HYPOTHERMIA

John Knight

The title of this talk is hypothermia. However, I am not going to be dealing with the effects of core temperatures below 34.5° which is commonly accepted as hypothermia in medical terminology, but rather with the effects of cold on divers and their survival.

HEAT BALANCE

Human life is a balancing act between heat gain and heat loss. The heat content of a 70kg man, is some 9000 Kcal. This is the amount of heat needed to take 55L of water, containing a soup of fats, proteins, carbohydrates and minerals, from 0°K to 37°C.

The balance is pretty fine as a gain or loss of 200Kcal, just over 2% of the heat content, will incapacitate that 70 kg man, either by hyperpyrexial delirium or hypothermic coma.

Human heat regulation is centrally controlled, in the hypothalamus, in response to blood temperature variations and messages from the skin. There is a constant heat output from the heart, liver, respiratory muscles, kidneys and gut in the torso (the core) and from the brain. In addition, bursts of heat are generated from the use of limb muscles.

Man evolved in the tropics and it is thought that he was a hunter-gatherer from the start. This involved running in the hot sun, so one of the adaptations that developed in man was a very efficient heat losing system. Heavy, workloads can be carried out in a large variety of temperatures and the rectal temperature maintained within the normal range. Extra blood flow through the skin increases radiant heat loss and extra sweating increases evaporative cooling.

The human race spread all over the world before the days of the steamship. In most places the first Europeans discovered the inhabitants of faraway islands to be dependent on stone tools, so a primitive technology allowed mankind to live in the arctic, the tropics, and anywhere in between. How was this achieved? It was by using extra insulation and extra heat. The extra heat was provided by fire. The insulation could be animal skins, as for the Eskimos, or other sorts of clothing. The adaptations of the human to cold should be well known to those of us who do not live in Queensland. They are a decrease in heat loss due to skin and limb vasoconstriction and an increase in heat output by shivering.

The normal human response to cold is vasoconstriction in the skin, and then vasoconstriction in the arms and legs occurs. The major limb blood vessels form a counter current heat exchanger. So the arterial blood reaching the limb has been already cooled by the cold venous blood, coming back from the limb, which picks up heat, thus not cooling the core quite as much as one would expect.

Vasoconstriction effectively reduces heat loss from the torso, limbs and face. Most Australians have an insulating layer of fat over the muscles. Heat loss is mostly from the neck, axillae and groins where major arteries are near the surface. Another area of heat loss is the scalp which does not develop vasoconstriction in response to cold.

COLD ADAPTATION

Humans can adapt to cold. It is not something that happens quickly. It requires long exposures to cold. Adaptation to cold involves some changes in the body's reaction to cold, the major ones being that the basal metabolic rate is increased and the shivering threshold is decreased. The person adapted to cold produces more heat at rest and starts to shiver at a lower core temperature than the normal person. Most sports divers are not exposed to cold often enough to develop any adaptation.

There has been some dispute as to whether cold adaptation really occurred in humans, but the studies of the Korean diving women, the Ama, carried out by Professor SK Hong over many years have shown that it does occur (see p6).

In the middle 1960s, when Professor Hong started studying the Ama they were fatter than the non-diving village women and, in winter, had higher basal metabolic rates. At that time these women, dressed only in thin cotton drawers, could dive for shellfish and seaweed in up to 10m of water, in the summer for about 30 minutes twice a day before they had to get out of the water. They were too cold to carry on and their core temperatures had dropped to the region of 35°C. In winter they could only tolerate one half hour dive a day.

In 1977 wetsuits were introduced. The wetsuit works by trapping a layer of water between the suit and the body. That layer of water warms up to skin temperature. The wet suit prevents various currents that take heat away from the bare skinned swimmer. The air in the fabric of the wetsuit, which is a mass of bubbles of nitrogen or air in rubber, acts as an efficient insulator and reduces heat loss. Someone in a well fitting wetsuit, that does not allow water to slosh in and out with each movement, can stay quite warm for some time. The wetsuit is an excellent insulator on the surface, as anyone who has worn one on a hot day will know. Unfortunately, it compresses with depth and becomes a less efficient insulator.

Now the Ama can dive for up to two hours, in summer and winter, for a drop of only a degree or so in their core temperatures. Their cold stress has been very considerably reduced. In the three years after the introduction of wetsuits the raised metabolic rate that had developed as a result of the cold stress declined to the same metabolic rate as those onshore. Over the same period the time that these women could stay in the water without their wetsuits became shorter. Now they are dependant on their wetsuits for their livelihood, as they have lost their adaptation to cold.

All the women in the village are fatter now than their mothers were in the 1960s. This is probably due to better economic circumstances for the villagers.

WATER CONTACT REFLEXES

There are a number of reflexes that occur when cold water is applied to the skin. If the face, the beak area of the face especially, is put into cold water, the response is bradycardia and apnoea. Naturally enough one does not try to breathe water. The bradycardia is known as the diving reflex, and is to be found in all mammals and birds. With bradycardia goes vasoconstriction of everything except the vessels supplying the brain and heart. This of course has survival value by restricting the supply of oxygenated blood to vital organs.

Another reflex that occurs is a gasp when cold water is applied to the skin. I have had plenty of experience of this as for four years at school I had to have a cold shower every morning, regardless of the weather. It is possible, if you know the cold water is coming, to suppress the gasp, but it can be very difficult. Some people suffer an exaggerated form of gasp when they fall into very cold water. They develop an extremely rapid and deep respiratory pattern which is quite beyond voluntary control. Under these circumstances, they must keep their faces out of the water or they will drown. The effort required to keep your head out of the water is quite high, and trying to swim when you are breathing at 30 to 40 breaths a minute and paddling hard to keep your face out of the water, is very exhausting. This phenomenon explains many mysterious deaths of good swimmers who have fallen into cold water. It was discovered quite by chance one day during cold exposure experiments at Cambridge when a champion swimmer fell into the water and developed this pattern of respiration and was unable to reach the side of the swimming pool only a few strokes away. He was rescued as his head was disappearing.

With very cold water, this hyperventilation is sometimes combined with an inability to move. I have seen one case of this when the Royal Australian Naval Reserve diving team in Melbourne was searching just below the Eildon reservoir dam for a missing person, who was not there. The water temperature was about 5°C and the shade temperature was about 35°C. The divers, united by buddy lines, dropped out of the boat. The fourth one rolled out but did not bob up as the others had. When he had been pulled up and was hanging onto the side of the boat he said “If I had not had my regulator in my mouth, I would have drowned. I was breathing as hard as I could, and I couldn’t move”. A respiratory pattern like this, of course, is immediately fatal, unless you happen to have a regulator in your mouth and a buddy by your side.

IMMERSION

Water is a much more hostile environment than air because of its thermal capacity and specific heat. It takes a thousand times more heat to heat one volume of water than it does to heat a similar volume of air. Water conducts heat 25 times faster than air does. Seventy one per cent of the body volume is within an inch (or 2.5cm) of the skin, thus reducing the distance through which heat has to be transported to the outside world. This very adaptation for losing heat is a danger to those of us who entertain ourselves by submerging. It is even more of a danger for those who involuntarily find themselves in the water. Very many of the deaths from drowning that occur after aircraft land in the water, or ships are sunk, are precipitated by hypothermia interfering with the ability of the person to think or swim.

The body in contact with water which is colder than itself, the normal situation, rapidly loses heat to the surrounding water. This sets up convection currents in the water which move the heated water away from the body, cold water moves in and the process starts again. Add to this small scale heat transfer the water movement due to swimming movements and one can see that this is a potential for very high heat loss. In fact it is much better for the submerged individual to avoid moving and huddle in to a little ball, the so-called Heat Exchange Lessening Posture (HELP) than to try and swim. Lack of movement reduces heat loss considerably.

The factors governing heat loss are the temperature of the water, the amount of heat generated in the body and the amount of insulation to slow down heat loss from the body. If one compares the heat losses of a thin person and a fat person, both while sitting still in water and swimming, one discovers that a thin person cannot sustain the swimming without a large drop in core temperature, while the fat person, thanks to his insulation keeping heat in his core, can maintain his body temperature, which is one of the things that explains why long distance swimmers on the whole are well covered people.

The human body copes with cold by vasoconstriction and increased heat output. When the human body goes into water, at first there is a high rate of heat loss. This decreases as vasoconstriction occurs. Then the rate of heat loss decreases again as increased heat production starts. The use of a wetsuit removes the first, steep part of the heat loss curve, and by increasing the insulation around the person, allows more efficient retention of the extra heat generated. However, a wetsuit does not stop heat loss. It merely reduces it.

Cold induced vasoconstriction affects both the arterial and venous sides of the vascular tree. This results in increased resistance, causing a rise in blood pressure, and an increased venous return to the heat resulting in a larger cardiac output which accentuates the rise in blood pressure. Both systolic and diastolic pressures rise in the immersed vasoconstricted human.

If the person has hypertension, this rise in blood pressure can be extremely high. This increased cardiac workload has been thought to be responsible for a number of diving deaths in those with the older age groups, that is the over 30s. This is based on American figures which do show that as divers get older, the proportion of definite cardiac deaths increases. Many of these deaths occur at the end of the dive when the person is on the surface of the water. They are not drownings.

At the beginning of cold water immersion experiments there is a rise in core temperature because the shut down of limb circulation keeps the warm blood in the core.

COLD INDUCED MALFUNCTIONS

The first symptoms of heat loss are feeling cold, followed soon after by shivering. And then, long before you have reached a dangerous temperature at your core, there are the mental changes of slowness of thought, slurred speech, with these goes inco-ordination. Cold affects the transmission of nerve impulses down nerves, and also affects the rate of contraction of muscles. The combination results in malfunction and difficulty in fine movements, and as one grows colder, the grosser movements get affected as well. Anyone who has been exposed to low environmental temperatures knows that their fingers go numb, that the sensation of touch is impaired and their fine movements are soon impaired.

The early signs of hypothermia are very similar to those of the early signs of alcoholic intoxication, a certain sense of well being and ignoring the obvious problems around one. This is a very dangerous situation for a diver. One of my colleagues in Melbourne went diving in October some years ago. When he surfaced at the end of the dive, he was unable to climb into the boat. He had to be helped in. In his own words, he was blue with cold, and yet he was not the slightest bit upset that he was too weak to climb up into the boat, a thing he could normally do quite easily. He has no real memory of this, all he remembers is what his friends have told him. He obviously had difficulty concentrating. He did not progress through slurred speech, disorientation and hallucinations to drowsiness and coma.

Of course, somebody floating in a lifejacket who gets cold enough to go unconscious will not have the protective reflexes to avoid breathing in water when a wave gets up and slaps him in the face.

People who are becoming hypothermic often stop swimming. They just quietly sink. History is full of sad stories of wrecked sailors clinging to the mast until one by one they lost their grip and fell into the water. This is certainly due to hypothermia, a hypothermic loss of muscular control, leading to falling into the water and drowning. During the Second World War, many men were found floating dead in their life jackets. They had not drowned. Their lungs were perfectly normal. They had died from cold, from loss of body heat.

On Arctic convoys from the UK to Murmansk, the expectation of life for a downed fighter pilot in his standard flying suit was less than five minutes after he was in the water. They were often still alive when they were pulled into the escorting destroyer's whaler which reached them in five minutes or less, but they died in the boat on the way back to the destroyer. Those that did survive always had to be helped up the scrambling nets, they could not get themselves up as muscular power had gone from cold. Introduction of immersion suits that kept the man's clothes dry dramatically changed the picture. With the layer of dry clothing trapping air between him and the survival suit, he could live for half an hour or more without getting into the situation that five minutes exposure had given him before.

Under cold water it is necessary for insulation to be applied to the head because the scalp, unlike the rest of the body, does not have a cold induced vasoconstriction. The head goes on losing heat even though all the other surface vessels are severely constricted. As the head is some nine to ten per cent of the body surface area, and a good half of this is scalp, there is a large loss in heat from in the head. Mind you, it is a lot more comfortable to go diving without a hood, but in cold water it is very sensible to wear one. Without a hood there is only a very small distance between cold water and the brain and the tissues are not efficient insulation. So the brain cools locally as well as being cooled by a cooler blood flow.

Cold induced mental change is the major problem of incipient hypothermia for divers because once one's brain does not work properly, one makes wrong decisions.

Heat loss in a wet suited diver does not stop when he gets out of the water. Most wetsuits have nylon cloth on both sides of the neoprene. The water trapped in outside cloth will evaporate in the air currents that eddy round the diver as the boat moves to the next dive site. The heat for this evaporation comes from the diver's body. So he will start the second dive colder than he was when he finished the first dive unless he takes his wetsuit off and puts dry clothes on between the dives.

AFTER DROP

Once a drop in core temperature has occurred the core temperature continues to drop after a person is removed from the water and dried. When wrapped up well and no longer losing heat the core temperature continues to drop. It continues even when active rewarming is started.

This after drop can be as much as 1°C. It is due to the cold parts of the body draining heat from the core as they warm up. Whatever method of warming is employed this after drop will occur.

PREVENTION AND TREATMENT

Hypothermia only occurs when heat loss exceeds heat gain. The most important treatment is to prevent the occurrence of hypothermia. Not staying underwater too long, not diving when chilled and warming up thoroughly between dives are simple, sensible things to do. Feeling warm is no guarantee that your heat losses have been replaced. The only way to be certain that heat losses have been replaced is to start sweating. This shows that the body needs to lose heat.

Recognition of diving induced hypothermia must be clinical. The essential treatment is to stop further heat loss. So the victim must be taken out of his wetsuit and dried and covered with as much insulation as is available. Adding heat is the next step. In a diving boat the only available source of heat may be other human bodies.

Acute hypothermia should be treated by rapid rewarming. The simplest method of adding heat is to immerse the body in warm water. The difference between skin temperature and the bath temperature should not be more than a few degrees; anything more is painful. Of course there are problems associated with a reduced blood volume (both immersion and cold cause a diuresis) and the peripheral vasodilatation due to the warm water on the skin and the continuing after drop of core temperature with this method. But it is efficient and well tried.

THE RISKS OF HYPOTHERMIA TO DIVERS

The risks of hypothermia to a diver are not those of death through cardiac irregularities and arrythmias brought on by cold. They are much more the risks of cold induced errors due to clumsiness in muscles, clumsiness in thinking, inappropriate thoughts, and if the person does go unconscious from cold, drowning through loss of protective reflexes.

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THE DROWNED LUNG

V Callanan

I am going to talk about some of the pathophysiology of the drowned lung. This was not always the part of drowning that received much emphasis. In the 40's and 50's more emphasis was placed on changes in serum electrolytes and blood volumes. In the 60's and 70's the lung problems and the acidosis associated with it became a subject of research. In the last 10 years or so lung problems and cardio-vascular functions, in particular, have become prominent and in more recent years, brain preservation has become a widespread topic in this area.

I intend confining myself to talking about cardio-pulmonary aspects of near drowning. I will exclude victims of dry drowning, that is those who have laryngeal spasm and do not actually have water entering the lung. So I am talking about patients who get water in their lungs. Water in the lung quickly produces profound hypoxia, hypercarbia and a profound metabolic acidosis. By that time the patient reaches hospital, some of this may be reversed slightly by cardiopulmonary resuscitation. The hypercarbia may be reversed, however the profound hypoxia and metabolic acidosis will always be present. Usually the patients present with all of this triad unless the patient has recovered sufficiently to restore his cardio-pulmonary function almost to normal.

By the time the patient reaches hospital it really doesn't matter whether the patient drowned in salt or fresh water because by that time the syndromes are fairly similar. In fresh water aspiration the patient will finish up with surfactant damage and the adult respiratory distress syndrome (ARDS). If they drown in salt water, for various reasons, they finish up with the same syndrome. If they happen to aspirate their stomach contents then the same thing can happen. I would like to highlight the importance