Digestive System

University of Jordan

Faculty of Medicine

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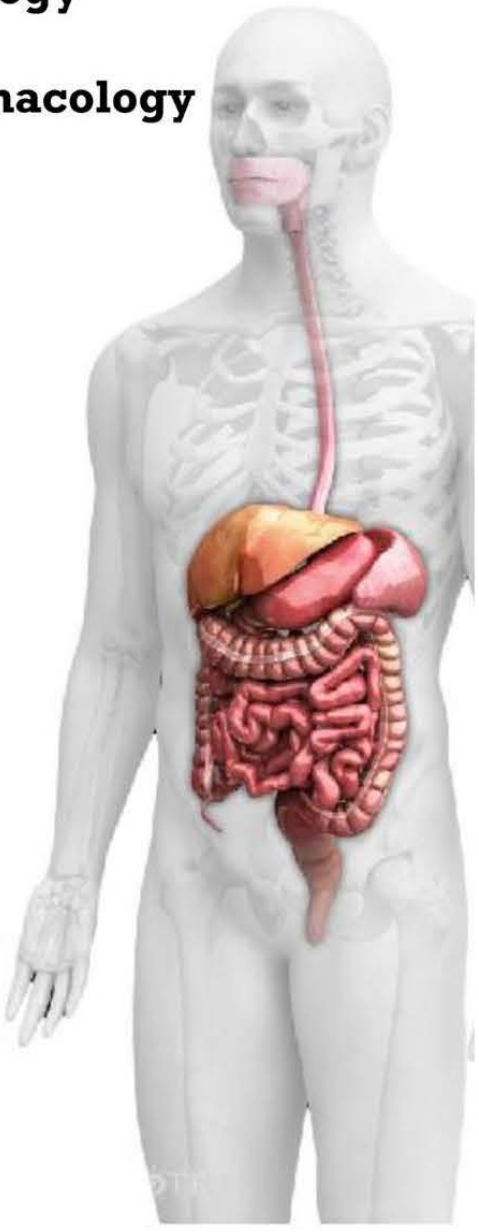

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Gastrointestinal Physiology, Pt IV.

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ENERGETICS, METABOLIC RATE, DIETARY BALANCE and REGULATION OF FOOD INTAKE:

After the chemical transformation of food into smaller food stuffs and their absorption, food stuff will undergo many processes by the cells of human body to produce energy for their activities.

The energy produced by these reactions is stored in highly energetic phosphate bonds in a compound known as ATP. The formed ATP then is used for body works which could be as external or internal works. These include:

Chemical works: building of cellular components, secretions, etc.
Mechanical works: muscle contractions, heart pumping, etc.
Electrical works: after nerve conduction by maintaining a concentration gradient for K+ and Na+ across membrane by the activity of Na+/K+ pumps and other pumps).

Another highly energetic compound that can transfer energy (when needed) to ATP is phosphocreatine. This occurs by the following reaction:

Phosphocreatine + ADP ⇆ ATP + Creatine

The abundance of creatine permits more storage of energy in this high energetic compound which can energize the ADP when there is a decrease in ATP concentration.

ATP formation by chemical reactions in the body:

The energy produced by chemical reactions that need oxygen is known as aerobic energy. Most of energy produced in our body is in the form of aerobic energy.

Some ATP molecules can be produced by anaerobic reactions such as glycolysis (break down of glucose into pyruvic acid). This is a form of **anaerobic energy**. This anaerobic energy can be generated when there is

lack of oxygen such as in hypoxia or when there is a high activity (such as in muscle) and inadequate supply of oxygen. This later condition will result in accumulation of lactic acid in the muscle.

The **aerobic energy** is produced by enzymatic reactions (chemical burning of food stuff by using O_2 to produce energy). These reactions are very well controlled in our body. The final products of complete break down of food stuff will result in the formation of H_2O and CO_2.

In the case of chemical burning of glucose, we have the following reaction: $C_6 H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$

From this reaction we can calculate "Respiratory Quotient" (RQ) (CO2 produced/O2 consumed) when glucose is used as a source of energy

In this reaction (RQ) = CO_2/O_2 = 1.0 in the case of glucose break down.

When **fat** is used as source of energy, RQ = **0.7**.

When **protein** is used, RQ = **0.8**.

The RQ when **mixed** food stuff is used = **0.82**.

From the respiratory exchange ratio by the lung over a period of time we can estimate the respiratory quotient for all body to indicate the main type of food stuffs used for metabolism in the body.

METABOLIC RATE:

Metabolism refers to all chemical reactions in our body.

The energy produced and consumed in chemical reactions and body works will finally generate **heat** (appears by the interconversion between the forms of energy). The rate of heat production is known as the *metabolic rate*. The heat produced can be measured to reflect the metabolic activities in the human body.

The measurement of metabolic rate has clinical importance mainly when is measured under **basal conditions**. The metabolic rate under these conditions is known as **basal metabolic rate** and refers to the minimal energy expenditure by a body to exist.

Basal conditions:

The person to whom we intend to measure the metabolic rate is **not in sleep** and the following basal conditions must be met:

1. No eaten food for at least 12 hours.
2. measurement after a night of restful sleep.
3. No exercise and physical activities in at least one hour prior to and during the test.
4. elimination of all factors that may cause excitement.
5. comfortable temperature during measurement.

Measurements of metabolic rate:

The Calorie is the used unit for measuring heat produced by the body. Calorie spelled with C capital to mean 1kilocarie (1000 calories).

Direct calorimetry:

Measuring the heat produced with direct methods by calorimeter (an insulated chamber constructed with a constant rate of water flow (in and out) to measure the heat taken by the flow of water).

Indirect calorimetry:

Closed circuit method:

More than 95% of the energy is produced by oxygen consuming chemical reactions. The rate of heat production can be calculated from the amount of oxygen consumed. The heat produced by our body is about 4.825 Calories per one liter of oxygen consumption (*energy equivalent of oxygen*). By using the spirometer as metabolator by equipping it (filling it with pure oxygen and adding in the way of expired air a substance to adsorb the CO_2 produced) we can measure O2 consumption.

The heat produced is calculated as **the amount of heat/m^2 surface body/hour**.

There is an example for calculation of metabolic rate:

If we measure in 5 minutes:
oxygen consumption of 1000ml of pure oxygen/5minutes.
Per hour the Oxygen consumed would be:

1000ml X 12 = 12 Liters/hour.

For that amount of oxygen consumed
the energy produced is:
12 liters/hour X 4.825 Cal./liter = 57 Cal./hour.

We can have the surface area of the body from tables designed to have the surface area by knowing the weight and height of a person.

If we have it as $1.7m^2$.

Then the amount of heat produced is:
57 Cal. $hour^{-1}$/1.7 m^2 = 34 Cal. $hour^{-1}/m^2$.

The basal metabolic rate can be related to the ideal basal metabolic rate and expressed as a % increase or decrease from the ideal basal metabolic rate for that person.

Opened Circuit method

Other indirect methods are used for measuring metabolic rate during certain activities is by using **opened circuit methods**:

In these methods a bag is used for collection of expired air during the physical activity.

By knowing the concentration of oxygen in the atmosphere and in collected air. We can know how much oxygen was consumed and then we can calculate oxygen consumption and the metabolic rate in the same way as above.

Factors affecting metabolic rate:

Exercise: increases metabolic rate. This increase is well related with the strength of the exercise.

Daily activities: the metabolic rate depends on the daily activities. For a lie in bed all day the metabolic rate is about 1600 Cal/day. Eating process increases the rate by 200 Cal. Etc.

Age: the metabolic rate calculated for the surface are of the body decreases with age. It is higher in children and less in old people.

Sleep: decreases the metabolic rate.

Climate: the metabolic rate for people living in tropical regions is less.

Fever: during infection there is an increase in metabolic rate.

Malnutrition: Decreases metabolic rate.

Effect of hormones:

Thyroid hormones: increase the metabolic rate.
Male sex hormones increases the basal metabolic rate by 10-15%.
Growth hormones: Increases metabolic rate by15-20%.

Effect of sympathetic stimulation: increases metabolic rate.

DIETARY BALANCE:

As mentioned above food has energetic values. These values must be sufficient to supply the metabolic needs of our body. The mixed food contains different proportions of proteins, carbohydrate, fat, minerals, vitamins, etc. An appropriate balance must be maintained between these materials to satisfy the needs of our body for its activities.

The energetic value of food depends on its constituents of carbohydrates, proteins, and fat. The available energy in food stuff generated by oxidation is about 4Cal/g carbohydrate, 9Cal/g fat and 4Cal/g proteins. (in the living systems is less).

To maintain the normal store of protein we need an intake of about 30-55grams/day. If for a long time some constituents of food stuff are lacking, it will generate some diseases. The absence of proteins from the diet for a long time may result in a syndrome known as *Kwashiorkor*. This is a protein deficiency syndrome characterized by (failure to grow, lethargy, mental depression and hypoproteinic edema) that may result from insufficient intake of proteins.

According to thermodynamics laws, *the energy neither be created nor destroyed*. For a healthy living we have to maintain a balance between the input (energetic value of eaten food) and the expenditure which can be represented by the internal and the external works of the body (output).

To create a *neutral balance*, we must have food (input) with energetic values that balance the expenditure (output).

If there is an increase in energy input over the output this will result in a *positive energy* balance. This can be induced when there is an intake of food with energetic values greater than expenditures. In this case the unneeded amounts are stored in our body.

If the input is less than the body energetic requirements this will result in a *negative balance,* and the body begins using its stores and this will result in a decrease in body weight.

Normal adults usually maintain a constant body weight. This appears by maintaining a long term balance between the input and the output. This balance is taking place by control systems that regulate the magnitude of the input according to the expenditures (output).

REGULATION of FOOD INTAKE:

Hypothalamic control of food intake:
(hunger, appetite, and satiety)

In the hypothalamus there are centers that control food intake. These centers are known as *feeding center* and *satiety center*. Stimulation of the lateral hypothalamus will result in an excess of feeding (hyperphagia). While stimulation of the ventromedial nuclei of the hypothalamus will cause satiety feeling. The destruction of these centers will induce an opposite effect of their stimulation. Thus the feeding center tell us to eat while the satiety center tell us to stop eating.

Other areas and other higher centers (such as amygdala and prefrontal cortex) in the brain are known to contribute in the regulation of feeding, but their contribution is not fully understood. The destruction of amygdala in both sides in the brain will result in 'psychic blindness' in the choice of food. This may appear by losing the appetite control to the type and the quality of eaten food.

The feeding centers receive signals from the body about the status of food storage and the needs for energy by the cells. At these centers there is an integration of these signals. This integration will govern the feeding behaviors of the body.

Theories of food intake regulation:

Long term regulation:

Glucostatic theory of hunger and feeding regulation:

It is known that the decrease in blood glucose causes hunger. While after meal when there is a plenty glucose in the metabolic pool this will cause satiety. Others have related this theory to an increase in glucose utilization by the effect of insulin rather than the concentration of glucose in blood. Insulin is released when there is an increase in the glucose level of blood. And the increase in this hormone will cause an increase in glucose utilization and production of ATP by cells which in turn initiate neural signals that act in the hypothalamus to stop feeding.

Lipostatic theory:

According to this theory, the presence of some fat products in the blood such as keto acids and some fatty acids act to inhibit feeding. Other studies have related the lipostatic theory to the fat storage in adipose (fat) cells. The presence of high storage of fat in these cells results in the secretion of ***leptin*** hormone (hormone produced by adipose cells) that acts on specific receptors in the hypothalamic centers to reduce feeding behaviors. This hormone is important in long term regulation of the body weight.

Aminostatic theory:

The concentration of amino acids in the blood has an effect in the feeding behaviors.

Body temperature and its relation to food intake:

In cold conditions there is tendency for overeating and in warm conditions the tendency is to eat less. This process appears by the regulatory mechanisms that depend on the metabolic rate of the body. Some believe that there is an interaction between temperature regulatory centers and feeding centers in the hypothalamus to cause an increase in feeding in cold which provides more stores of nutrients and cover the needs of the body for the increase in metabolic rate.

Psychosocial factors:

Eating is influenced also by psychological and social factors. Eating 3 meals per day no matter of our hunger and satiety status is determined by psychological factors. The missing of one meal let you feel hungry. Also food plays an important role in our leisure and entertainment because of our social customs. The pleasure by eating food with an enjoyable smell and taste will increase appetite and consequently food intake.

Short term regulation of food intake:

These are rapid signals that affect feeding.

Gastrointestinal filling:

Eating will cause distension of the stomach and duodenum and activation of signals that are transmitted by the vagus to suppress the activities of feeding centers and thereby stopping food intake.

Hormonal factors:

The presence of food in the in the gastro-intestinal tract will result in the release of hormones. Many hormones have been known to affect feeding behaviors such as cholecystokinin and insulin. Cholecystokinin is released in response to fat in the duodenum. Insulin is increased by the presence of food in duodenum and the high level of glucose in the blood. The presence of fat and carbohydrates in chyme will stimulate release of GIP (gastric inhibitory peptide). This hormone acts also to increase insulin release from pancreatic islets. Other name for this hormone is (glucose-dependent insulinotropic polypeptide).
All these hormones act to suppress feeding.

Suppression by oral receptors:

It is postulated that they are oral factors which can interfere also with feeding behaviors. These are related to swallowing, salivation, chewing and tasting. These factors are considered to meter the amount of eaten food. After a certain amount that has passed through oral cavity, feeding is inhibited.

The long-term and the short-term factors of regulations are probably sending signals to the hypothalamus. Some neurotransmitters that are released in that area has been known to affect the feeding behaviors. Such as neuropeptide Y, dopamin and serotonin.

OBESITY:

Obesity results from maintained and continued imbalance between the intake and the expenditure (positive energy balance) for a long time, which results in the deposition of fat in the adipose tissue stores.

Obesity is defined as an increase in the amount of adipose tissue by more than 20% of the ideal body weight. This term is deferent from *overweight* which represents an increase in the body weight which can be related to the increase in the muscle mass rather than an increase in the adipose tissue in the body.

Causes of obesity:

As mentioned above, we have long and short-term regulatory mechanisms that regulate food intake. The abnormalities in these mechanisms that result in decreased responses of the hypothalamic centers to the signals that induce the stop in feeding will result in continuation of feeding and this will result in the generation of obesity.

Neurogenic abnormalities:

It is known that lesions in the satiety center (ventromedial nuclei) of the hypothalamus will cause excessive eating and as a result obesity will develop. The absence of the response of these nuclei to signals from the periphery will result in impaired satiety feeling. This may appear in some conditions such as in the genetic absence of leptin receptors or the presence of a receptor that is **not** responsive to leptin. Other abnormalities could be related to feeding centers. All these abnormalities are considered as abnormal functional organization of hypothalamic nuclei that may result in changing of the 'set point' of the regulatory mechanisms and inducing an excess in food intake and consequently obesity.

Genetic factors:

It is known that obesity runs in families. Due to the complexity of the mechanisms, many genetic abnormalities could be theoretically responsive in obesity. Recent studies have linked the genetic abnormalities to OB gene (leptin producing gene in adipocytes). Leptin inhibits feeding and increases the metabolic rate in the body. The congenital absence of this gene or the presence of a defective gene (due to mutation) will result in the generation of obesity. Other studies have related the genetic abnormalities to leptin receptor producing gene.

Psychogenic factor:

Obesity can be determined by our eating habits. These habits indicate that healthy person must eat 3 meals a day and these meals must be filling meals.

Some people are eating to release their tension. This happens during or after stress. Others develop obesity after emotional disturbances or in the case of mental depression.

Childhood overnutrition:

The overnutrition of a child will result in new formation of fat cells. This will increase the capacity of adipose cells to store more fat. While the overnutrition of the adult will result in the hypertrophy of the existing fat cells rather than the formation of new fat cells. It is suggested that the overnutrition of the child will result in a lifetime obesity by increasing the number of fat cells in the body.

Other causes of obesity:

- Lack of exercise.
- Disorders of the endocrine system such as in hypothyroidism.

Treatment of obesity:

Decreasing the input by a diet or other procedures.
Increasing output by exercise.
Using drugs that inhibit feeding centers.

INANITION:

The opposite of obesity. This condition could be caused by inadequate availability of food. It can also be related to some psychogenic or hypothalamic abnormalities.

In *anorexia nervosa* the person loses all the desire for food and sever inanition may occur (*cachexia*). Destruction of hypothalamic centers by thrombosis may result also in inanition.

Depletion of body stores during starvation:

Usually the body prefers carbohydrates as a source of energy over other sources. The availability of carbohydrates in the body is limited. Some is stored as glycogen mainly in the liver and muscle. In this case there is a breakdown of glycogen by a process known as glycogenolysis to provide the metabolic pool with glucose. This can supply the needs of the body for few hours only. Therefore, if there is starvation, after few hours the body will begin using other stores (fat and proteins) to provide energy supply for the body needs.

The energy stored in the body as fat is about 100 times greater than carbohydrate energy. The body will begin using the fat as a source of energy at a constant rate over the starvation period. The utilization of fat and the conversion of fat products to ketone bodies will induce acidosis in the body. Brain can use these ketone bodies as a source of energy because these can pass the blood brain barrier.

Proteins undergo three phases of depletion. In the **first phase** there is a rapid depletion followed by a slower rate of depletion then in the third phase there is a rapid depletion that appear before death. In the first phase there is depletion of proteins that are easily mobilized from the protein stores. These proteins are used for direct metabolism and for the formation of glucose by a process known as gluconeogenesis. In the **second phase** the rate of gluconeogensis is decreased as well as the rate of protein utilization.

The depletion of proteins in the **third phase** (after 5 – 6 weeks of starvation) appears after depletion of almost all fat stores. This phase will be followed by death.