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The Biology of Thermoregulation in the Animal Kingdom

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Abstract—*The core body temperature in the animals is under homeostasis. Any variation from its normal physiological temperature is perceived as stress. It affects the body adversely and reduces the capacity to perform. Ectotherms try to fight this stress by either changing their microenvironment or going into hibernation. Whereas the endotherms adapt to the ambient temperature by changing their microenvironment and by thermoregulation. This improves their capacity to perform and also withstand various other types of stressors. Thermoregulation is a multidimensional process of adaptation. It can confer adaptation for short or long duration. Acclimatization or acclimation is thermoregulatory adaptation for short duration. The adaptation for long duration is the basis of evolution. Initially in acclimation these adaptations can be acquired by modifying behavioral, physiological and biochemical activities in the organism. The evolutionary adaptations include genetic and morphological changes as well. The adaptations can be reversible or irreversible. Adaptation to heat and cold stress have several similarities and certain uniqueness. Thermoregulation in heat and cold stress are like two sides of the same coin. It brings down heat in heat stress by diverting circulation to skin surface which cools the body by sweating. In cold stress it increases body temperature by achieving thermogenesis by shivering and increasing basal metabolic rate. Chaperones which are upregulated in thermoregulation of heat and cold stress can impart cellular stability and protect against apoptosis. The adaptation against heat stress protects the body from dehydration by increasing plasma volume by regulating water and electrolyte balance. The adaptation against cold stress provides increased thermogenesis by regulating the energy metabolism. The habituation is part of long term adaptation to these stressors as the organism gets used to these conditions mentally which helps them to perform optimally in stressed conditions. The evolutionary adaptation is provided by decreased threshold of regulatory switches.*

1. INTRODUCTION

The ambient temperature can affect the physiological temperature of the animals in various ways. In those animals in which the physiological temperature remains nearly constant are called homeotherms or endotherms e.g mammals. Whereas the animals whose physiological temperature varies as the ambient temperature does are referred as poikilotherms or ectotherms e.g frog, snakes etc. Any change in physiological temperature in living being is perceived as stress. If the heat affects the physiological temperature it is seen as heat stress. On the other hand if the cold condition affects the physiological temperature it is seen as stress due to cold. The living beings try to protect themselves from the hot and cold stress by changing their environment around themselves i.e their clothes, habitats etc. Besides this the thermoregulatory systems within their body help both the endotherms and the ectotherms to bring about changes in their body which helps them to withstand heat and cold stress better.

2. EFFECTS OF HEAT AND COLD STRESS

In Human beings the heat and cold stress affects the children, aged and the women more then men. The effect of stress differs with available skin surface area, subcutaneous deposits under the skin and fitness. These conditions are called as Hyperthermia and Hypothermia [3].

2.1. Hyperthermia

In the heat stress the core body temperature (CBT) and skin temperature increases above normal which is called as Hyperthermia. The skin/rectal temperature also shows an increase in these individuals. It is accompanied by increased heart rate and diminished ability to sweat, vasodilation in the skin, vasoconstriction in the visceral organs, decreased plasma volume etc. This decreases the functioning capacity of an individual and causes illness due to heat[4,6]. There are four types of diseases associated with hyperthermia viz. heat cramp, heat syncope, heat exhaustion and heat stroke. In heat cramp the limb muscles show pain due to increased loss of sweat. In heat syncope there is fainting due to heat and this occurs due to decreased blood flow to the brain. In the heat exhaustion stage the athletes cannot show optimal performance due to heat syncope or heat cramps etc. Heat

stroke occurs due to decreased blood flow to brain which can cause dizziness and fainting. It is the most serious condition of hyperthermia. In all these cases there is less blood flow to the skin, low sweat rate, increased heart rate, respiratory rate and Basal Metabolic Rate (BMR). The energy metabolism becomes sluggish whereas the electrolyte and water metabolism becomes active. The biochemical effects of heat stress show changes in hormones and proteins. Serum creatine kinase (CK) Lactate Dehydrogenase (LDH), Aspartate Transaminases (AST) and Alanine Transaminases (ALT) are increased in heat stroke[2]. These are indicative of tissue injuries. The enzymes LDH, creatine kinase (CK) and citrate synthase show change in their isozyme pattern and decrease in enzyme activity. The enzymes show changes in conformation and increased proteolysis[24]. The hormones like prolactin, catecholamines, antidiuretic hormone show an increase whereas the growth hormone and thyroxine show a decrease. Catecholamines appear to help in bringing about the changes in cardiovascular system. The decreased thyroxine affects the BMR. As the rate of respiration increases the acid base balance is affected in cattle. It leads to alkalosis in hot day climate which manifests as low urine pH. Whereas at night the ammonia secretion increases in urine[9]. The genes related transcription levels of chaperones, osmotic stress apoptosis, transcription, translation, protein folding response are upregulated. Some of the protein folding proteins called chaperones like Hsp 40, 70, 90 and 105 have been shown to increase with increased exposure to heat[10,15]. The Nuclear factor of activated T cell (NFT5) which is also reported to increase due to hypertonicity. They help to regulate osmotic stress. They can act through Map K1 or CsnK1 genes to regulate hypertonicity. These genes are also linked with antiapoptotic genes like ERK[2].

2.2. Hypothermia

In the cold stress the CBT and skin temperature decreases and the condition is called as Hypothermia. It shows less blood supply to the skin surface. It increases shivering. The heart rate decreases, blood flow to the visceral organs increases, and BMR decreases. To counter the cold stress the thyroxine levels increases which helps to increase the Basal metabolic rate. The lipid and carbohydrate metabolic rate increases. The enzymes like LDH show change in conformation and increase in specificity. They exhibit greater thermal stability[24]. Cold stress increases the plasma concentrations of hormones like adrenaline, glucagon, growth hormone, ACTH, insulin, adrenal steroids and TSH. The stress hormones like epinephrine and norepinephrine also increases. It also activates the sympathetic nervous system. The hypothermia decreases the level of heat shock proteins. It increases the concentration and activity of enzyme proteins for lipid and glucose metabolism. The Hsp72 levels are increased by cold shock in the tissues in visceral organs. There is upregulation in heat shock factor 1 (HSF1). This is similar to that seen in hyperthermia but the mechanism of action of HSF1 in inducing chaperone in hypothermia is different [9].The Hsp70 b has been reported to decrease but cold shock proteins have been reported to increase in mammalian cells in response to cold shock [8,25].

3. THE THERMOREGULATORY RESPONSES

Thermoregulation is an adaptation which brings about homeostasis in CBT and restores the normal physiological temperature[13]. It improves the performance of the person. These adaptations can be shown within short term or long term.

3.1. Short term adaptations

These are popularly called as acclimitization or acclimation. Acclimitization responds to more than one stressor e.g temperature and humidity. Whereas acclimation occurs in response to one stressor alone e.g temperature in a controlled environment as in laboratory or aquarium. It can manifest within a short duration of 1-4 days or little longer duration of two weeks. These exposures improve the vital responses of the living body. These effects are short lived and disappear within three weeks. These occur in an individual and are reversible. These are also called as ecological responses.

3.1.1. In Hyperthermia

The adaptation decreases the CBT and skin temperature as blood flow to skin increase and the sweat rate increases. This causes increased loss of sodium. These changes are manifested as small changes but increase when the exposure to heat increases. It leads to increase in plasma volume[20,22]. There is increase in total body water which may be due to aldosterone upregulation which helps to conserve sodium and water [23]. The antidiuretic hormone increases which prevents water loss from the body. Some of the regulatory small RNAs like mir23a increase in heat stress. These microRNAs can affect the expression levels of chaperones and antapoptotic genes[7,21]. There is different expression level of genes which confers cellular adaptation to heat stress. The apoptotic genes, chaperone genes participating in protein unfolding responses are upregulated. The chaperones are one of the major group of proteins which show a rapid rise in concentration within few hours of heat stress and continue to remain upregulated. The genes which are known to be the transcription factor like Nuclear factor of activated T cell (NFAT 5) and heat stress specific factor (HSF1) have been seen to be upregulated in heat stress. NFAT5 has been shown to respond to dehydration[18]. Toner enhancer binding protein (ToneE BP)/NFAT 5 increases Hsp70 response in response to hypertonicity[28]. Increased Hsp70 protects cell from apoptosis [10,16,17]. It inhibits the mitochondrial pathway of apoptosis. Hsp 70 can also inhibit caspase 9 one of the key players of apoptosis and help to release proapoptotic factors from mitochondria. These actions of Hsp 70 are helped by cochaperones like Hsp40. NFAT5 regulates the transcription of aqauaporin (AQP2) which are water channels which help to absorb water from the collecting duct under the influence of

vasopressin (ADH) Acclimitisation can help to cope up with all these situations[5,19]. Thus we see that adaptation to heat upregulates several genes which control water and electrolyte balance along with the apoptotic genes.

3.1.2. In Hypothermia

The adaptation increases the CBT and skin temperature. There is increase in metabolic rate, decrease in heat conductance and total heat loss. The shivering activity reduces[11, 14]. Fat insulation help to adapt to cold stress better. The heat shock protein expression increases further[1,27].There is increase in cold shock proteins e.g CIRP (cold-inducible RNAbinding protein) Cirp and Rbm3, in mammalian cell lines. These acts as RNA chaperones[12]. Differential expression of genes is an adaptation to anoxia. In poikilotherms three group of genes like iron binding proteins, antioxidants and anticoagulants prevent the blood from freezing in the cold water. The antioxidant enzymes are superoxide dismutase, catalase, glutathione peroxidase, glutathione

S-transferase, and peroxiredoxin, proteins like thioredoxin, and metabolites like ascorbate and glutathione. These genes are under the regulation of transcription factors like hypoxia inducible factor (HIF-1), mitogen activated protein kinase (MAPK), c Jun N terminal kinase (JNK) , stress activated protein kinase (SAPK) and ERK. These may confer short term adaptations. MAPK responds to environmental stressors and is involved in osmotic regulation. Some freeze responsive proteins like FR10, FR47 and Li16 are also seen to be upregulated. The iron binding proteins are hemoglobin, transferrin and ferritin which may be helping in oxygen delivery to tissues. The anticoagulants upregulated in hypothermia are antithrombin and heparin cofactor II which prevent thrombin formation [26]. Thus adaptation in hypothermia is upregulating genes which would increase nonshivering thermogenesis and those genes which will prevent freezing of blood.

3.2. Long term adaptations

These are popularly known as habituations or evolutionary adaptations. Habituation is also a kind of adaptation which has the involvement of neural pathway which helps in getting mentally adapted to stress condition. The evolutionary adaptation makes them better suited for the environment. These are the adaptations which can be passed on from generations to generations. These changes are seen in a group of individuals living in a particular habitat. These are evolutionary responses. These individuals are hardy and can withstand several other stressors without affecting the health of the individual.

3.2.1. In Hyperthermia

In the case of individuals living in hot places the rate of sweating is lower and heart rate does not increase too much. They also maintain lower rectal temperature resulting in a better thermal homeostasis even while working[11]. They also develop decreased threshold to various regulatory switches involved in the process.There is lower sweat threshold along with better distribution of sweat. Their BMR is low in warm weather. The levels of chaperones continue to remain higher.

Psychological adaptations are the habituations which are the neural adaptation. These help to better the performance. Thus these adaptations help the individuals to perform optimally in heat stressed conditions without affecting their health adversely.

3.2.2. In Hypothermia

The long term adaptation to hypothermia can be of three types viz habituation, metabolic adaptations and insulative adaptation. Habituation mainly decreases the physiological and psychological responses. Whereas the metabolic responses increase the metabolic rate. Insulative adaptations are the changes in the body fat cover which prevent heat loss[26]. These are seen in individuals living in very cold countries. The skin blood flow shows vasoconstriction and non shivering thermogenesis. The adapted individual will show lesser fall in skin temperature when exposed to cold due to adaptation in vasomotor responses. But this shows greater decline in CBT. The well adapted individuals show delayed shivering in response to cold. The metabolic rate which are higher in short term responses decrease in long term adaptations. Their BMR increases seasonally in cold weather. They show hypertrophy of thyroid, adrenal cortex, heart, kidney, liver, digestive system as compared to non cold exposed individuals. There is marked increase in brown adipose tissue which may contribute to nonshivering thermogenesis[11]. The oxygen consumption of visceral organs is higher than muscle and skin. Their sympathetic stimulations in response to cold are also decreased. Thus the long term adaptations help the individual to perform better in hypothermia keeping their physiological response almost normal.

4. CONCLUSION

Hyperthermia and hypothermia are clinically opposite conditions. The thermoregulatory mechanisms including the physiological, biochemical and genomic changes help to restore it to normal. The changes in water/energy metabolism and activity of heat shock proteins/cold shock proteins appear to be key points of regulation.

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