Introduction to Exercise Physiology & Sports Performance
Wg Cdr (Dr.) Chandrasekara Guru
Directorate of Medical Services

Lecture - 16
Endocrine responses to Exercise - Part 1

Does exercise training commensurate with hormonal secretion? Does the hormone secreted has an influence on the exercise metabolism, and the energy that is being utilized during the exercise? How does the body adapt to such exercise training? And the knowledge of hormonal secretion, is it necessary for periodization of exercise training? If you are the gym trainer or the sports scientist who is looking for answers for such questions, you are in the right place. Welcome to this NPTEL course on Introduction to Exercise Physiology and Sports Performance. I am Wing Commander Chandrasekara Guru. I am a sports medicine specialist and an Assistant Professor in the field from the Armed Forces Medical College. Today I will be discussing about the endocrine system and exercise.

I shall be covering this system in two parts. What will you learn? From this session, you will be learning about the various endocrine glands of the body, the basic concepts of the endocrine system, hormone responses to the exercise, and how it regulates the exercise metabolism. We will also look into various key scenarios with respect to the application in exercise training.

So why do you need endocrine system? Endocrine system is a key system which intricately controls and regulates the internal environment of the body. In association with the nervous system, together called the neuroendocrine system, both the system communicates the complete internal organs as well as with the external stimuli. Thus the importance of this system, and hence the function is totally varied. It controls most of the functions of the body, and hence it is very important that we understand the hormones and the endocrine systems of the body. In the body, the glands are divided broadly as exocrine glands and endocrine glands.

What do you mean by exocrine glands? Exocrine glands have ducts and the gland which secrete that secretion lands through the duct into the site of action. For example; sweat glands. Sweat glands are located in the subcutaneous region of the skin and the duct ends up on the surface of the skin where the sweat is secreted outside. What about endocrine? Endocrine are group of glands where there are no ducts. These are specialized cells which secrete the chemicals and then these chemicals are secreted into the blood. So, as it is secreted into the blood, it travels across and then acts at the target cells.

And these target cells may be close to the area of secretion or can be at a remote location. But still it identifies the target based on certain specific receptors that are present in the cells. So,

these are the unique features of the endocrine system. So the chemicals that are secreted by these specialized cells are called hormones. What are the various endocrine glands which are important and their location in the body? So in this case, you can see the hypothalamus is considered the master gland, and that it is located in the hypothalamic region.

And just beneath it is the pituitary gland, which again secretes various important hormones which control various functions of the body. Going down, below at the midline you have thyroid, which is a butterfly shaped structure in front of the neck just below the mandible. Then, situated within the thyroid is specialized tissues on four such locations on both sides called as parathyroid glands. Then you have pancreas, which is an abdominal organ, which again secretes various digestive enzymes, also certain endocrine hormones. There are a pair of conical shaped structures which are located on top of the kidneys and these are called adrenal glands. And these are again an important endocrine glands of the body. Also you have the reproductive gonads in the females with the ovaries, and in males is the testis. Also in the past adipose tissue is also considered as an endocrine gland which secretes hormones. Having known about various endocrine glands of the body, let us see what is the function of the hormone. Broadly the function of the hormones encompasses changing the cell function, growth and development, maintaining and regulating the body mass and the composition of the body. It also aids in the reproductive function. It controls the metabolism and nutritional utilization of the body, and it maintains the fluid balance as well. In addition, certain hormones also control and regulate bone metabolism. So these are the broad functions that are relevant to exercise and sports.

You want to classify hormones based, as mentioned it is a chemical right. So based on the chemical structure, the hormones can be broadly classified as steroid hormones or non-steroid hormones. Steroid hormones basically because they are derivatives of cholesterol, and they form the reproductive hormones namely the testosterone, estrogen and progesterone. Also another group which are kind of steroid hormones, are the adenine cortex hormones namely the cortisol and aldosterone. With respect to the non-steroid hormones, they are formed of proteins. So, if they are formed of smaller amino acids, they are amino acid derivatives; and if they have peptide chains they are called peptide derived hormones. The amino acid derived hormones are thyroid hormone, adrenal medulla namely the catecholamines called epinephrine and the norepinephrine. The rest of the hormones which I have not mentioned here fall in the category of peptide derived non-steroid hormones.

How do they act? It is important to understand this. Again the mechanism of action depends on the classification that we have done earlier, steroid and non-steroid. The steroid hormones have different way of action, and the non-steroid hormones act differently.

So the steroid hormones as you are aware are made of cholesterol, so they are not soluble in the plasma or the blood. So, they have to be transported in the blood. So endocrine hormones are

secreted into the blood. So, these steroid hormones have to be transported in the blood with the help of some protein molecules. As they are transported they reach the target site. In the target site, as and when they reach, since they are derivatives of cholesterol they can easily diffuse through the cell membrane. They diffuse through the cell membrane and reach the cytoplasm. The moment they reach the cytoplasm there are specific receptors which are available for them to combine. So either the receptors will be in the cytoplasm, or in the nucleus. Once they join the receptor the hormone receptor complex triggers a sequence of events, resulting in the execution of that necessary function of the steroid hormone.

Whereas in case of non-steroid hormones, since they can easily dissolve they are water soluble. So they can easily dissolve in the plasma, hence, they do not need any transport molecule. So they get transported in the blood as they dissolve in the plasma and reach the target site. But, when they reach the target site since they are water soluble, they cannot easily diffuse to the cell membrane. Here, you have the expression of the specific receptor which is available in the cell surface.

The hormone combines with the receptor which is expressed on the cell membrane, and thereafter it triggers a sequence of chemical reactions called the second messenger system. So, the hormone acts as the first messenger; it triggers the receptor on the cell surface which in turn triggers the second messenger system. There are various second messengers which are the final products which further helps in executing the function of the hormone. So one of the commonest second messenger in the body is the cyclic AMP, adenosine monophosphate.

So, let us see what are the various endocrine glands, the hormones secreted by them and their function. Let us focus on hypothalamus and pituitary. Hypothalamic hormones are secreted by the thalamic neurons, here the nerve endings secrete these particular hormones. And these hypothalamic glands basically integrate the central nervous system and the endocrine system. So this is the basic integrator or the overall controller, and hence it is called as the true master gland. The hypothalamo-endocrine axis exists between the various endocrine glands.

The hypothalamus controls directly the pituitary which is beneath it, and then thereafter through the pituitary it also controls various other glands. One of the commonest axis is the hypothalamo pituitary gonadal axis, wherein the secretion of the reproductive hormones are controlled by the hypothalamic gland. The pituitary hormones are regulated by the hypothalamus based on an intricately controlled feedback mechanism. So, you have a release hormone which stimulates a certain hormone in the pituitary. The hypothalamus also secrete inhibitory hormones which in turn also can reduce the secretion of that particular pituitary hormone.

Thus, the feedback mechanism is very well maintained in the hypothalamic and pituitary loop. There are three categories of hormones that are secreted by the hypothalamus. One is the anterior

pituitary regulating hormone, the second one is the posterior pituitary regulating hormone and the third category are the rest of the hormones, which are basically related with the food intake namely the Neuropeptide Y and Orexins.

So, let us go in detail about the pituitary gland and thereafter the hormones that are secreted by the pituitary, and the target organ in which the hormone is intended to act, and what is the major function that is attained by that particular hormone. So I will first discuss about the anterior pituitary. In the anterior pituitary you have six hormones that are being secreted. One is the growth hormone. The growth hormone targets almost all the cells in the body, and it is very essential for growth and development. In fact, deficiency or disturbance in the growth hormone action during pubertal age can result in what is called as dwarfism. So there will be stunted growth, and it is also important in increasing the protein synthesis as well as mobilization of fat and utilizing it as a source of fuel.

Thereby it also spares the carbohydrate from using. So these are the points which are important to remember with respect to exercise metabolism. The other hormone which is secreted by anterior pituitary is thyroid stimulating hormone. It is basically a hormone which acts on the thyroid gland, which is the target organ to induce production of the various thyroid hormones. The other hormone is the adrenocorticotropin commonly called as ACTH, which acts on the adrenal cortex to control the secretion of the hormone secreted in the adrenal cortex.

Prolactin is basically produced to act on the breast to secrete milk production in lactating females. Follicle stimulating hormone (FSH) acts on the gonads, basically to stimulate the follicle and estrogen secretion in ovaries and in the testis it promotes sperm development. The last hormone that is secreted by anterior pituitary is the luteinizing hormone. The luteinizing hormone targets on the ovaries and the testis, to stimulate secretion of the estrogen progesterone and the testosterone, basically the sex hormones of the body. So what is the importance? So growth hormone in this list as well as the luteinizing hormone when they are given exogenously, they are found to increase the performance.

So thus they are abused to a greater extent in the field of sports. Hence the world anti-doping agency has rightly banned it, and it is banned under the S2 substance of the prohibited list of the WADA 2023 prohibited list.

Let us move on to the posterior pituitary hormones. The posterior pituitary secretes two hormones. One is called as antidiuretic hormone or vasopressin. As the name suggests, it basically acts on the kidneys. Diuresis means urine production. So it acts on the kidneys so that it maintains the water balance and regulates the blood pressure by causing vasoconstriction. So, this is an important hormone in maintaining the fluid and water balance when you do exercise. Oxytocin is another hormone which is secreted by the posterior pituitary, and this acts on the

uterus and the breast, and it is responsible for uterine contraction during the labor. So vasopressin regulates water and fluid balance during exercise. Moving on to the next gland that is the thyroid gland. Thyroid gland is located as I mentioned before in front of the neck. It is a butterfly shaped organ. It also has the parathyroid gland. So, thyroid gland produces two hormones namely the thyroxine and the tri-iodo-thyronin as well as the calcitonin. So the thyroxine hormone is the active form, which acts on almost all the cells of the body, and it is important in maintaining the basal metabolism of the body. So it increases the cell metabolism, as well as it acts on the cardiovascular system so it increases the heart rate as well as the contractility of the heart per se thereby increasing the performance. The other hormone here is the parathyroid hormone and the calcitonin which are important in terms of calcium metabolism. So, thus on a long term with exercise training it is important that these hormones are maintained at normal levels; so that there is adequate calcium metabolism which happens in the skeletal as well as the muscle function.

So T3 and T4 in exercises: increases with increased rate of work. So, as the gradation of the work intensity increases there is increase in the T3 and T4 levels in the blood, thereby increasing the metabolism of the body. The calcium and parathyroid hormone as I mentioned are important and essential for calcium metabolism, for optimum performance and function of both bone as well as the muscle.

Moving ahead let us focus on adrenal gland. So adrenal gland has two important regions with respect to the endocrine function. One is the cortex, which is outer and then the inner medulla. The adrenal gland per se is considered, or rather the adrenal medulla is considered as one of the part of the sympathetic nervous system per se. Because, we have studied earlier in the nervous system as well as in the cardiovascular and respiratory nervous respiratory system that the activation of sympathetic nervous system results in production of epinephrine and norepinephrine. These are the main chemicals that are released by the sympathetic nervous system. It also has important effect on the adrenal medulla, wherein there is something called as sympatho adrenal drive.

So the activation of the sympathetic nervous system directly stimulates the adrenal medulla to release these hormones in the bloodstream as well. So thus, adrenal medulla acts as a important endocrine gland, releasing these hormones in the bloodstream for the required function. The epinephrine and norepinephrine both actually target most of the cells of the body. With respect to them, they are basically catabolic hormones. If you consider that way catabolic in the sense, they are group of hormones which aid in breaking down of the complex stored form of energy, like as we discussed in the session on bioenergetics.

So carbohydrates are stored as glycogen. So catabolism would mean catabolic hormone will result in breaking down of the glycogen into glucose called glycogenolysis. Lipids will be broken down to yield energy, that is lipolysis. Proteins will be broken down, and they will be

used as alternate source of glucose and glycolysis. It is called gluconeogenesis. So these are the functions that epinephrine and norepinephrine does.

As I mentioned there will be stimulation of glycogenolysis in the muscle and the liver, lipolysis in the adipose tissue and the muscles. They also increase the skeletal muscle blood flow because of their action on the blood vessel. Also it acts on the cardiovascular system to increase the heart rate as well as contractility. And, because of the overall effect there is also an increase in the oxygen consumption. Norepinephrine predominantly causes vasoconstriction, and causes an increase in the blood pressure.

So, with these hormones obviously endogenous production aids in better performance. So when they are given from outside exogenously, they may unethically or illegally increase the performance and hence they are banned. They are specifically banned in competition and they are grouped under the S6 group of the prohibited list by WADA. However, when epinephrine that is adrenaline if used as local, you know administration for an ophthalmic solution or a nasal administration. Or if it is mixed along with a local anesthetic agent while doing a suture, or you know any local procedure these are all not prohibited.

So this is an important thing that as a practitioner, if you are a medical doctor you need to be aware about these things. Moving ahead with the cortex part of the adrenal gland. The cortex part of the adrenal gland secretes three important hormones. One is the mineralocorticoids or the main hormone, that is 95% of the mineralocorticoids is the aldosterone. Then the second one is the glucocorticoids, the majority of the glucocorticoids is the cortisol or the hydrocortisone.

And the third group is the androgens and the estrogens, which are mainly the sex hormones. So the adrenal cortex collectively you know produces hormones which are basically steroid hormones. All these hormones are steroid hormones. So let us see one by one. The aldosterone targets the kidneys as we mentioned earlier it helps in the sodium retention. So, when sodium is retained, it automatically retains water as well. So because of which, in exchange you either lose potassium or the hydrogen ions. So, by which there is water balance, as well as the minerals are balanced because of which there is a proper internal milieu that is maintained in the body. Coming on to the glucocorticoids, glucocorticoids or cortisol acts on most of the cells of the body. And the cortisol has an anti-inflammatory effect as well as a catabolic effect.

It controls the metabolism of the carbohydrates, fats and proteins. And, it also has anti-inflammatory action as I mentioned. The third group are the androgens and the estrogens. They are the target organs of the gonads basically. And they assist in the you know various male and the female sex characteristics.

So, the anabolic androgenic steroids, when they are used exogenously they are prohibited; and they are banned under S1 group of the WADA prohibited list. Another important endocrine gland, which is essential when you are performing exercise, is the pancreas. Pancreas is an abdominal organ. It is retroperitoneal, present more towards the back. And the pancreas produces both you know as exocrine function, like it produces various pancreatic enzymes, which aids in digestion of fats mainly amylase and lipase as well as the proteins.

The endocrine function of the pancreas are done by specialized cells which are present in the pancreas tissue. They are called the islet of langerhans. And, these have different types of cells which produce different hormones. So, the insulin is the hormone which is produced by the pancreas, which targets almost all cells. The main function is to decrease the blood glucose level and it is an anabolic hormone. So the anabolic effect of insulin is important for all this positive effect that happens in the energy stores. Glucagon is antagonistic to insulin. Whenever there is a drop in the blood glucose level immediately glucagon is released; and it causes catabolism, that is production of glucose from the other sources. So thus it tries to maintain the blood glucose level. The third group of hormones which is important is the somatostatin, which basically has an effect on both insulin and glucagon secretion.

So, when insulin is again used exogenously, this is again banned under S4. Kidney also has some endocrine function. Kidney produces two hormones. One is called renin, which acts on the adrenal cortex. And thereby, it causes an increase in the blood pressure and it assists in the aldosterone for blood pressure regulation.

The other hormone that is produced by the kidney is your erythropoietin. Erythropoietin is very important with respect to sports and exercise, because erythropoietin is essential for stimulation of red blood cells. So, when red blood cells or erythropoiesis happens you will have more amount of red blood cells available for better oxygen transport, which we have discussed in our cardiovascular system. So, when the same thing is given from outside; genetically engineered erythropoietin are available and if they are given, they can further increase the performance. So when they are used from outside, they are banned for athletic competitions by WADA, and they are banned under the S2 group of the prohibited list. So the remaining part of the endocrine gland is the gonads, the reproductive system wherein in males the testis produces testosterone which acts on the sex organs as well as the muscle.

So the action on the muscle is important, because of which there is increased muscle growth. So, we are all aware that there is increased production of the sex hormones when the individual reaches puberty. So it is important especially in the case of children as well as adolescent athletes who practice. So, testes producing testosterone have a major effect on muscle growth and thus also favors exercise during the pubertal growth phase.

The other important in the female is the estrogen and the progesterone. The estrogen and progesterone is the predominant female sex hormone which is targeting the sex organs as well as the adipose tissue and the bones. So, in addition to the stimulation of female sexual characteristics, it also aids in menstrual cycle regulation and increases the fat storage. And it is also essential to maintain bone mineralization in the skeletal tissues. So thus, a certain amount of testosterone in the males also gets converted to estrogen and thus gives that protective effect for the bones, both in males and females. So the sex hormones is important with respect to the exercise periodization, especially as I mentioned in younger adults and young adolescent athletes.

Menstrual cycle again has to be aligned with the exercise training for optimum performance. And these again, are also produced with respect to various types of training, and hence the ratio is also used in the diagnosis of overtraining syndrome. Deficiency of these hormones can result in a condition called as relative energy deficiency syndrome especially in athletes, because of low energy availability. So that is an important aspect with respect to the sex hormones, and these hormones as we know they promote performance. So if they are used exogenously they are banned by the WADA under S1 anabolic agents.

So, we have seen various endocrine glands, the hormones produced by them, what are the target organs and the major functions of these hormones. Let us see how they act. So, they stimulate the target cells basically to either increase the intracellular protein synthesis rate or they influence the enzyme activity rate. Or they also influence the cell membrane transport which happens in the cell and they also can secrete various molecules and that can be influenced by the hormones. So an example for influencing the intracellular protein synthesis is growth hormone which acts on the protein synthesis.

Say with respect to the enzyme activity rate we discussed Glucagon is a catabolic hormone it affects the enzyme activity rate and thereby causes the lipolysis. With respect to the cell membrane transport, an example would be insulin, insulin increases the glucose uptake by increasing the glucose transport into the cell. About the secretory activity, thyroid stimulating hormone which is secreted by the anterior pituitary acts on the thyroid gland to produce or secrete T3 and T4. So, how is this secretion and inhibition of the hormones maintained or regulated?

So the feedback mechanism happens by three broad ways. One is by hormonal stimulation, or it can be by the increase or decrease in certain molecules or compounds or chemicals or ions in the blood. It is called as humoral factors. Or it can be by the activation or inhibition of the certain nerves. So that is called the neural influence. An example for hormonal is, we discussed about the hypothalamus and the pituitary. So hypothalamus secretes hormones which act on the pituitary to either secrete or inhibit the production of the anterior pituitary hormones.

So that is an example of hormonal feedback mechanism. For a humoral factor example, you can have an example of blood glucose. Whenever there is an increase in the blood glucose level beyond 100 milligram immediately stimulation of the insulin. Whenever the value goes down, it immediately stimulates the glucagon. So thus the feedback mechanism is regulated by this blood glucose level in the blood. What about the neural influence? As we discussed earlier, the sympathetic nervous system stimulation of that would immediately stimulate the adrenal medulla to release catecholamines, or epinephrine and norepinephrine.

So how are these hormones regulated? The regulation happens mainly by the level of hormone that is available in the plasma, and also the number of target receptors that is available in the target cells. And the bonding that happens between the hormone and the receptor complex. These factors, in addition to the feedback mechanism, regulate the hormonal milieu. So these are the factors which also undergo various adaptations whenever there is exercise training.

So to summarize, we saw various endocrine glands. What is an endocrine gland? What are the basic concepts with respect to the function of a hormone? Classification of hormone based on the chemical structure and then the mechanism based again on the different chemical structure. We saw in detail about the functions and the hormones in the target cells of the hypothalamus, anterior pituitary hormones, posterior pituitary hormones, thyroid hormones, the pancreas hormones namely the insulin, glucagon, somatostatin, also the adrenal medulla and the cortex. And the kidneys acting as an endocrine gland as well as the sex hormones. We also discussed the various of this hormone system in the body. So if you are interested in further reading you can consult the standard textbooks on exercise physiology and strength conditioning. Thank you.