction. Electrical energy is used to ignite the fuel; as the fuel is burning, it will heat up the surrounding air, which expands and escapes through a tube that leads the air out of the calorimeter. When the air is escaping through the copper tube it will also heat up the water outside the tube. There is no heat exchange between the calorimeter and surroundings. The temperature of the water allows for calculating calorie content of the fuel. Basically, a bomb calorimeter consists of a small cup to contain the sample, oxygen, a stainless steel bomb, water, a stirrer, a thermometer, the dewar (to prevent heat flow from the calorimeter to the surroundings) and ignition circuit connected to the bomb.

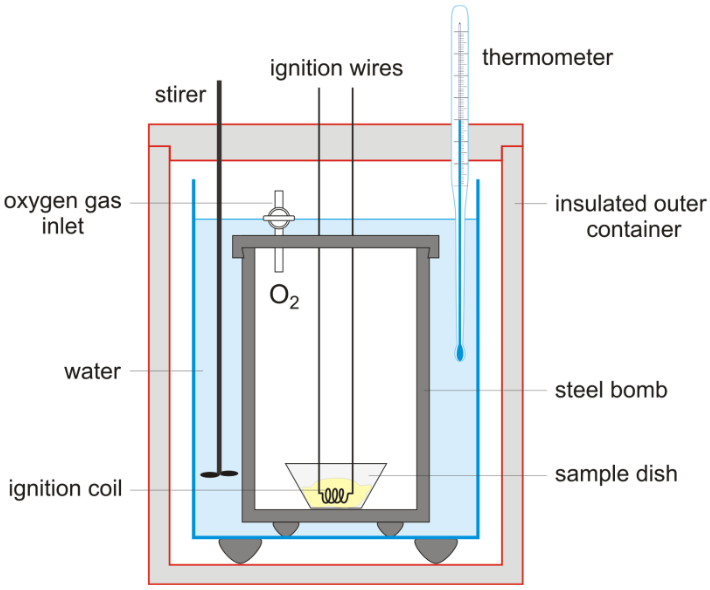

Figure 2: Bomb Calorimeter

Source: https://glossary.periodni.com/glossary.php?en=bomb+calorimeter

Calculation of the food energy:

Total water in the instrument - 1000 ml

Initial temperature - 24°C

Final temperature - 28°C

Weight of sample ignited - 2 gms

Energy value — 2000 X 4°C = 4000 cals or 4 Kcals

3.6. MEASURMENT OF ENERGY EXPENDITURE

Human energy requirements are computed on the basis of total energy expenditure. There are different methods developed, broadly they are classified under calorimetric and non-calorimetric methods

Calorimetric methods:	Non calorimetric methods
Direct Calorimetry	Measurement of heart rate

In Direct Calorimetry	Use of doubly labelled water Time motion analysis Prediction equation

3.6.1 CALORIMETRIC METHODS

Direct calorimetric method: This method is based on the principle that energy utilized is ultimately degraded into heat, and that the amount of heat output from the body, therefore, provides a direct measure of metabolic rate.

Atwater Rosa Respiro-Meter: This measures energy expenditure directly by measuring heat dissipated from the body based on isothermal principles. The instrument is adiabatic chamber of dimension just sufficient for a person to stay comfortably. The room is constructed with a system containing thermally-insulated walls to prevent significant heat exchange. The room has two openings one to provide food and water while the other opening is used to eliminate material. The room is fitted with pipelines for circulating water of known temperature in order to determine heat produced. The room is ventilated by a current of air, and the carbon di oxide and water given out is removed by soda lime and sulfuric acid respectively.

The figure gives the outline structure of the chamber, the subject undergoing the test is provided with, a chair and a table.

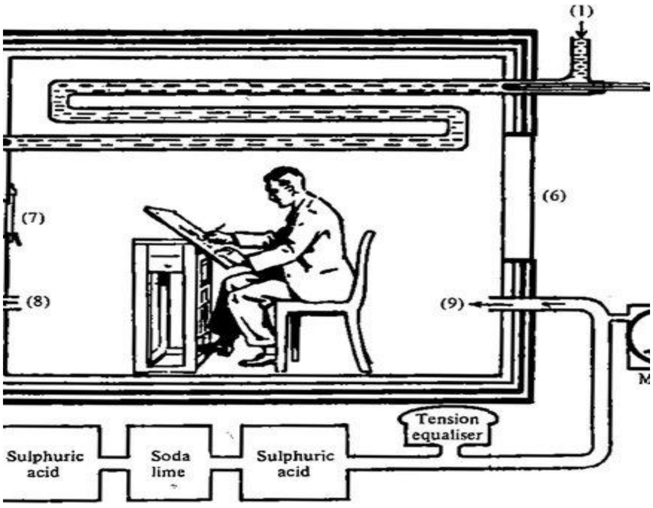

Figure 3: Human Calorimeter

Source: https://www.researchgate.net/figure/Atwater-and-Benedicts-calorimeter-for-man-from-Bell-et-al-1965-Numbers-1-5-represent_fig2_318718293

Heat production per day is derived from the following observations obtained from the calorimeter:

Volume of water circulated through the tube: 1860 L

Average rise in temperature: 0.515 °C

Water vapor produced: 1060 gms

Heat of vaporization of water: 0.586 Kcals/g

Therefore, heat production = (1860 x 0.515) + (1060 x 0.5860) = 1580 Kcals / day.

Indirect Calorimetric Methods: The indirect calorimeters work on the principle that oxygen utilized and the carbon dioxide released is proportional to the amount of energy liberated. Hence measuring oxygen consumption and carbon di oxide given out either alone or both indicate energy utilized.

Benedict-Roth spirometer: It is a closed circuit breathing apparatus which is filled with oxygen and has a capacity of 6 litres. Oxygen is contained in a metal drum which floats on a water seal. The subject whose oxygen intake has to measured breaths in oxygen through inspiratory valve and breaths out into the drum through expiratory valve and a soda lime canister, so that the carbon dioxide produced is absorbed. As the oxygen is used up, the drum sinks and its movement is recorded on a moving paper, mounted on a kymograph, from this the rate of oxygen consumed is read. The apparatus is accurate and simple to use, but the limitation of this apparatus is that, the subjects has to be in a supine position and resting. This method is used to measure basal metabolic rate.

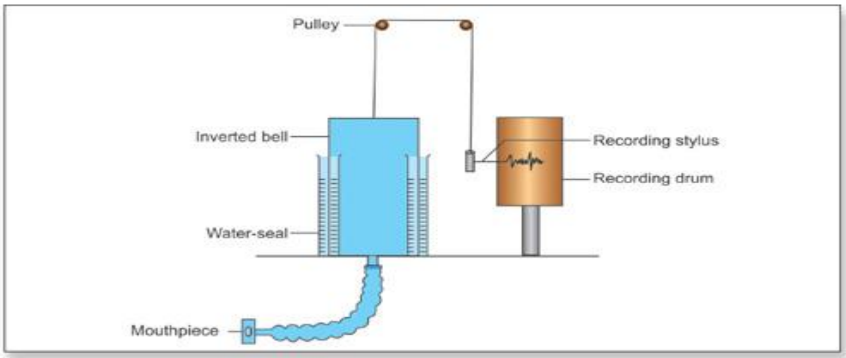

Figure 4: Benedict-Roth spirometer

Source: https://www.jaypeedigital.com/book/9789352500161/chapter/ch4

Douglas bag: This is a canvas or plastic bag with varying capacity, usually 100 to 300-liter capacity. The subject breathes through a mouth piece which contains inspiratory and expiratory valves. Room air is breathed in but the breathing out is into The expired air is collected in Douglas bag. The bag is then emptied through a gas meter and a sample of the expired is taken for analysis of O2 and CO2 from which the rates of oxygen used and CO2 production can be calculated. The advantage of using this is, the bag is light weight and the subject can wear it on the back and perform the tasks. A number of such light weight apparatus have been developed for use. The two methods mentioned here and other based on indirect calorimeters, Respiratory Quotient (RQ) is calculated and the energy used is determined. RQ is a unit less number used in calculations of basal metabolic rate (BMR) and energy expended while performing a task. It provides information about energy expenditure and substrate oxidation.

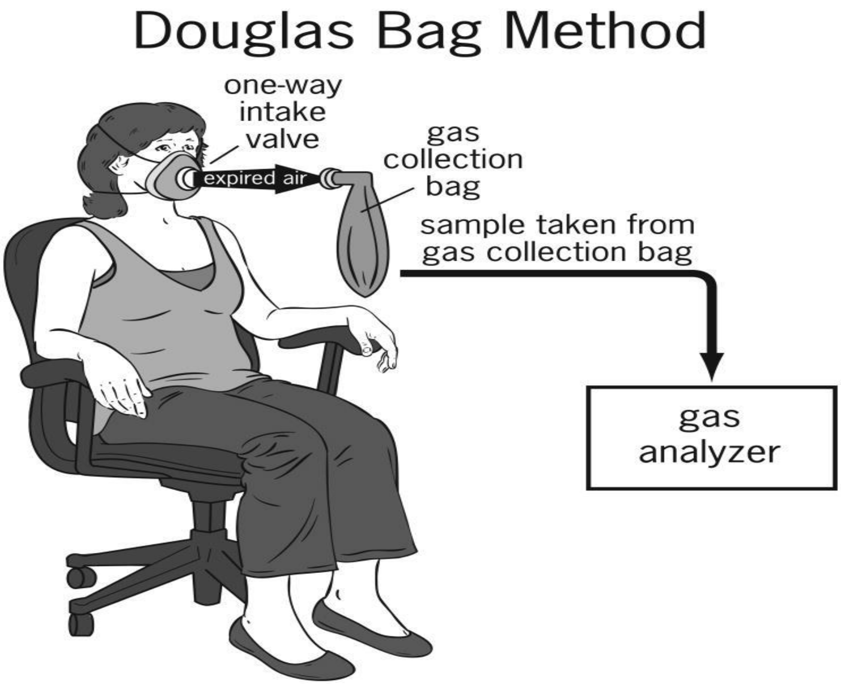

Figure: Execution of Douglas Bag

Source: https://europepmc.org/article/MED/21775638

$$RQ = \frac{CO2\ Expired}{O2\ Consumed}$$

Calorie Equivalent: 4.751 = 1L O2

6.253 = 1L CO2

Substrate Oxidation:

Carbohydrates- $RQ = \frac{6\ CO_2}{6\ O_2} = 1.0$

Fats - $RQ = \frac{114\ CO_2}{163\ O_2} = 0.7$

Proteins - $RQ = \frac{63\ CO_2}{77\ O_2} = 0.818$

3.6.2 NON CALORIE METERIC METHODS

Double labelled water: Lifson in 1949, demonstrated that total daily CO2 production could be measured from differential elimination of water labelled with stable isotopes of hydrogen and oxygen. When water with doubly labelled is administered, 2 H would be eliminated as water ($2H_2O$), corresponding to water output, whereas the oxygen isotope would be eliminated as water and as expired air carbon dioxide. By measuring the difference between the elimination rates of labelled oxygen and hydrogen, the carbon dioxide production rate can be calculated. The carbon dioxide production rate is converted into energy expenditure by knowing the respiratory quotient of the food ingested during the observation period. There are certain basic assumptions; that is the total body water pool (N) is a homogeneous compartment that remains constant during observation. And that the tracer isotopes of hydrogen and oxygen exit the body only as water and carbon dioxide and that the dietary and atmospheric sources of water and oxygen do not change the background levels of isotopes.

The simple equation to calculate the rate of carbon dioxide production was

$$R\ CO2 = (N/2)\ (k18 - k2)$$

N= total body water pool; k18 = rate of disappearance of ^{18}O and k2 is the rate of 2 H disappearance.

However, the differentiation in the exit routes for both oxygen and hydrogen occurs, that is the vaporization of moisture and total water loss, as well as the CO2 production. Therefore, the equation is substituted as follows:

$$rCO2 = (N/2\ f3)\ (k18 – k2) – rH2\ OG\ (f2 –f1)/2\ f3$$

Where fell is the deuterium fractionation factor between water and water vapor, f2 is the ^{18}O fractionation factor between water and water vapor, f3 is the 18O fractionation between water and carbon dioxide and rH2 OG is the rate of water loss via isotopically fractionated routes.

The study protocol includes determination baseline values for the hydrogen and oxygen isotopes. The subject is then given a single oral bolus dose of heavy water (2 H218O). Generally, adult's dose consists of 0.15 g H2 18O/kg body weight and 0.06 g 2 H2 O/kg body weight. The post dose analysis begins after 24hours; urine or saliva sample is collected within the first six hours to determine total body water (TBW). The following morning, 24 hours later, the urine voided marks the beginning of the measured energy expenditure period. The study period ends after 7 to 21 days when a urine sample is collected to close the energy expenditure period. The optimal metabolic period for observation in a doubly labelled period is predicted to be between 0.5 and 3 biological half-lives of water. Between the initial and final samples, the subject is free to engage in normal activities. A second dose of doubly labelled water is administered at the end of the study period and urine or saliva collected after 3 to 6 hours for a second determination of TBW. This second determination of TBW is used to measure any changes in the total body water pool during the observation period. The daily food intake is noted during the observation period and the RQ calculated based on the daily intake. Generally, the diet remains the same during the observation period for the most accurate results. The rate of carbon dioxide production is used in conjunction with the Weir equation to estimate energy expenditure Q over the period in which body water samples is collected.

The Weir equation (Equation 3) uses measured values for the respiratory quotient (RQ) and the urinary nitrogen production rate (UN):

$$Q = 3.941\ (rCO2 / RQ) + 1.106\ rCO2 - 2.17\ UN$$

Time and motion analysis: There are standard analytical procedures to determine time and energy spent in activities over a period of time. Certain specific procedures are:

- Recording techniques
- Diary Techniques

Self-reporting techniques: In all these, details of the movements made during performing a task or time spent in various activities during the 24 hours in a day is obtained. It is considered ideal to collect data for one to two weeks in order to arrive at usual activity pattern. All complex activities are broken down to work elements. The work elements are grouped further into like activities of relatively constant energy cost, of characteristic motion and composition for an individual under specific conditions. Work elements are easily definable activities such as washing dishes, digging, sweeping, swimming, walking and strolling etc. There is vast data available to indicate the energy equivalent for different activities per unit time, and referred as PAR (physical Activity Rate), this is the ratio of the energy cost of an individual activity per minute to the cost of the basal metabolic rate (BMR) per minute. PAR= Energy cost of an activity per minute ÷ Energy cost of basal metabolism per minute. WHO has presented a list of activities and their PAR.

Prediction Equations: It is very well understood that energy requirement and BMR are related; thereby BMR is an important factor in computing energy requirements/ energy expenditure. BMR of an individual is proportional to the body weight and surface area. Based on this concept several equations have been developed and validated for their efficacy against standard techniques such as calorimetric determinations. If BMR has to be known, it is impossible to determine using standard measurement techniques because of high cost and non-availability of the equipment. Therefore, for practical purposes, prediction equations are useful in computing BMR and thereby arrive at the energy expenditure or energy requirements. The major problem in use of prediction equations is the racial variability, which is overcome by modification/development of the equations suitable for different populations. Some of the equations which are widely used are listed here. FAO/ WHO/ UNU and Schofield equations and Harris and Benedict equations.

3.7. THERMOGENESIS

The thermic effect of meal ingestion is primarily influenced by the quantity and macronutrient quality of the ingested calories. The thermic effect of food has also been termed meal-induced thermogenesis, or the specific dynamic action of food. The increase in metabolic rate that occurs after meal ingestion occurs over an extended period of at least 5 hours; the cumulative energy cost is equivalent to around 10% of the energy ingested. In other words, if one consumed a mixed meal of 2.1 MJ, the body would require 210.0 kJ to digest, process, and metabolize the contents of the meal. The thermic effect of feeding is higher for protein and carbohydrate than for fat. This is because, for fat, the process of energy storage is very efficient, whereas, for carbohydrate and protein, additional energy is required for metabolic conversion to the appropriate storage form (i.e., excess glucose converted to glycogen for storage, and excess amino acids from protein converted to fat for storage). In addition to the obligatory energetic cost of processing and storage of nutrients, a more variable facultative thermogenic component has been described. This component is mainly pertinent to carbohydrates, which through increased insulin secretion produce a diphasic activation of the sympathoadrenal system. The initial phase is an insulin-mediated increase in sympathetic activity, which produces a β-adrenoceptor mediated increase in energy expenditure. The second and later phase occurs when a counter-regulatory increase in plasma epinephrine is elicited by the falling blood glucose. This increase in epinephrine has a similar slight stimulatory effect on energy expenditure. As a result of the mediation by β-adrenoceptors the thermic effect of carbohydrate-rich meals can be slightly reduced by pharmacological β-adrenoceptor antagonists

CHECK YOUR PROGRESS - 2

Fill in the blanks

1. _______________ is the instrument that is a type of constant-volume calorimeter used in measuring the heat of combustion of a reaction.
2. ________________ requirements are computed on the basis of total energy expenditure.
3. _________________ method provides a direct measure of metabolic rate.
4. __________________________ measures energy expenditure directly by measuring heat dissipated from the body based on isothermal principles.

5. The ________________________ work on the principle that oxygen utilized and the carbon dioxide released is proportional to the amount of energy liberated.
6. ________________________ is a unit less number used in calculations of basal metabolic rate (BMR) and energy expended.

Answer the Following

1. Mention the techniques used to determine Time and motion analysis
2. What is Thermogenesis?

3.8. SUMMARY

Energy is the driving force and defined as the capacity to do work. Energy is required not only to perform voluntary activities but is crucial for the cellular activities to continue uninterrupted. The most important property of energy is that it cannot be created or destroyed. Energy exists in universe in different forms such as electrical energy; mechanical energy; thermal energy; and chemical energy. The ultimate source of energy is sun, called reservoir of nuclear energy 'Energy cycle', is the unique process of energy transfer starting from nuclear energy into food energy into physiological energy and ending into CO2 + H2 O + Heat that is liberated into the atmosphere. In a physiological system, energy occurs in two forms, that is, Free energy and Potential energy. Energy nutrients: carbohydrates, proteins and fats. 'Heat of combustion', 'Atwater factor' or 'physiological energy value'- indicative of energy value and available energy.

3.9. GLOSSARY

Newton force - force needed to accelerate one kg mass by one meter/sec.

Heat of vaporization - amount of heat that is dissipated during insensible loss of moisture

Thermogenesis - production of heat

3.10. FURTHER SUGGESTED READING

1. Barbara A. Bowmaw and Robert M. Russell, Nutrition, Eighth Edition, ILSI press, Washington, DC, 2001.
2. Corinne H. Robinson and Marilyn R. Lawler, Normal and Therapeutic Nutrition, sixteenth edition, Maemillaw publishing, Co., INC New York and collier Maemillaw publisher London, 1982.
3. Judith E. Brown, Nutrition Now, 3rd edition. Wads worth, Thomas learning, 10 Davis drive Belmont C A 94002-3098 USA, 2002
4. Sir Stanley Davidson, R Passmore, Human Nutrition and Dietetics. The English language book society and Churchill hivingstome 1971.
5. Shubhangin A Joshi, Nutrition and Dietetics, Tata McGraw-Hill Publishing Company Limited, New Delhi, 2002.

3.11. ANSWERS TO CHECK YOUR PROGRESS - 1

Fill in the blanks

1. Energy metabolism.
2. Electrical energy; mechanical energy; thermal energy; and chemical energy.
3. Photosynthesis.
4. Free energy
5. Potential energy
6. Kilo calorie (Kcal).

Answer the Following

1. There are three laws of thermodynamics
2. Currency of energy is Adenosine Tri Phosphate (ATP)
3. Total daily energy expenditure is the sum of the individual components of energy expenditure and represents the total energy requirements of an individual that are required to maintain energy balance.

3.12ANSWERS FOR CHECK YOUR PROGRESS -2

Fill in the blanks

1. Bomb calorimeter
2. Human energy
3. Direct calorimetric method.
4. Atwater Rosa Respiro-Meter
5. Indirect calorimeters
6. Respiratory Quotient.

Answer the Following

1. The techniques used to determine Time and motion analysis are Recording techniques and Diary Techniques

2. The thermic effect of food is termed as meal-induced thermogenesis or the specific dynamic action of food.

Unit 4: Energy metabolism and physical performance

Unit 4: Energy metabolism and physical performance

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4.1. OBJECTIVES

After reading this chapter you will be able to:

- Understand about energy metabolism and physical performance
- Understand fuels for energy
- Anaerobic and aerobic exercise and their role

4.2. INTRODUCTION

Physical activity in the form of exercise requires the metabolism of bodily fuel reserves to provide energy for muscle contraction. Under normal circumstances, very little protein is metabolized to provide the energy for muscle contraction. At rest and at low exercise intensities, the metabolism of fat provides a considerable proportion of the energy for resting metabolic processes and muscle contraction. However, at exercise intensities at which athletes train and compete, the metabolism of bodily carbohydrate reserves (e.g., blood glucose and liver and muscle glycogen) provides the predominant fuel for muscle contraction. Furthermore, when these substrates reach critically low amounts or are decreased by some amount, fatigue occurs. There is a significant body of literature examining the effects of ingestion of various types of sugars at various times during exercise and during recovery from exercise on carbohydrate fuel reserves and on physical performance.

The continual supply of ATP to the fundamental cellular processes that underpin skeletal muscle contraction during exercise is essential for sports performance in events lasting seconds to several hours. Because the muscle stores of ATP are small, metabolic pathways must be activated to maintain the required rates of ATP resynthesize. The relative contribution of these metabolic pathways is primarily determined by the intensity and duration of exercise.

4.3. PHYSIOLOGY OF EXERCISE

Exercise poses a substantial increase in demand for the body, at rest, nervous system maintains a parasympathetic tone, which affects the respiratory rate, cardiac output, and various metabolic processes. Exercise stimulates the sympathetic nervous system and will induce an integrated response from the body; This response works to maintain an appropriate level of homeostasis for the increased demand in physical, metabolic, respiratory, and cardiovascular efforts.

Organ Systems Involved

Physical activity in the form of exercise induces a coordinated response of multiple organ systems.

- **Musculoskeletal System-** Muscle contraction acts upon the skeleton and initiates movement. When a progressive force is applied to the muscles over time, they will adapt to the increasing load. The process of exercise, whether through long-distance running or powerlifting, places a burden of stress on muscle fibers and bones, which causes micro-tears and trauma. In response to this, cells are activated and mobilize to regenerate damaged muscle tissue. This process is made possible by the donation of a daughter nuclei from the satellite cells after multiplication and fusion. Bones will increase its mineral density over time to manage this increasing load.
- **Circulatory System-** The circulatory system plays a critical role in maintaining homeostasis during exercise. To accommodate the increased metabolic activity in skeletal muscle, the circulatory system must properly control the transport of oxygen and carbon dioxide, as well as help to buffer the pH level of active tissues. This action is accomplished by increasing cardiac output and modulating microvascular circulation. Also, the action of local vaso-mediators such as nitric oxide from endothelial cells helps to ensure adequate blood flow.
- **Respiratory System-** The respiratory system works in junction with the cardiovascular system. In response to the increased cardiac output, perfusion increases in the apex of each lung, increasing the available surface area for gas exchange. With more alveolar surface area available for gas exchange, and increased alveolar ventilation due to increased frequency and volume of respiration, blood gas and pH balance can be maintained.
- **Endocrine System-**Plasma levels of cortisol, epinephrine, norepinephrine, and dopamine increase with maximal exercise and return to baseline after rest. The increase in levels is consistent with the increase in the sympathetic nervous system activation of the body. Growth hormone is released by the pituitary

gland to enhance bone and tissue growth. Insulin sensitivity increases after long-term exercise. Testosterone levels also increase, leading to enhanced growth, libido, and mood

4.4. FUELS FOR EXERCISE

The human body uses carbohydrate, fat, and protein in food and from body stores for energy to fuel physical activity. In order to utilize these nutrients as fuel for the body, their energy must be transferred into the high energy molecule known as adenosine triphosphate (ATP). ATP is the body's immediate fuel source and can be generated either with aerobic metabolism in the presence of oxygen or anaerobic metabolism without the presence of oxygen. The type of metabolism that is predominately used during physical activity is determined by the availability of oxygen and how much carbohydrate, fat, and protein are used.

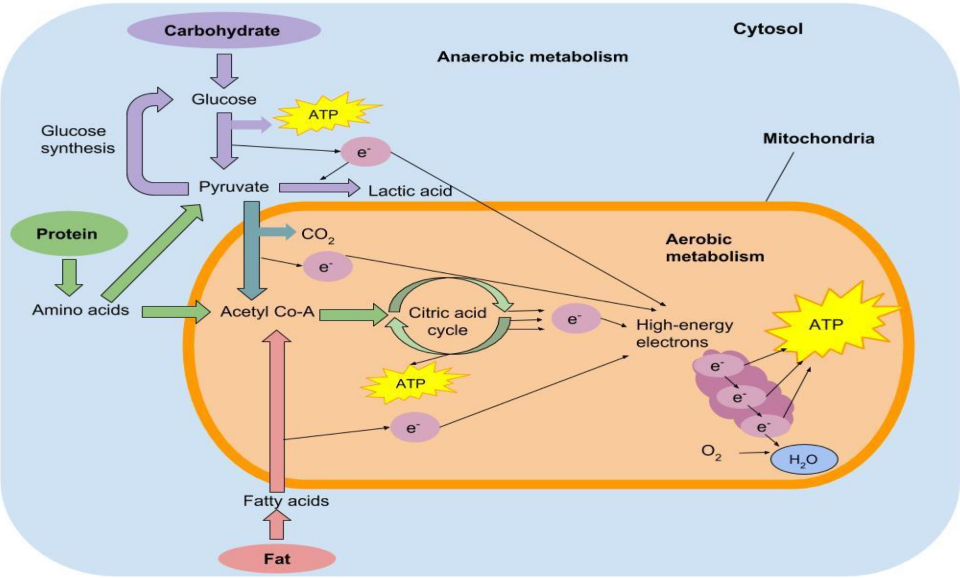

Figure 1: Anaerobic and aerobic metabolism.

Source: https://openoregon.pressbooks.pub/nutritionscience/chapter/10b-fuel-sources-exercise/

The fuel sources for anaerobic and aerobic metabolism will change depending on the amount of nutrients available and the type of metabolism.

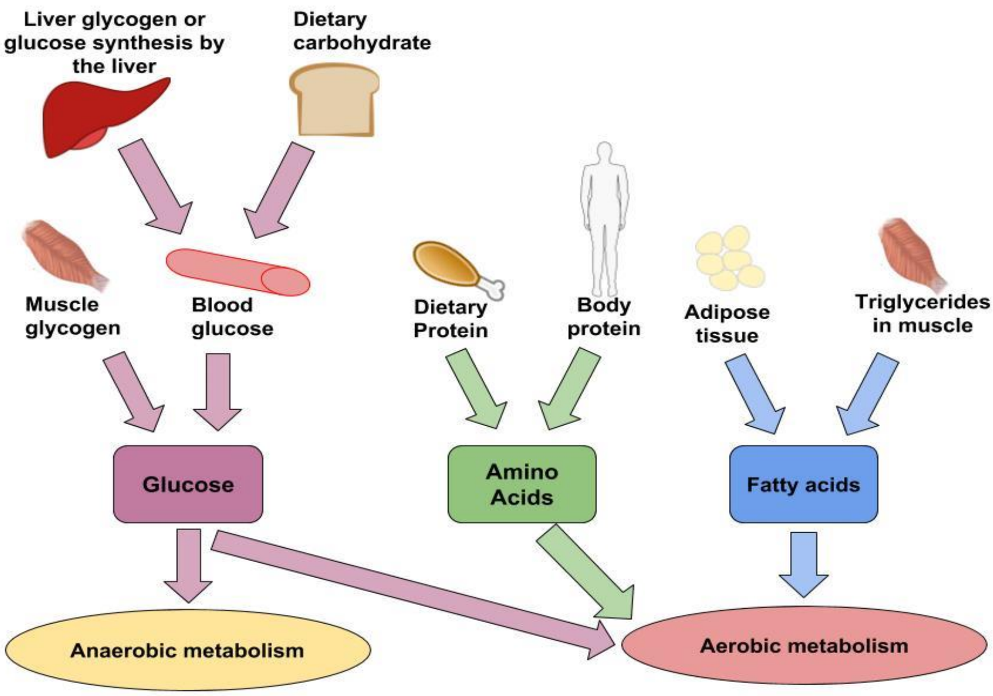

Figure 2: Fuel sources for anaerobic and aerobic metabolism

Source: https://openoregon.pressbooks.pub/nutritionscience/chapter/10b-fuel-sources-exercise/

Carbohydrates: Carbohydrates fuel your brain and muscles. Glucose may come from blood glucose (which is from dietary carbohydrates, liver glycogen, and glucose synthesis) or muscle glycogen. Glucose is the primary energy source for both anaerobic and aerobic metabolisms. Carbohydrates like brown rice, quinoa, whole-grain bread and pasta, sweet potatoes, fruits, and vegetables are better.

Fat: Fat is essential to a healthy diet. Fat provides energy and helps body absorb vitamins. Some vitamins (like A, D, E and K) actually need fat to properly benefit body. Unsaturated fats are healthy and good sources are avocado, olive and canola oils, flaxseed and nuts. Fatty acids are stored as triglycerides in muscles, but about 90 percent of stored energy is found in adipose tissue. As low- to moderate-intensity exercise continues using aerobic metabolism, fatty acids become the predominant fuel source for exercising muscles.

Protein: Protein is important because it provides the amino acids the body needs to build and repair muscle. Most research suggests very active people should eat 1.2 to 2 grams of protein per kilogram of body weight. Although protein is not considered a major energy source, small amounts of amino acids are used while resting or doing an activity. The amount of amino acids used for energy metabolism increases if the total energy intake from the diet does not meet nutrient needs or involved in long endurance exercise. When amino acids are broken down and the nitrogen-containing amine group is removed, the remaining carbon molecule can be broken down into ATP via aerobic metabolism, or it can be used to make glucose. When exercise continues for many hours, amino acid use will increase as an energy source and for glucose synthesis. Good sources of protein are poultry, fish, soybeans, legumes like beans, peanuts and chickpeas. Eggs, Greek yogurt, cheese and tofu are good sources, too.

CHECK YOUR PROGRESS - 1

Answer the Following

1. Mention the organ systems involved in Exercise?

2. Which are the fuels for Exercise?

3. What does exercise stimulate?

4.5. CONTROLLING THE RATE OF ENERGY PRODUCTION

Alterations in factors that control food intake and regulate energy metabolism are related to well-known pathological conditions such as obesity, type 2 diabetes and the metabolic syndrome, and some types of cancer. In addition, many effects and regulatory actions of well-known hormones such as insulin are still poorly understood. The consideration of adipose tissue as a dynamic and active tissue, for instance, raises several important issues regarding body weight and the control of food intake.

Energy metabolism is the general process by which living cells acquire and use the energy needed to stay alive, to grow, and to reproduce. The energy released while breaking the chemical bonds of nutrient molecules are captured for other uses by the cells. The coupling between the oxidation of nutrients and the synthesis of high-energy compounds, particularly ATP, which works as the main chemical energy carrier in all cells.

There are two mechanisms of ATP synthesis:

1. oxidative phosphorylation, the process by which ATP is synthesized from ADP and inorganic phosphate (Pi) that takes place in mitochondrion; and
2. substrate-level phosphorylation, in which ATP is synthesized through the transfer of high-energy phosphoryl groups from high-energy compounds to ADP. The latter occurs in both the mitochondrion, during the tricarboxylic acid (TCA) cycle, and in the cytoplasm, during glycolysis.

The transformation of the chemical energy of fuel molecules into useful energy is strictly regulated, and several factors control the use of glucose, fatty acids, and amino acids by the different cells. For instance, not all cells have the enzyme machinery and the proper cellular compartments to use all three fuel molecules. Red blood cells are devoid of mitochondria and are therefore unable to oxidize neither fatty acids nor amino acids, relying only on glucose for ATP synthesis. In addition, even in cells that can use all nutrients, the type of food substrate that is oxidized changes according to the physiological situation of the cell, such as the fed and fasting states. Different signals dictate how cells can adapt to each situation, such as hormones, which may exert powerful effects by switching key enzyme activities in a matter of seconds, or how they may modulate gene expression profile, changing the whole cell metabolic profile.

4.6. STORING ENERGY– HIGH ENERGY PHOSPHATES

The body is a complex organism, and as such, it takes energy to maintain proper functioning. Adenosine triphosphate (ATP) is the source of energy for use and storage at the cellular level. The structure of ATP is a nucleoside triphosphate, consisting of a nitrogenous base (adenine), a ribose sugar, and three serially bonded phosphate groups. ATP is commonly referred to as the "energy currency" of the cell, as it provides readily releasable energy in the bond between the second and third phosphate groups. In addition to providing energy, the breakdown of ATP through hydrolysis serves a broad range of cell functions, including signaling and DNA/RNA synthesis. ATP synthesis utilizes energy obtained from multiple catabolic mechanisms, including cellular respiration, beta-oxidation, and ketosis.

The majority of ATP synthesis occurs in cellular respiration within the mitochondrial matrix: generating approximately thirty-two ATP molecules per molecule of glucose that is oxidized. ATP is consumed for energy in processes including ion transport, muscle contraction, nerve impulse propagation, substrate phosphorylation, and chemical synthesis. These processes, as well as others, create a high demand for ATP. As a result, cells within the human body depend upon the hydrolysis of 100 to 150 moles of ATP per day to ensure proper functioning. In the forthcoming sections, ATP will undergo further evaluation of its role as a crucial molecule in the daily functioning of the cell. ATP is an excellent energy storage molecule to use as "currency" due to the phosphate groups that link through phosphodiester bonds. These bonds are high energy because of the associated electronegative charges exerting a repelling force between the phosphate groups. A significant quantity of energy remains stored within the phosphate-phosphate bonds.

4.7. BASICS OF ENERGY SYSTEMS

There are three energy systems: the immediate energy system, the glycolytic system, and the oxidative system. All three systems work simultaneously to a degree, but parts of the system will become predominant depending on what the needs of the body are.

- The Immediate Energy system, or ATP-PC, is the system the body uses to generate immediate energy. The energy source, phosphocreatine (PC), is stored within the tissues of the body. When exercise is done and energy is expended, PC is used to replenish ATP. Basically, the PC functions like a reserve to help rebuild ATP in an almost instantaneous manner.

- The glycolytic system copes with demands that require a relatively high energy output for a relatively short amount of time. The glycolytic system, sometimes called anaerobic glycolysis, is a series of ten enzyme-controlled reactions that utilize carbohydrates to produce ATP and pyruvate as end products. Glycolysis is the breakdown of glucose. The glucose enters the cell membrane to begin the process to produce a net of two ATP and two pyruvate molecules. The process is fast, there is generally plenty of glucose available and the reactions can occur anywhere within the cell's sarcoplasm.

- The oxidative system copes with lower output work for longer durations of time. The Aerobic System resides within a specific organelle of the body's cells. This specific organelle is the mitochondria – the "power house of the cell." The bulk of the ATP produced by the human body comes from the mitochondria. Therefore, the bulk of the ATP produced is via "aerobic" processes.

The first two energy systems are anaerobic, meaning they do not require oxygen. The aerobic energy system must have oxygen or the entire process will slow down and potentially stop completely. The oxygen needed by this system is provided by the cardiovascular and respiratory systems via blood flow to the tissues.

4.8. ENERGY EXPENDITURE AND FATIGUE

Fatigue is a state of physical and mental exhaustion; fatigue leads to overall decrease in productivity. Fatigue can be classified into two: mental fatigue and physical fatigue. Physical fatigue is the transient inability of muscles to maintain optimal physical performance, and is made more severe by intense physical exercise while mental fatigue is a transient decrease in maximal cognitive performance resulting from prolonged periods of cognitive activity. In view of the mental nature of fatigue, it is possible that fatigue may impair cognitive functions and influence health and safety adversely. The physiological conditions are crucial prerequisite in every ergonomics study and play a crucial role in enhancing productivity, safety, and wellbeing. Physiological thresholds for manual work leads fatigue which are showed by activity metabolic rate, heart rate, age and body mass index. There is significant effect on the mental fatigue on excessive physical output, thus energy expenditure.

4.9. ENERGY EXPENDITURE AT REST AND EXERCISE (BASAL AND RESTING METABOLIC RATES)

Physical activity is a complex construct encompassing different dimensions, a range of contexts such as occupation, transportation, exercise, and daily activities; and different types of activity or exercise. Physical activity amounts to about 30–40% of the total energy expenditure during 24 hours. In addition, BMR is also of importance due to the long time factor. Therefore, energy expenditure at rest and during and after different types of exercise is of outmost importance when discussing energy balance, body mass maintenance and health. Since aerobic metabolism is the main energy system of interest different valid methods depending on situation are available such as direct measurement of or indirect estimation of oxygen consumption through heart rate measurements, core temperature, diary intake and doubly-labelled water. Due to the great individual variation in energy expenditure due to variations in diet, substrate used during exercise, training status, type of exercise etc. one cannot apply strict mathematical principles to biologic systems, but when analyzing energy balance for longer periods of time.

Basal Energy Expenditure: BEE or basal metabolic rate is the energy needed to carry out fundamental metabolic functions, such as breathing, ion transport, normal turnover of enzymes and other body components, etc. It is measured with the subject in the fasted state, lying quietly in a room of comfortable temperature. Basal Energy Expenditure varies between the sexes. Lean body mass, age. It is at the peak in infancy and declines rapidly through childhood and adolescence. They decline in old age is due largely to loss of muscle. Weight-bearing exercise will prevent or reverse muscle loss among the elderly.

Resting energy expenditure: Resting energy expenditure or RMR represents the largest proportion of Total Energy Expenditure. Simply defined, REE represents the energy expended at rest by a fasted individual in a thermo-neutral environment. RMR is typically slightly higher than *basal metabolic rate* (BMR) that is measured under stricter conditions. Major factors contributing to individual variation in REE include age, gender, body size, body composition, ethnicity, physical fitness level, hormonal status, and a range of genetic and environmental influences.

4.10. METABOLIC RATE DURING SUBMAXIMAL EXERCISE

Obesity and other metabolic dysfunction such as abnormal fat and carbohydrate oxidation may contribute to metabolic inflexibility, which is the inability to switch from fat to carbohydrate oxidation in response to a meal or insulin administration. The concept of metabolic inflexibility also may extend to metabolism during aerobic exercise, wherein the normal response in the fasted state is to shift from utilizing fat to carbohydrate during the transition from rest to exercise of increasing intensity. Because fat cannot be oxidized at high enough rates to supply all of the energy for moderate to vigorous exercise, this shift from fat to carbohydrate oxidation supplies the necessary energy as exercise intensity increases. The lower cardiorespiratory fitness levels in type 2 diabetes may extend to obese, older adults with metabolic inflexibility. Middle-aged and older, overweight-obese subjects with IGT often have metabolic abnormalities such as impaired glucose uptake in response to insulin, and also have lower glycogen content in skeletal muscle and higher intra myocellular lipid levels in the post absorptive state. These metabolic abnormalities may affect the ability to switch from fat to carbohydrate oxidation when going from rest to exercise of increasing intensity.

The ability to shift from fat to carbohydrate oxidation when going from rest to submaximal aerobic exercise of increasing intensity is reduced in overweight and obese, older subjects with IGT, and is related to the degree of postprandial hyperglycemia. This limitation in obese, older adults with IGT may affect the ability to supply energy to skeletal muscle during moderate-vigorous aerobic activities. Because regular exercise training and weight loss can improve glucose tolerance and reduce progression to type 2 diabetes. The lifestyle interventions may improve metabolic flexibility in response to exercise in subjects with IGT.

4.11. MAXIMAL CAPACITY FOR AEROBIC EXERCISE

Maximal aerobic capacity is the maximal oxygen uptake percentage (VO2 max) which allows the subject to base his/her effort only on the aerobic metabolism. Maximal aerobic capacity represents 50% VO2 max in untrained subjects and 80% VO2 max in trained subjects. As effort capacity is best estimated by the oxygen uptake, aerobic power measures the maximal oxygen uptake (VO2 max) in time units. Aerobic power is thus defined as oxygen volume consumed per minute in a maximal effort, and is essential in endurance tests and activities. Aerobic capacity favors training for both sexes, starting from childhood and adolescence. It increases between the ages of 10 and 20, even in untrained individuals, to gradually decrease with age after that. VO2 max decreases in the same manner in untrained individuals, both in those with a higher and in those with a lower VO2 max. It usually decreases by 8-10% after ten years. Physical maturity once reached, aerobic capacity can remain optimal even at an advanced age, around 50. Physical condition in older people reduces to half, stimulating at the same time weight gain. Maximal aerobic capacity can be reduced by dividing the entire amount of oxygen to the number of kilos. VO2 max /kg body weight/min can be increased through weight and fat loss.

Environmental factors (e.g.: high altitude) often limit aerobic capacity development. Decreased physical capacity at high altitude often occurs in endurance tests. The level of physical activity is one of the most important factors in the maintenance of aerobic capacity.

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4.12. ANAEROBIC EFFORT AND EXERCISE CAPACITY

Anaerobic exercise helps boost metabolism as it builds and maintains lean muscle. The leaner muscle, more calories will burn during sweat session. High-intensity exercise is also thought to increase post-workout calorie burn. By regular exercise anaerobic threshold in the body increases its ability to handle lactic acid and thus helping work harder and longer. Anaerobic effort helps fight depression, reduce risk of diseases, protects joints and boost energy.

CHECK YOUR PROGRESS - 2

Fill in the Blanks

1. There are two mechanisms of ATP synthesis namely ________________________ and ______________________.
2. ____________________________ is the source of energy for use and storage at the cellular level.
3. The basics of energy system are _________________________, ___________________, and _____________________.
4. ______________ is a state of physical and mental exhaustion.

5. ___________________ is the energy needed to carry out fundamental metabolic functions

6. ________________________ represents the largest proportion of Total Energy Expenditure

4.13. SUMMARY

Energy metabolism is central to life and the main function of the respiratory system is to maintain aerobic metabolic processes in the body. Despite this important role, energy metabolism is poorly integrated in the diagnostic workup of chronic respiratory diseases. Increased attention during the last decade has focused on the contribution of energy imbalance in the pathogenesis of weight loss. Several factors contribute to the amount of energy spent by an individual: resting energy expenditure, physical activity, and to a lesser extent diet-induced thermogenesis. Resting energy expenditure as well as total daily energy expenditure are incredible of metabolism. Factors responsible for increase in resting energy expenditure as well as total energy expenditure are dependent on different variants. Food intake as well as food utilization are essential components in the maintenance of energy balance.

4.14. GLOSSARY

ATP - Adenosine 5′-triphosphate, abbreviated ATP and usually expressed without the 5′-,is an important "energy molecule" found in all life forms.

Microvascular circulation: The microcirculation is the circulation of the blood in the smallest blood vessels, the micro vessels of the microvasculature present within organ tissues.

Vaso-mediators: A vasoactive substance is an endogenous agent or pharmaceutical drug that has the effect of either increasing or decreasing blood pressure and/or heart rate through its vasoactivity, that is, vascular activity

Anaerobic metabolism: ATP production without oxygen (or in the absence of oxygen), occurring by direct phosphate transfer from phosphorylated intermediates, such as glycolytic intermediates or creatine phosphate (CrP), to ADP forming ATP.

Aerobic metabolism: Aerobic metabolism is when the body produces energy (in the form of ATP) using oxygen.

Substrate phosphorylation: It is a metabolism reaction that results in the production of ATP or GTP by the transfer of a phosphate group from a substrate directly to ADP or GDP.

4.15. FURTHER SUGGESTED READING

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4.16. ANSWERS TO CHECK YOUR PROGRESS - 1

Answer the Following

1. Musculoskeletal System, Circulatory System, Respiratory System and Endocrine System
2. Carbohydrate, Fat and Protein
3. Exercise stimulates the works to maintain an appropriate level of homeostasis for the increased demand in physical, metabolic, respiratory, and cardiovascular efforts.

4.17. ANSWERS FOR CHECK YOUR PROGRESS -2

Fill in the blanks

1. There are two mechanisms of ATP synthesis namely oxidative phosphorylation and substrate-level phosphorylation.
2. Adenosine triphosphate (ATP) is the source of energy for use and storage at the cellular level.
3. The basics of energy system are the immediate energy system, the glycolytic system, and the oxidative system.
4. Fatigue is a state of physical and mental exhaustion.
5. Basal metabolic rate is the energy needed to carry out fundamental metabolic functions
6. Resting energy expenditure or RMR represents the largest proportion of Total Energy Expenditure

Unit 5: REGULATION OF FOOD INTAKE

Unit 5: REGULATION OF FOOD INTAKE

5.1. OBJECTIVES

After reading this chapter you will be able to:

- Understand the role of hunger and satiety centers
- Understand the effect of physical activity on food intake
- Interpret the Factors affecting food choices
- Role of hormones and neurotransmitters

5.2. INTRODUCTION

The quality and quantity of food that is consumed are closely regulated by the body. Food intake is regulated by a number of factors involving complex interactions among various hormones, neuroendocrine factors, the central nervous system, and organ systems (e.g., brain and liver), and environmental and external factors.

Appetite is usually defined as a psychological desire to eat and is related to the pleasant sensations that are often associated with specific foods. Scientifically, appetite is used as a general term of overall sensations related to food intake. Hunger is usually defined as the subjective feeling that determines when food consumption is initiated and can be described as a nagging, irritating feeling that signifies food deprivation to a degree that the next eating episode should take place. Satiety is considered as the state of inhibition over eating that leads to the termination of a meal, and is related to the time interval until the next eating episode.

Thus, hunger and satiety are more intrinsic instincts, whereas appetite is often a learned response. The internal factors that regulate the overall feeling of hunger and satiety include the central nervous system (primarily the hypothalamus and the vagus nerve), the major digestive organs such as the stomach and liver, and various hormones. In addition, environmental factors (e.g., meal pattern and composition, food availability, smell and sight of foods, climate), emotional factors (e.g., stress), and some diseased states (e.g., anorexia, trauma, infection) may influence the feelings of both hunger and appetite.

The factors that influence appetite include factors external to the individual (e.g., climate, weather), specific appetite cravings, specific learned dislikes or avoidance (e.g., alcohol), intrinsic properties of food (e.g., taste, palatability, texture), cultural practices or preferences, specific effects of some drugs and diseases, and metabolic factors such as hormones and neurotransmitters. The satiety cascade describes four distinctly different but overlapping categories of mechanisms involved in acute within-meal feeling of satiety (referred to as satiation) and the in between-meal satiety

5.3. ROLE OF HUNGER AND SATIETY CENTERS

The hypothalamus acts as the control center for hunger and satiety. Part of the hypothalamus, the arcuate nucleus (or, in humans, the infundibular nucleus), allows entry through the blood-brain barrier of peripheral peptides and proteins that directly interact with its neurons. These include neurons that express peptides that stimulate food intake and weight gain, specifically, neuropeptide and agouti-related peptide, as well as those expressing pro-opiomelanocortin and cocaine- and amphetamine-regulated transcript (CART) which inhibit feeding and promote weight loss. Together, these neurons and peptides control the sensations of hunger and satiety and ultimately weight gain and weight loss.

The medial arcuate nucleus contains the neurons which project to the paraventricular nucleus, hypothalamic nucleus, lateral hypothalamic area, and other hypothalamic sites. Peptide synthesis and release are regulated by leptin and insulin (both inhibitory), and glucocorticoids and ghrelin (both stimulatory), among many other factors. The most noticeable physiological response to central administration of is the stimulation of feeding. Peptide initiates appetite drive through the protein coupled receptors Peptide also represses the anorexigenic effect of melanocortin signaling in the arcuate. In the hypothalamus, Peptide is one of the most potent orexigenic factors.

The hypothalamus is also the master regulator of satiety, via production of Proopiomelanocortin (POMC) and cocaine- and amphetamine-regulated transcript (CART). The POMC gene is expressed by multiple tissues, including the skin and immune system, as well as the pituitary gland and the arcuate nucleus of the hypothalamus. POMC undergoes tissue-specific post-translational cleavage, with the product depending on the endoproteases expressed in that tissue.

With respect to the hypothalamus in humans, leptin (a peptide produced by adipose tissue) is thought to stimulate POMC conversion into α-MSH in the arcuate nucleus. The neurotransmitter in turn binds to the melanocortin-4 receptor (MC4R), a key receptor involved in appetite control and energy homeostasis, in the paraventricular nucleus and in numerous other sites throughout the brain. POMC deficiency also leads to obesity (due to lack of binding at MC4R), hypocortisolism (due to lack of binding of ACTH to the MC2R in the adrenal gland), and alteration of pigment (due to lack of binding at MC1R in the skin). This syndrome is defined by severe early onset obesity, adrenal insufficiency, and red hair.

Another important satiety regulator in the hypothalamus is cocaine- and amphetamine-regulated transcript (CART), which is expressed with POMC in arcuate neurons. Similar to POMC neurons, CART neurons are directly stimulated by leptin. CART neurons target areas throughout the hypothalamus and are associated with reinforcement and reward, sensory processing, and stress and endocrine regulation.

5.4. EFFECT OF NUTRIENTS AND PHYSICAL ACTIVITY ON REGULATION OF FOOD INTAKE

Regulation of short-term energy intake involves the balance of positive drives to eat arising from the sight, smell and palatability of food with negative feedback signals from learned associations, gastrointestinal and metabolic signals. The stomach and small intestine are major sites in the feedback inhibition of food intake and subsequent period of appetite suppression. Nature of the regulatory signal suppressing food intake depend on the type and energy content of nutrient consumed, but also the specific chemical composition of the nutrients and the site at which they are delivered. Feedback inhibition of feeding can be modulated by the particular chemical structure of nutrients (e.g. specific sugar or triacylglycerol structures). These differences in response are likely to be a consequence of differences in physical properties of particular nutrients depending on their chemical structure, and may also result from different receptor affinities for specific dietary structures. Moreover, the site of administration of nutrients can also profoundly affect the size and nature of the subsequent feeding response, suggesting that feed-forward interactions occur between the taste of foods and gastrointestinal stimulation.

Knowledge of the regulation of food intake is crucial to an understanding of body weight and obesity. Food intake is the vehicle for energy supply whose expression is modulated by a metabolic drive generated in response to a requirement for energy. Eating behavior is stimulated and inhibited by internal signaling systems in order to regulate the internal environment (energy stores, tissue needs). The term 'obesigenic environment' has entered into scientific discourse and implies that the potency of the external environment is in large part responsible for the increases in food intake that is one of the causal agencies underlying the epidemic of obesity. This approach has revitalized interest in the sensory and external stimulation of food intake and has drawn attention to the hedonic dimension of appetite. There is now a very strong current of thought that a major cause of an increase in food intake associated with the rise of obesity resides in the hedonic rather than the homeostatic system. This does not mean that the so-called 'energy homeostasis system' is no longer important. There is a cross-talk between the neurochemical substrates of the two systems. This is an exciting concept that offers the possibility of some re-unification of the dualism underlying homeostatic and hedonic processing of information.

Physical Activity (PA) is interrelated with energy intake. The working body requires energy and nutrients in order to fuel activity and function. PA manipulates energy expenditure and regulates the use of fuels. When prolonged strenuous PA is performed on a regular basis, it causes an increase in overall energy and leads to loss of body weight or to a need for an increase in food intake.

5.5. FACTORS AFFECTING FOOD CHOICES

The key driver for eating is of course hunger but choice to eat is not determined solely by physiological or nutritional needs. Some of the other factors that influence food choice include:

- Biological determinants such as hunger, appetite, and taste
- Economic determinants such as cost, income, availability
- Physical determinants such as access, education, skills (e.g. cooking) and time
- Social determinants such as culture, family, peers and meal patterns
- Psychological determinants such as mood, stress and guilt
- Attitudes, beliefs and knowledge about food

5.5.1 Biological determinants of food choice

Hunger and satiety: Our physiological needs provide the basic determinants of food choice. Humans need energy and nutrients in order to survive and will respond to the feelings of hunger and satiety (satisfaction of appetite, state of no hunger between two eating occasions). The central nervous system is involved in controlling the balance between hunger, appetite stimulation and food intake.

Palatability: It is proportional to the pleasure someone experiences when eating a particular food. It is dependent on the sensory properties of the food such as taste, smell, texture and appearance. There is an increase in food intake as palatability increases.

Sensory aspects: 'Taste' is consistently reported as a major influence on food behavior. In reality 'taste' is the sum of all sensory stimulation that is produced by the ingestion of a food. This includes not only taste per se but also smell, appearance and texture of food. These sensory aspects are thought to influence, in particular, spontaneous food choice.

5.5.2 Economic and physical determinants of food choice

Cost and accessibility: Cost of food is a primary determinant of food choice. Whether cost is prohibitive depends fundamentally on a person's income and socio-economic status. Low-income groups have a greater tendency to consume unbalanced diets and in particular have low intakes of fruit and vegetables. However, access to more money does not automatically equate to a better quality diet but the range of foods from which one can choose should increase.

Accessibility to shops is another important physical factor influencing food choice, which is dependent on resources such as transport and geographical location. Healthy food tends to be more expensive when available within towns and cities compared to supermarkets on the outskirts.

Education and Knowledge: The level of education influence dietary behavior during adulthood. In contrast, nutrition knowledge and good dietary habits are not strongly correlated. This is because knowledge about health does not lead to direct action when individuals are unsure how to apply their knowledge. Thus, it is important to convey accurate and consistent messages through various media, on food packages and of course via health professionals.

5.5.3 Social determinants of food choice

Influence of social class: What people eat is formed and constrained by circumstances that are essentially social and cultural. Problems that face different sectors of society, requiring different levels of expertise and methods of intervention.

Cultural influences: This leads to the difference in the habitual consumption of certain foods and in traditions of preparation, and in certain cases can lead to restrictions such as exclusion of meat and milk from the diet. Cultural influences are however amenable to change: when moving to a new country individual often adopt particular food habits of the local culture.

Social context: Social influences on food intake refer to the impact that one or more persons have on the eating behavior of others, either direct (buying food) or indirect (learn from peer's behavior), either conscious (transfer of beliefs) or subconscious. Even when eating alone, food choice is influenced by social factors because attitudes and habits develop through the interaction with others.

Social support can have a beneficial effect on food choices and healthful dietary change. Social support from within the household and from co-workers was positively associated with improvements in fruit and vegetable consumption and with the preparative stage of improving eating habits, respectively. Social support may enhance health promotion through fostering a sense of group belonging and helping people to be more competent and self-efficacious.

The family is widely recognized as being significant in food decisions. Because family and friends can be a source of encouragement in making and sustaining dietary change, adopting dietary strategies which are acceptable to them may benefit the individual whilst also having an effect on the eating habits of others.

Social setting: Although the majority of food is eaten in the home, an increasing proportion is eaten outside the home, e.g. in schools, at work and in restaurants. The venue in which food is eaten can affect food choice, particularly in terms of what foods are on offer. The availability of healthy food at home and 'away from home' increases the consumption of such foods. However, access to healthy food options is limited in many work/school environments. This is particularly true for those with irregular hours or with particular requirements.

5.5.4 Meal patterns

People have many different eating occasions daily, the motivations for which will differ from one occasion to the next. The factors that influence habitual food choice is as per different eating occasions. The effects of snacking on health have been debated widely. Individuals with normal weight or overweight may differ in their coping strategies when snack foods are freely available and also in their compensatory mechanisms at subsequent meals. Moreover, snack composition may be an important aspect in the ability of individuals to adjust intake to meet energy needs.

5.5.5 Psychological factors

Stress: Psychological stress is a common feature of modern life and can modify behaviors that affect health, such as physical activity, smoking or food choice. The influence of stress on food choice is complex not least because of the various types of stress one can experience. The effect of stress on food intake depends on the individual, the stressor and the circumstances. In general, some people eat more and some eat less than normal when experiencing stress.

Mood: Hippocrates was the first to suggest the healing power of food, however, it was not until the middle ages that food was considered a tool to modify temperament and mood. Today it is recognized that food influences our mood and that mood has a strong influence over our choice of food. Interestingly, it appears that the influence of food on mood is related in part to attitudes towards particular foods. The ambivalent relationship with food – wanting to enjoy it but conscious of weight gain is a struggle experienced by many.

CHECK YOUR PROGRESS – 1

Answer the Following

1. List the factors affecting food choices.

Fill in the Blanks

1. _____________is usually defined as a psychological desire to eat and is related to the pleasant sensations that are often associated with specific foods.
2. The internal factors that regulate the overall feeling of hunger and satiety include the ____________________.
3. The __________________acts as the control center for hunger and satiety
4. The hypothalamus is also the master regulator of satiety, via production of _________________________ and ____________________________________.

5.6. REGULATION OF FOOD INTAKE- HUNGER, APPETITE, SATIETY

The hunger-satiety cycle involves preabsorptive and postabsorptive humoral and neuronal mechanisms. Psychological, social and environmental factors, nutrients and metabolical processes and gastric contractions originate hunger signals. Eating, in turn, activates inhibitory signals to produce satiety. There are a number of physiological mechanisms that serve as the basis for hunger. When our stomachs are empty, they contract. Typically, a person then experiences hunger pangs.

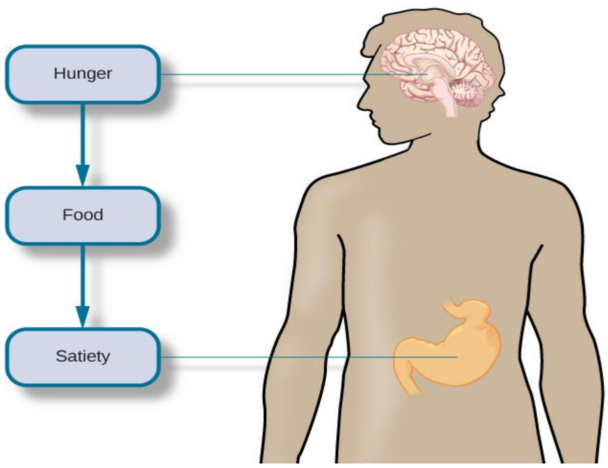

Figure 1: Hunger and satiety signals that are integrated in the brain

Source: https://digitaleditions.library.dal.ca/intropsychneuro/chapter/hunger-and-eating/

Chemical messages travel to the brain, and serve as a signal to initiate feeding behavior. When our blood glucose levels drop, the pancreas and liver generate a number of chemical signals that induce hunger and thus initiate feeding behavior. For most people, once they have eaten, they feel satiation, or fullness and satisfaction, and their eating behavior stops. Like the initiation of eating, satiation is also regulated by several physiological mechanisms. As blood glucose levels increase, the pancreas and liver send signals to shut off hunger and eating. The food's passage through the gastrointestinal tract also provides important satiety signals to the brain, and fat cells release leptin, a satiety hormone. The various hunger and satiety signals that are involved in the regulation of eating are integrated in the brain. The hypothalamus and hindbrain are especially important sites where this integration occurs Ultimately, activity in the brain determines whether or not we engage in feeding behavior

5.7. ROLE OF HORMONES, NEUROTRANSMITTERS

5.7.1 Hormones

Homeostatic regulators control energy balance with circulating signals generated in proportion to body fat stores influence food intake and energy expenditure in a coordinated manner to regulate body weight. Hypothalamus is critical in regulation of food intake. The circulating peptides and steroids that are produced in the body have a substantial influence on appetitive behavior through their actions on the hypothalamus, the brain stem, or afferent autonomic nerves. These hormones come from at least three sites: fat cells, the gastrointestinal tract, and the endocrine pancreas.

Leptin: The critical importance of leptin in the control of energy homeostasis has been clearly established. The hypothalamus receives and integrates neural, metabolic, and humoral signals from the periphery. In particular, contained within the arcuate nucleus of the hypothalamus are two populations of cells that are the best characterized leptin-responsive neurons in the brain. The first population of neurons express two potent appetite-stimulating peptides, the melanocortin anatagonist Agouti-related peptide (AgRP) and Neuropeptide Y (NPY). The second population expresses the peptide cocaine and amphetamine-related transcript (CART) and the large precursor peptide pro-opiomelanocortin (POMC). Both sets of neurons project to second-order, melanocortin 4 receptor (MC4R) expressing neurons within the hypothalamus and elsewhere in the brain. Leptin inhibits NPY/AgRP neurons, and fasting significantly upregulates the expression of NPY and AgRP.

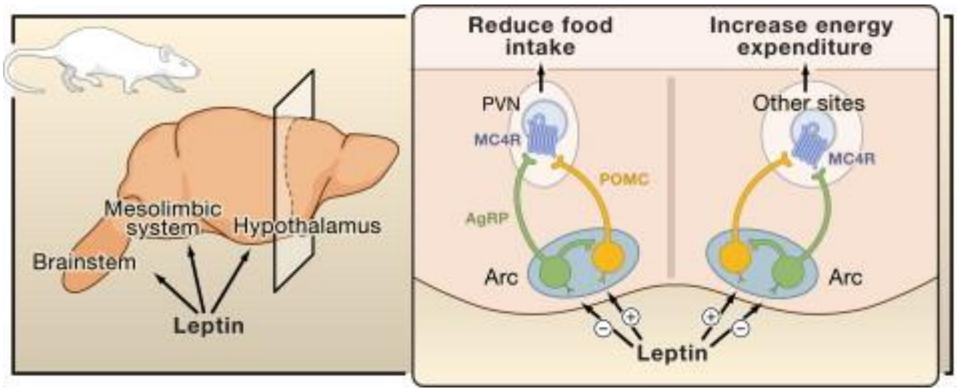

Figure 2: Leptin Mechanism

Source: https://www.cell.com/fulltext/S0092-8674(07)00447-3

Melanocortin Receptors (MC4R): MC4R mutations are responsible for childhood obesity and adult obesity to lesser extent. The phenotypic features of MC4R deficiency include hyperphagia, an increase in fat and lean mass, and an increase in bone mineral density

Brain-derived neurotrophic factor (BDNF): BDNF is a regulator of brain development and plasticity and exerts its effects through the tyrosine kinase receptor TrkB. Both BDNF and its receptor TrkB are widely expressed in the brain. Deficiency of BDNF n the postnatal brain develops hyperphagia and obesity. genetic disruption of the neurotrophin receptor TrkB and in its ligand BDNF cause severe hyperphagia and obesity, developmental delay, impaired short-term memory, and unusually hyperactive behavior.

Melanin-Concentrating Hormone: Melanin-concentrating hormone (MCH) is an orexigenic (appetite-stimulating) peptide produced by neurons in the lateral hypothalamus. Transgenic overexpression of MCH in the lateral hypothalamus leads to obesity and insulin resistance.

Orexins: Orexins were originally identified as peptides produced selectively in the lateral hypothalamus. Central administration of orexin appeared to increase food intake and the principal function of orexins was to control food intake. Orexins also play important role in the maintenance of alertness with genetic or acquired deficiency of orexin signaling resulting in narcolepsy

5.7.2 Neurotransmitters

Acetylcholine: It serves as a neurotransmitter at the neuromuscular junctions, ganglionic synapses, and at diverse sites within the central nervous system. The food sources include brinjal, squash, spinach, peas, mung beans, common bean, orange, strawberry, radish. In particular, mistletoe had a traditional use in the treatment of patients with high blood pressure, arteriosclerosis, hypertensive headache, epilepsy, chorea, hysteria, and other neurological diseases. The cardiac-depressant and sedative properties of mistletoe were attributed to various biologically active constituents, such as Acetylcholine itself.

Glutamate: Glutamate is a non-essential amino acid and the most important excitatory neurotransmitter in the brain. Glutamate and glutamic acid are ubiquitously present in foods. At pH 7, dietary glutamic acid is transformed into glutamate, which is its anionic form. Glutamic acid naturally occurs in foods with high protein content (for example, meats, seafood, stews, soups, and sauces)/ Upon ingestion, monosodium glutamate and other glutamate salts dissociate, releasing free glutamate. Foods sources of monosodium glutamate and glutamic acid are often the same.

Gamma-Aminobutyric Acid (GABA): GABA is a major inhibitory neurotransmitter of the vertebrate central nervous system. Levels of GABA were demonstrated to increase in response to biotic and abiotic stresses, such as drought, the presence of salt, wounds, hypoxia, infection, soaking, and germination. In particular, sprouts of lupin, adzuki bean and other germinating edible beans. GABA is known for its analgesic effects, anti-anxiety, and hypotensive activity.

Dopamine: Dopamine plays an essential role in humans for the coordination of body movements, motivation, and reward. Fruits of the *Musa* genus, such as bananas and plantains, and avocado were reported to contain high levels of dopamine. More specifically, dopamine levels were found in the banana peel (700 μg/g), the banana pulp (8 μg/g), and in avocado (4–5 μg/g). Episodic movement disorders (that is, shaking the head from side to side) were reported after the consumption of skim milk.

Serotonin: In the central nervous system, 5-HT pathways modulate behaviors, eating, and sleep, whereas, in the gut, they are involved in the regulation of gastrointestinal motility. Fruits, vegetables, and seeds are major sources of 5-HT. Higher concentrations were found in banana peels compared to the pulp. The accumulation of 5-HT was also detected in pepper and paprika.

Histamine: Histamine is neurotransmitter that is present in mammalian hypothalamic neurons with widespread projections to nearly all regions of the brain mediating arousal, attention, and reactivity. It is a heterocyclic, nitrogenous, and naturally occurring compound formed from histidine. Despite being considered endogenous in certain foods, relatively high levels of histamine and other biogenic amines indicate defective food processing, microbial activity, and general deterioration. In fact, the food industry aims to maintain the levels of amines in foods as low as possible in order to meet the quality standards. Consumption of fish, ham, and other cured dry meat products. The release of adrenaline and noradrenaline, the excitation of smooth muscles within intestines and respiratory tract, the stimulation of both sensory and motor neurons, and the excessive gastric acid secretion were associated with histamine intoxication.

5.8. EPISODIC AND TONIC SIGNALS FOR APPETITE CONTROL

There are two types of peripheral signals: episodic and tonic. Episodic signals are mainly involved in short-term (meal to meal) while tonic signals are mainly involved in long-term (days and weeks) regulation of appetite and satiety.

Episodic signals: They are mainly triggered by glucose levels inside cells. Before meals, the “hunger hormone” ghrelin is secreted into the bloodstream by special cells in the gastrointestinal system in response to decreases in cellular glucose. It then travels to the brain to activate orexigenic neurons, which causes hunger. Ingested food moves into the gastrointestinal tract where the volume and nutritive content are sensed by mechanical and chemosensory mechanisms. Depending on the type of foods eaten, different hormones or signal molecules are produced in the gastrointestinal tract. For example, CCK (cholescystokinin) is mainly produced in response to protein and fat ingestion while GLP-1 and PYY are produced in response to carbohydrate and fat ingestion. These signal molecules, along with others such as amylin, obestatin and enterostatin all work through the central nervous system to suppress appetite and are often called "satiety signals".

Tonic signals: They are mediated by the amount of energy stored as fat in the body. The major tonic signal is leptin, a hormone that is produced in fat tissue, which travels through the bloodstream and functions in the hypothalamus of the brain. When leptin binds to a leptin receptor, it activates a special signaling pathway to regulate genes involved in energy metabolism. When leptin levels are high, it suppresses hunger by turning the POMC gene and GLP-1 gene on and the AgRP gene off. The POMC gene product stimulates anorexigenic neurons (in the "satiety center") while the AgRP product stimulates the orexigenic neuron (in the "hunger center"). When leptin levels are low, it increases hunger by turning the POMC gene off and the AgRP gene on. Leptin also regulates the genes involved in basal metabolism. Higher leptin levels are associated with increased basal metabolism and lower levels are associated with decreased basal metabolism. It is believed that the hormones progesterone and estrogen modulate a women's appetite during pregnancy through their effects on leptin level regulation.

CHECK YOUR PROGRESS - 2

Answer the Following

1. List the neuron which express appetite.

Fill in the Blanks

1. __________ mutations are responsible for childhood obesity

2. ____________ is a regulator of brain development and plasticity.
3. __________________________________ is an orexigenic (appetite-stimulating) peptide produced by neurons in the lateral hypothalamus
4. ____________ were originally identified as peptides produced selectively in the lateral hypothalamus
5. ________________serves as a neurotransmitter at the neuromuscular junctions, ganglionic synapses, and at diverse sites within the central nervous system
6. ________________ is a non-essential amino acid and the most important excitatory neurotransmitter in the brain.
7. ______________ is a major inhibitory neurotransmitter of the vertebrate central nervous system.
8. ______________ plays an essential role in humans for the coordination of body movements, motivation, and reward.
9. _____________ is neurotransmitter that is present in mammalian hypothalamic neurons with widespread projections to nearly all regions of the brain mediating arousal, attention, and reactivity.
10. __________________ are mainly triggered by glucose levels inside cells
11. __________________ are mediated by the amount of energy stored as fat in the body.

5.9. SUMMARY

Eating behavior is critical for the acquisition of energy substrates. As discussed in this review, the gut–brain axis controls appetite and satiety via neuronal and hormonal signals. The entry of nutrients in the small intestine stimulates the release of peptides which act as negative feedback signals to reduce meal size and terminate feeding. Hormones and cytokines secreted by peripheral organs exert long-term effects on energy balance by controlling feeding and energy expenditure. Neurons involved in the homeostatic regulation of feeding are located mainly in the hypothalamus and brainstem. In addition, neuronal circuits in the limbic system mediate the motivational and reward aspects of feeding. Insights into how peripheral metabolic signals interact with the brain will be gained from brain imaging and metabolic studies in humans, and preclinical experimentation in animal models, utilizing molecular, genetic, physiological and behavioral tools. Knowledge of the neurobiological basis of eating will promote the understanding and rational treatment of disorders of energy homeostasis, such as obesity and cachexia.

5.10. GLOSSARY

Proopiomelanocortin (POMC): It is the pituitary precursor of circulating melanocyte stimulating hormone (α-MSH), adrenocorticotropin hormone (ACTH), and β-endorphin.

CART (cocaine- and amphetamine-regulated transcript): A brain-located peptide, is a satiety factor and is closely associated with the actions of two important regulators of food intake, leptin and neuropeptide Y.

Melanocortin: They agonists are ancient neuropeptides that have steroidogenesis and anti-inflammatory properties.

Hyperphagia: Abnormally increased appetite for consumption of food frequently associated with injury to the hypothalamus

Brain-derived neurotrophic factor (BDNF): It is a protein that, in humans, is encoded by the BDNF gene.

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5.12. ANSWERS TO CHECK YOUR PROGRESS - 1

Answer the Following

The factors affecting food choices.

- Biological determinants such as hunger, appetite, and taste
- Economic determinants such as cost, income, availability
- Physical determinants such as access, education, skills (e.g. cooking) and time
- Social determinants such as culture, family, peers and meal patterns
- Psychological determinants such as mood, stress and guilt
- Attitudes, beliefs and knowledge about food

Fill in the Blanks

1. Appetite.
2. Central nervous system.
3. Hypothalamus
4. Proopiomelanocortin (POMC) and cocaine- and amphetamine-regulated transcript (CART).

5.13 ANSWERS FOR CHECK YOUR PROGRESS -2

Answer the Following

1. The first populations of neurons express two potent appetite-stimulating peptides, the melanocortin antagonist Agouti-related peptide (AgRP) and Neuropeptide Y (NPY). The second population expresses the peptide cocaine and amphetamine-related transcript (CART) and the large precursor peptide pro-opiomelanocortin (POMC).

Fill in the Blanks

1. MC4R
2. BDNF
3. Melanin-concentrating hormone (MCH)
4. Orexins
5. Acetylcholine
6. Glutamate
7. GABA

8. Dopamine
9. Histamine
10. Episodic signals
11. Tonic signals