



4b. The Elimination of Carbon Dioxide Concentrations from the Body Increases Life Span

The elimination of carbon dioxide from human lungs is regulated to maintain body homeostasis (that is, to maintain a constant internal environment). The most important regulator of carbon dioxide elimination is the concentration of carbon dioxide in the arterial blood. As the concentration of carbon dioxide increases in arterial blood, the respiratory centre in the brain is stimulated reflexly to increase ventilation in the lungs. The increase in ventilation facilitates the elimination of carbon dioxide from the lungs to the atmosphere. However, the process of carbon dioxide elimination from the lungs is time-dependent. It takes several minutes or more for an increase in arterial carbon dioxide concentration to result in an increase in ventilation. The elimination of acid from the body is even more time-dependent. Acid is eliminated in a complex manner via the kidneys and is secreted and excreted into the urine. The response of the kidneys to an increase in plasma acid concentration may take twenty-four hours or longer.

The time dependencies for the elimination of carbon dioxide and acid from the body result in the constant failure of homeostasis at the cellular level. Intracellular homeostasis is very dependent on the "here and now"; is very dependent on the immediate maintenance of ideal biochemical conditions. Failure of cell homeostasis contributes to (if not initiates) the processes of ageing.

Many hundreds of experiments have been conducted over the past fifty years in attempts to increase the life spans of humans, other mammals and other animals. The only known repeatable experiments that successfully increase life span within a single generation all correlate to the decreasing of carbon dioxide concentrations in body cells. When carbon dioxide concentrations are decreased in body cells, life span is increased by thirty to fifty percent in mammals and one hundred percent in fish and reptiles. When carbon dioxide concentrations are increased in body cells, life span is decreased.

The original experiments to increase life span were conducted in mammals over fifty years ago and involved restricting the amounts of food (calories) consumed. These experiments later became known as the calorie restriction experiments. They have been repeated successfully many times by many independent scientific institutions of international repute. When food is restricted, less carbon dioxide gas is produced per unit of time from the metabolism of food in body cells.

Carbon dioxide concentrations have been decreased experimentally in fish and reptiles by the lowering of the body temperatures of these animals. When body temperature is lowered, the metabolic rate of body cells is lowered and less food is metabolised to carbon dioxide gas per unit of time. Fish and reptiles have their life spans increased by one hundred percent or more when their body temperatures are lowered. In nature, fish such as the sturgeon and rock fish that live at very cold temperatures have very long life spans.



Indeed, in nature, animals that have evolved ways to eliminate carbon dioxide efficiently from their bodies can have extraordinarily long life spans. Some animals even demonstrate negligible signs of senescence and may be potentially immortal - save for accidents, starvation and predation. Examples include species of bivalve molluscs, lobsters, tortoises and birds. Some species of ocean fish also may be potentially immortal. These fish eliminate carbon dioxide from their gills into an alkaline (magnesium bicarbonate and calcium bicarbonate) ocean environment. This process is so efficient in eliminating carbon dioxide that it gives the fish a blood carbon dioxide concentration less than ten percent of that of humans (4mm Hg carbon dioxide partial pressure or 5,000 parts per million in fish; compared with 45mm Hg carbon dioxide partial pressure or 60,000 parts per million in humans).

Perhaps the most interesting and innovative ways of eliminating carbon dioxide efficiently, and subsequently living longer, have evolved in some flying animals. Flying requires very large amounts of energy and results in the production of very large amounts of carbon dioxide. This carbon dioxide needs to be eliminated efficiently so that acid conditions do not arise in the muscles associated with flying. Flying birds and bats have evolved ways of eliminating carbon dioxide efficiently and, as a result, flying birds and bats have much longer life spans relative to other animals.

Normally, animals with a low body weight live for short periods of time and animals with a high body weight live for long periods of time. The reason for this is that the metabolic rates of body cells in small animals, especially mammals, are much higher (by up to ten times) than the metabolic rates of body cells in large animals. Hence, in large animals much less carbon dioxide gas is produced in a body cell per unit of time. Large animals live longer. A mouse lives three years, a horse lives thirty years, an elephant lives seventy years and the bowhead whale lives two hundred years (or longer). However, some flying birds and bats have evolved ways of eliminating carbon dioxide so efficiently that they live five to ten times as long as non-flying animals of similar body weights. Some species of bats that have the same body weight as a mouse live for thirty years (ten times as long as a mouse). Some species of birds live to ninety years. Many species of small birds live to sixty years. The Scottish fulmar (a small sea bird) shows little, if any, signs of senescence or ageing at all.

Birds have high metabolic rates and body temperatures that are 3°C higher than mammals. The average flying bird (strictly, flying passerine bird) has a metabolic rate that is fifty percent higher, and produces fifty percent more carbon dioxide in its body cells, than a mammal of similar body weight. However, birds eliminate carbon dioxide from their bodies several hundred percent more efficiently than mammals. This is achieved by having anatomically very efficient lungs. Birds are able also to take up oxygen through the lungs into the body more efficiently than mammals. The high oxygen uptake is needed for the high metabolic rate of birds. This high oxygen uptake helps to displace carbon dioxide from the haemoglobin in red blood cells and helps to displace carbon dioxide from the tissues.



In mammals, the lungs consist of millions of blind-ending alveoli where gas exchange occurs. These alveoli are never empty completely, so inspired air is mixed always with "stale" air of relatively high carbon dioxide concentration. By comparison, the lungs of birds consist of long narrow open ended tubes called parabronchi. Fresh air is moving always through the parabronchi in one direction due to a system of air sacs that function somewhat like bellows. The air sacs allow birds to keep fresh air flowing in flight during both inspiration and expiration. There is no "stale" air of high carbon dioxide concentration in the lungs of birds. In addition, air flowing through the avian lung moves in the opposite direction to the blood supply. This allows for an efficient counter-current exchange of gases. Birds have also a comparatively large heart with a rapid heartbeat. This gives birds a rapid and efficient blood circulation which assists in gas exchange in the lungs.

On the other hand, bats are mammals and have mammalian lungs with blind-ending alveoli containing high carbon dioxide concentrations. Yet the twelve gram little brown bat (*Myotis lucifugus*) lives to thirty years and many bats that weigh less than ten grams live ten to fifteen years.

Bats possess different methods of eliminating carbon dioxide concentrations from their bodies than birds possess. On a weight basis, bats have a relatively large skin surface area. This contributes to the elimination of carbon dioxide. For example, the large thin hairless wing membranes contribute to about ten percent of total carbon dioxide elimination during rest and many times this amount during flight. But bats eliminate carbon dioxide by spending most of their time hanging around upside down. Because carbon dioxide is fifty percent heavier than air, carbon dioxide tends to pool in the lower parts of the mammalian lung. When bats hang upside down, the heavy carbon dioxide falls from the alveoli of the lung and is replaced by lighter oxygen. By eliminating carbon dioxide efficiently from their bodies, birds and bats possess long life spans.

People who live at high elevations have long life spans (strictly, long life expectations). In the U.S.A., people who live at elevations above three hundred metres live longer statistically than people who live on the coast. Throughout the world, people who live at elevations above two to three thousand metres have exceptionally long life spans. For example, people who live in the high valley areas of Ecuador, Georgia and Kashmir often live past one hundred years. At these elevations, the human body undergoes an adaptive response (acclimatisation) to the low partial pressure of oxygen in the atmosphere. Lung size is increased, red blood cell numbers increase, haemoglobin concentrations increase, and the respiration rate increases. These adaptive responses increase oxygen concentrations in the tissues and help to increase the transport and elimination of carbon dioxide concentrations in the body. In addition, at high elevations the carbon dioxide partial pressure in the atmosphere is almost zero. This increases the strength of the pressure concentration gradient for carbon dioxide between the lungs and the atmosphere. More carbon dioxide is eliminated. When carbon dioxide is eliminated efficiently from the human body, life span is increased.