ISBN: 978-81-961210-6-8

10. Biochemical Metabolism and Disease

Shweta Tyagi, Kapil Tyagi

Assistant Professor,
Department of Chemistry,
Greater Noida Institute of Technology,
Gr. Noida, U.P.

Ankita Tyagi

Assistant Professor,
Govt. Women PG College,
Kandhla, Shamli, U.P.

Abstract:

Biochemical Metabolism is the set of chemical processes that occur within living organisms to maintain life. Dysregulation of metabolism can contribute to the development of various diseases, including metabolic disorders such as diabetes, obesity, and metabolic syndrome.

This chapter will provide an overview of the biochemical processes involved in metabolism and how they are dysregulated in disease states. The role of hormones, such as insulin and thyroid hormone, in regulating metabolism will be discussed, as well as the impact of environmental factors such as diet and exercise. Overall, this chapter aims to provide a comprehensive understanding of the complex interplay between metabolism and disease.

Keywords:

Proteins Metabolism, Biochemical Metabolism, Lipid Metabolism, Carbohydrates Metabolism, Nutrients.

10.1 Introduction:

Biochemical metabolism is the set of chemical reactions that occur within a living organism to maintain life. These reactions involve the conversion of nutrients into energy and the synthesis of new molecules necessary for growth, repair, and reproduction. **(Berg, J.M. et.al., 2015).**

Biochemical metabolism is the set of chemical reactions that occur within living organisms to maintain life. These reactions involve the conversion of small molecules into larger ones, and vice versa, and are coordinated by a series of enzymes and other proteins. Understanding the intricacies of biochemical metabolism is crucial for developing treatments for metabolic diseases and for optimizing cellular processes in biotechnology applications. **(Voet, D. et.al. 2016).**

10.2 Types of Metabolic Processes:

There are numerous metabolic processes that occur in living organisms, including catabolic and anabolic reactions. Here are some examples of different metabolic processes. **(Nelson, D.L. & Cox, M.M. 2017).**

1. ***Glycolysis:*** This is a catabolic pathway that occurs in the cytoplasm of cells and involves the breakdown of glucose to produce ATP.
2. ***Citric Acid Cycle:*** This is also known as the Krebs cycle or the tricarboxylic acid cycle, and it is a central metabolic pathway that occurs in the mitochondria of cells. It involves the breakdown of acetyl-CoA to produce ATP, NADH, and FADH2.
3. ***Photosynthesis:*** This is an anabolic pathway that occurs in plants and some bacteria. It involves the conversion of light energy into chemical energy, which is stored in the form of glucose.
4. ***Protein Synthesis:*** This is an anabolic pathway that occurs in cells and involves the formation of proteins from amino acids. This process involves transcription and translation.
5. ***Lipid Metabolism:*** This involves the breakdown and synthesis of lipids, including fatty acids, triglycerides, and phospholipids. Lipid metabolism occurs in various organs, including the liver, adipose tissue, and muscle.

10.2.2 Biochemical Metabolism and Nutrients:

Biochemical metabolism and nutrients are closely related as nutrients serve as the building blocks for various metabolic pathways in the body. Nutrients, such as carbohydrates, proteins, and lipids, are essential for the production of energy and the maintenance of cellular function. **(Gropper, S. S.et. al. 2009).**

Carbohydrates are broken down into glucose, which is used as a primary source of energy in the body. Glucose is then metabolized through glycolysis, the citric acid cycle, and oxidative phosphorylation to produce ATP, which is the main energy currency of the body.

Proteins are broken down into amino acids, which are then used for the synthesis of new proteins, enzymes, and other molecules required for cellular function. Amino acids also play a role in the regulation of metabolic pathways, such as the urea cycle and gluconeogenesis.

Lipids, such as triglycerides and phospholipids, are broken down into fatty acids and glycerol, which are used for the production of ATP, as well as for the synthesis of cell membranes, hormones, and other molecules.

The metabolism of nutrients is highly regulated, with enzymes and other proteins controlling the flow of metabolites through various pathways. Dysregulation of these pathways can lead to metabolic disorders, such as diabetes, obesity, and cardiovascular disease. Overall, understanding the relationship between biochemical metabolism and nutrients is crucial for developing treatments for metabolic disorders and for optimizing nutrient utilization in the body.

10.2.3 Carbohydrates Metabolism:Metabolism of Carbohydrates

Carbohydrate metabolism is a complex process that involves the breakdown and synthesis of carbohydrates for energy production and other cellular functions. Understanding the mechanisms and regulation of carbohydrate metabolism is important for treating metabolic disorders such as diabetes, obesity, and cardiovascular disease. **(Berg, J.M., et.al. 2012)**

10.2.4 Proteins Metabolism:

Protein metabolism is the process by which the body breaks down and synthesizes proteins, which are essential for cellular function and survival. Proteins are involved in a wide range of biological processes, such as enzymatic catalysis, structural support, and immune defense.

Protein metabolism is a complex process that involves multiple pathways, including protein digestion, amino acid transport and utilization, and protein synthesis and degradation. The breakdown of proteins begins in the stomach and continues in the small intestine, where proteases and peptidases break down proteins into amino acids and di- and tri-peptides. These amino acids are then transported to various tissues throughout the body, where they are used for protein synthesis or energy production.

Protein synthesis occurs through a process called translation, which is catalyzed by ribosomes and involves the assembly of amino acids into polypeptide chains. This process is regulated by a complex network of enzymes, hormones, and signaling pathways that control the rate of protein synthesis in response to various stimuli, such as nutrient availability and growth factors.

Protein degradation, on the other hand, involves the breakdown of proteins into smaller peptides and amino acids, which can be used for energy production or for the synthesis of new proteins. This process is also tightly regulated by a variety of enzymes and signaling pathways.

Understanding the mechanisms and regulation of protein metabolism is crucial for treating metabolic disorders such as obesity and muscle wasting, as well as for optimizing athletic performance and muscle building. **(Berg, J.M., et.al. 2015)**

10.2.5 Lipid Metabolism:

Lipid metabolism refers to the complex set of biochemical processes that involve the synthesis, transport, and breakdown of lipids in the body. Lipids play essential roles in a wide range of biological functions, including energy storage, membrane structure and function, and cell signaling.

Lipid metabolism is divided into two major pathways: anabolism, which involves the synthesis of lipids from simpler precursors, and catabolism, which involves the breakdown of lipids for energy production. The major types of lipids involved in these processes include fatty acids, triglycerides, phospholipids, and cholesterol.

The anabolic pathway of lipid metabolism involves the synthesis of fatty acids, triglycerides, and phospholipids from simpler precursors such as acetyl-CoA, glycerol, and amino acids. This process is regulated by a variety of enzymes and hormones, such as insulin and glucagon, and involves the transport of lipids from the liver to other tissues via lipoproteins.

The catabolic pathway of lipid metabolism involves the breakdown of fatty acids and triglycerides to generate energy through a process called beta-oxidation. This process occurs primarily in the liver and adipose tissue and involves the transport of fatty acids from the cytoplasm to the mitochondria, where they are oxidized to produce ATP.

Abnormalities in lipid metabolism can lead to a variety of metabolic disorders, including obesity, type 2 diabetes, and cardiovascular disease.

Therefore, understanding the mechanisms and regulation of lipid metabolism is important for developing effective treatments for these conditions. **(Berg, J.M., et.al. 2015)**

10.3 Hormones and Metabolism:

Hormones are chemical messengers that are produced by endocrine glands and play a crucial role in regulating metabolism, which refers to the chemical processes that occur within an organism to maintain life. Hormones influence metabolism by regulating the uptake, use, and storage of energy in the body.

Insulin is a well-known hormone involved in metabolism, which is produced by the pancreas. Insulin helps to regulate the level of glucose in the bloodstream by promoting the uptake of glucose into cells, where it can be used for energy or stored for later use. Insulin resistance, which occurs when cells become less responsive to insulin, can lead to metabolic disorders such as type 2 diabetes **(Kahn & Flier, 2000).**

Thyroid hormones, produced by the thyroid gland, also play a critical role in metabolism. These hormones regulate the body's metabolic rate, which is the rate at which the body burns calories to produce energy. Hypothyroidism, which occurs when the thyroid gland produces too little thyroid hormone, can lead to a slower metabolic rate and weight gain **(Mullur, Liu, & Brent, 2014).**

Cortisol is another hormone that influences metabolism, which is produced by the adrenal gland. Cortisol helps to regulate glucose metabolism and also plays a role in the body's stress response. Chronic stress and high levels of cortisol can contribute to metabolic disorders such as obesity and insulin resistance **(Pivonello, De Leo, Cozzolino, & Colao, 2015).**

Leptin, produced by fat cells, is a hormone that helps to regulate appetite and energy expenditure. Leptin signals to the brain to reduce appetite and increase energy expenditure when fat stores are sufficient. However, in obesity, leptin resistance can occur, leading to a decrease in leptin signaling and an increase in appetite and decreased energy expenditure **(Vella, Burguera, & Clegg, 2017).**

In conclusion, hormones play a critical role in regulating metabolism and the dysregulation of hormones involved in metabolism can contribute to the development of metabolic disorders such as diabetes, obesity, and metabolic syndrome.

10.4 Metabolism and Disease:

Metabolism plays a critical role in the development and progression of many diseases. Here are some examples of how metabolism is linked to different diseases:

1. Cancer: Metabolic reprogramming is a hallmark of cancer. The Warburg effect, where cancer cells rely on glycolysis for energy even in the presence of oxygen, is a well-known example of how metabolism is altered in cancer cells. **(Pavlova and Thompson., 2016).**
2. Cardiovascular disease: Disorders such as atherosclerosis, hypertension, and heart failure are linked to alterations in energy metabolism, oxidative stress, and inflammation. **(Kolwicz and Tian., 2018).**
3. Neurodegenerative diseases: Metabolic dysfunction has been implicated in the development of neurodegenerative diseases such as Alzheimer's disease and Parkinson's disease. Disruptions in glucose metabolism, mitochondrial dysfunction, and oxidative stress are common features of these diseases**. (Butterfield et al., 2017).**
4. Autoimmune diseases: Autoimmune diseases such as type 1 diabetes and multiple sclerosis are characterized by dysregulation of immune cells and inflammation. Recent evidence suggests that alterations in cellular metabolism play a role in the pathogenesis of these diseases. **(Michalek et al., 2013).**
5. Obesity and metabolic syndrome: Obesity and metabolic syndrome are linked to alterations in glucose and lipid metabolism, chronic inflammation, and insulin resistance. These conditions increase the risk of developing type 2 diabetes, cardiovascular disease, and other metabolic disorders. **(Després and Lemieux, 2006).**

These examples illustrate the diverse ways in which metabolism is involved in the pathogenesis of many diseases.

How to Improve Metabolism:

There are several actions that can be taken to improve metabolism:

1. Regular exercise: Regular exercise can boost metabolism by increasing muscle mass and reducing fat mass. **(Jakicic et al., 2003).**
2. Eating a balanced diet: Eating a balanced diet with adequate protein, healthy fats, and complex carbohydrates can help improve metabolism. **(Ludwig et al., 1999).**
3. Drinking enough water: Staying hydrated is important for metabolism as it helps in the breakdown of fats and carbohydrates. **(Thornton, 2016).**
4. Managing stress: Stress can increase cortisol levels which can negatively impact metabolism. Therefore, managing stress through techniques such as meditation, yoga, or deep breathing can help improve metabolism**. (Epel et al., 2000).**
5. Getting enough sleep: Lack of sleep can reduce metabolic rate, so getting enough sleep is important for maintaining a healthy metabolism. **(Nedeltcheva et al., 2010).**

6. Avoiding crash diets: Crash diets or very low-calorie diets can reduce metabolic rate and can be harmful to overall health.
7. Medical treatment: Certain medical conditions such as hypothyroidism or diabetes can affect metabolism. In such cases, medical treatment may be required to improve metabolism. **(American Diabetes Association, 2021)**

10.5 References:

1. Berg, J.M., Tymoczko, J.L., & Stryer, L. Biochemistry. 8th edition. Chapter 2: Basic Concepts of Metabolism. New York: W.H. Freeman and Company. (2015).
2. Voet, D., Voet, J.G., & Pratt, C.W. Biochemistry. 5th edition. Introduction to Metabolism. New York: John Wiley & Sons. (2016).
3. Nelson, D.L. & Cox, M.M.. Lehninger Principles of Biochemistry. 7th edition. Metabolism: Basic Concepts and Design. New York: W.H. Freeman and Company. (2017)
4. Gropper, S. S., Smith, J. L., & Groff, J. L. Advanced Nutrition and Human Metabolism. Belmont, CA: Wadsworth Cengage Learning. (2009).
5. Berg, J.M., Tymoczko, J.L., & Stryer, L. Biochemistry. 7th edition. Chapter 16: Glycolysis, Gluconeogenesis, (2012).
6. Berg JM, Tymoczko JL, Stryer L. Protein turnover and amino acid catabolism. In: Biochemistry. 8th ed. New York: W. H. Freeman;. p. 925-946. (2015)
7. Berg JM, Tymoczko JL, Stryer L. Lipid metabolism. In: Biochemistry. 8th ed. New York: W. H. Freeman;. p. 739-779. (2015)
8. Kahn, C. R., & Flier, J. S. Obesity and insulin resistance. Journal of clinical investigation, 106(4), 473-481. (2000).
9. Mullur, R., Liu, Y. Y., & Brent, G. A. Thyroid hormone regulation of metabolism. Physiological reviews, 94(2), 355-382. (2014).
10. Pivonello, R., De Leo, M., Cozzolino, A., & Colao, A. The metabolic syndrome and cardiovascular risk in Cushing's syndrome. Frontiers in hormone research, 44, 49-62. (2015).
11. Vella, C. A., Burguera, B., & Clegg, D. J. Mechanisms of leptin resistance in obesity. Current opinion in endocrine and metabolic research, 2, 26-31. (2017).
12. Pavlova and Thompson. "The Emerging Hallmarks of Cancer Metabolism." Cell Metabolism, DOI: 10.1016/j.cmet.2016.08.018) (2016).
13. Kolwicz and Tian. "Cardiac Energetics: From Physiology to Clinical Applications." Current Cardiology Reviews,. DOI: 10.2174/1573403X13666180511124651. (2018)
14. Butterfield et al. "Metabolic Dysregulation in the Pathogenesis of Alzheimer's Disease: Opportunities for Drug Development." Current Pharmaceutical Design,. DOI: 10.2174/1381612822666161005144913. (2017)
15. Michalek et al. "Metabolic Regulation of T Lymphocytes." Annual Review of Immunology,. DOI: 10.1146/annurev-immunol-032712-095956. (2013)
16. Després and Lemieux. "Abdominal Obesity and Metabolic Syndrome." Nature,. DOI: 10.1038/nature05488. (2006)
17. American Diabetes Association. Type 2 diabetes. Retrieved from https://www.diabetes.org/diabetes/type-2 (2021).
18. Epel, E., McEwen, B., Seeman, T., Matthews, K., Castellazzo, G., Brownell, K. D., ... & Ickovics, J. R. Stress and body shape: stress-induced cortisol secretion is

consistently greater among women with central fat. Psychosomatic medicine, 62(5), 623-632. (2000).
19. Jakicic, J. M., Marcus, B. H., Gallagher, K. I., Napolitano, M., & Lang, W. Effect of exercise duration and intensity on weight loss in overweight, sedentary women: a randomized trial. Jama, 290(10), 1323-1330. (2003).
20. Ludwig, D. S., Majzoub, J. A., Al-Zahrani, A., Dallal, G. E., Blanco, I., & Roberts Jr, S. B. High glycemic index foods, overeating, and obesity. Pediatrics, 103(3), E26. (1999).
21. Nedeltcheva, A. V., Kilkus, J. M., Imperial, J., Schoeller, D. A., & Penev, P. D. Insufficient sleep undermines dietary efforts to reduce adiposity. Annals of internal medicine, 153(7), 435-441. (2010).
22. Thornton, S. N. Increased hydration can be associated with weight loss. Frontiers in nutrition, 3, 18. (2016).