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Metabolic Rate and Body Temperature Reduction during Hibernation

Hibernation occurs in a number of animals. It is a way to escape unfavorable environmental conditions. An animal that hibernates can hibernate anywhere from a few days to a few weeks. After that set number of days, the animal will wake up for a few hours to raise its body temperature. It will then search for nutrition and then continue hibernation until the conditions are optimal. When hibernation occurs, there is a drop in both metabolic rate and body temperature. The severity of the drop depends upon the length of hibernation and the body mass of that particular animal. Recently, it was found that the reduction of body temperature does affect the metabolic rate in addition to other inhibitory mechanisms. However, it has also been found that metabolic rate, once affected by temperature, will affect the temperature during hibernation as a regulatory control.

The reduction of the metabolic rate and body temperature occurs as an energy saving mechanism during unfavorable conditions. With metabolic rates lowered, the animal can remain asleep and not eat for up to 7 months (Geiser 2004). This is attributed to the fat reserves that the animal generates prior to hibernation (Geiser 2004). With the body temperature being maintained lower than normal, an animal can save the energy that would be needed to boost temperatures to normal. The energy to raise body temperature comes from metabolic pathways. With these pathways still on but reduced an animal can remain in hibernation longer at a lower temperature and still save the energy produced. However along with the continued metabolic rates comes the continual production of waste that must be removed (Geiser 1988). Due to the production of waste an animal must wake up a few times during hibernation for about 24 hours to relive itself of that waste (Geiser 1988).

During hibernation both the metabolic rate and body temperature fall drastically. Typically the body temperature is reduced from 32°C-42°C to -3°C-30°C and the metabolic rate is reduced by 5-30% of the basal metabolic rate (Geiser 2004). As the animal enters hibernation the body temperature Tb falls due to thermal inertia (Geiser 2004). The Tb falls drastically below the thermoneutral zone (TMZ) which is the normal body temperature level of the animal (Geiser 2004). This low body temperature signals to the metabolic pathways through enzymes to reduce the metabolic rate of the animal (Geiser 2004). The intensity of the reduced temperature and metabolic rate and the importance of regulating enzymes are based upon the size of the animal (Geiser 2004). Smaller animals have a smaller surface area which means more heat lost as a result. With the ability to reduce their body temperature immensely, they are able to reduce Tb precipitously, and thus lowering their metabolic rate in a shorter time period without the use of enzyme regulation (Geiser 2004). Medium-sized animals rely on enzyme inhibition to initiate hibernation then use the low Tb to dive hibernation to completion (Geiser 2004). Larger animals have large surface areas, which causes their heat loss to be at a slower rate than smaller animals (Geiser 2004). Due to their size, larger animals must rely greatly upon enzyme inhibition to initiate and maintain hibernation (Geiser 2004). Since enzymes are the main regulatory molecules during hibernation, there must be many of them that work in a variety of environments since enzymes only work in a range of conditions. For example, enzymes that are most active at lower temperatures will work best at maintaining hibernation where as the enzymes active in lowering the Tb will work best in higher temperatures.

There are many ways an animal can regulate the body temperature and metabolic rates during hibernation. One possible mechanism is reversible phosphorylation of many key enzymes in metabolic pathways such as phosphofructokinase, pyruvate kinase, and pyruvate dehydrogenase (Storey 1997). This causes these enzymes to be deactivated and for the metabolic pathway to stop (Storey 1997). A main metabolic process that is affected is glycolysis. Since phosphofructokinase is a main enzyme in the glycolytic pathway, the reversible phosphorylation of this enzyme stops this pathway completely (Simon 2008). If half of the pathways in an animal's body are stopped by reversible phosphorylation of enzymes then the metabolic rate will be cut in at least half of its basal metabolic rate. As a way to ensure that energy is being produced while in hibernation many animals switch to fermentation (Storey 1997). In addition to reversible phosphorylation of key enzymes, these enzymes can be regulated at the genetic level as well (Storey 1997). By not coding for these enzymes beginning at transcription of the gene, the enzymes will not be present for the metabolic pathway to function (Storey 1997). Another regulatory method of enzymes in metabolic pathways is the use of allosteric inhibitors (Storey 1997). These inhibitors that are active at lower temperatures deactivate enzymes and shut down the metabolic pathway. Reduced tissue phosphogen and adenylate levels increase the depression of metabolic pathways (Storey 1997). Another control of the metabolic pathways for animals in hibernation deals with the waste products of the remaining active metabolic pathways after initiation into hibernation. Osmolytes are used to initiate the retention of water and urea to decrease the necessity to wake up and relieve itself (Storey 1997).

Another regulatory mechanism occurs at the mitochondria membrane. Here, the PDH enzymes that are responsible for bringing carbohydrates into the mitochondria, where many metabolic pathways occur, are suppressed and as a result no carbon source enters the mitochondria (Storey 1997). With no carbon source or substrate entering the mitochondria, no metabolic pathways can operate; therefore, the metabolic rate as a whole is suppressed (Storey 1997). With the decreased metabolic rate comes the maintenance of a low body temperature. The lowered body temperature depresses many enzymes since enzymes are functionally in their specific range of temperatures. The low Tb is not optimal for many of the enzymes necessary for the metabolic pathways; therefore, negative feedback occurs depressing the metabolic rate further (Storey 1997). With the use of a range of enzymes, metabolic reduction during reducing body temperature can be effortless (Storey 1997).

Hibernation is also under endocrine control through Neurosecretory System. This is located in the hypothalamus of the brain and is composed of many neurosecretory cells that secrete endocrine signals into the bloodstream that signal the body to remain in hibernation (Hudson 1979). The use of stains track the size of these cells throughout hibernation and it is found that they are the biggest during descent into hibernation and smallest during arousal (Hudson 1979). The neurohormones 5-hydroxytryptamine, norepinephrin, and acetylcholine, which are involved in reducing body temperature, these cells secrete also rise in concentration during hibernation (Hudson 1979). These neurohormones cause the animal's body to increase the heat loss per day in addition to the already reduced metabolic rate not producing enough heat (Hudson 1979). 5-hydroxytryptamine increased 15 fold during onset of hibernation and 24 fold during hibernation in the golden hamster (Hudson 1979). An additional injection of 5-hydroxytryptophan, a precursor to 5-hydroxytryptamine, prior to the hamster's arousal from hibernation delays arousal and causes a continuation of hibernation. However, the suppression of norepinephrin causes a decrease in body temperature especially in the arctic ground squirrel (Hudson 1979). In the arctic ground squirrel the norepinephrin levels were highest during the activity following hibernation (Hudson 1979). A tyrosine hydroxylase inhibitor, when injected before arousal from hibernation, interferes with the production of norepinephrin and causes a continuation in hibernation (Hudson 1979).

Regulation of the thyroid also has an effect on reducing body temperature (Hudson 1979). An inactive thyroid causes a reduced body temperature (Hudson 1979). In ground squirrels, the thyroid is temporarily shut off to maintain hibernation at a temperature of about 0°C (Hudson 1979). By turning the thyroid gland on and beginning secretions again, the animal is either arousing from hibernation of bringing the body temperature up from a critically dangerous low temperature (Hudson 1979). Chipmunks use the inactivation/activation cycle of the thyroid gland to maintain their body temperature between 5°C and 12°C during hibernation without falling below that minimum temperature (Hudson 1979). It has been found that desert squirrels can adapt to the high heat of desert life by inactivating their thyroid for short periods of time each day (Hudson 1979).

The process of conduction is another mechanism animals utilize to reduce their body temperature (Moyes 2008). The process of conduction involves the transfer of thermal energy from one environmental surface to the animal (Moyes 2008). An example of an animal that uses conduction is the echidna (Andersen 2007). The echidna buries itself into the earth to where the ground is cooler (Andersen 2007). Here, the low temperature of the soil combined with the reduced metabolic rate allows the echidna to lower its body temperature (Andersen 2007). These animals and others that burrow beneath the soil escape the suns radiation. Radiation from the sun warms an animal's body temperature up (Moyes 2008). Since the idea behind hibernation is to reduce body temperature, animals burrow beneath the soil to where the majority of the sun's rays and thermal energy cannot reach them. The low body temperature is maintained by another process called convection in which the animal will release thermal energy to the surrounding soil as a way to further reduce its body temperature (Andersen 2007).

Hibernation is a defensive mechanism that many animals utilize if the environmental conditions become unfavorable. These animals can temporarily shut down many metabolic pathways and reduce their body temperature through the many physiological processes discussed above. By utilizing these reduction processes an animal that might not have had a chance in the cold winters or time of drought can now adapt to these harsh conditions and make it through to the next season.

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