Conclusions

It is surprising that high flow non-rebreathing systems continue to be used in diving accidents. Conservation of oxygen, provision of warm, humidified gases and a clean breathing circuit for each patient are obvious advantages of closed circuit rebreathing systems.

The OXI-dive1™ closed circuit resuscitator achieves high inspired oxygen concentrations. An initial oxygen flow rate of 8 l/min for five minutes followed by 3 l/min provides 100% oxygen almost immediately and 99% indefinitely. A C size oxygen cylinder used at these rates with the OXI-dive1™ lasts for about 1.5-2 hours.

With an initial oxygen flow rate of 8 l/min for five minutes followed by 2 l/min the Inspired oxygen is 90+% after five minutes of 100%. A C size oxygen cylinder will last about 2.5-3 hours.

The duration of oxygen supply will be reduced if there is a poor seal with the facemask or if the facemask is removed for short periods.

Pain relief

In Australia methoxyflurane is now the most widely used agent for pre-hospital pain relief in ambulance services, defence, mining and ski areas. The efficiency of pain relief is at least equivalent to, and probably better than, the use of 50% nitrous oxide/oxygen (Entonox) in a demand valve system.[3,4] Entonox is, of course, contra-indicated in diving accidents as nitrous oxide is a more soluble gas than nitrogen so using Entonox after a dive will increase the diver's inert gas load and worsen any decompression illness present.

Methoxyflurane is administered using the hand held Penthrox™ Inhaler. 3-6 ml is carefully poured onto the base of the inhaler. The methoxyflurane then passes through circumferential openings into the polypropylene wick within the body. The mouthpiece can be fitted with a standard facemask or inserted directly into the patient's mouth. Inhalation provides pain relief for 25-55 minutes depending on whether 3 or 6 ml (the maximum recommended dose) is used. If higher concentrations of methoxyflurane vapour are required, the opening near the mouthpiece of the Penthrox™ Inhaler may be occluded with the index finger.

Oxygen can be connected to the nipple in the base. 3 l/min provides 35-40% and 8 l/min 50-60% inspired oxygen with the inhaled methoxyflurane vapour.

In 1987 Toomath published an article in the New Zealand Medical Journal[5] describing two patients who died following several weeks of intermittent administration of methoxyflurane for pain relief. The doses administered were approximately four times those approved by the Food and Drug Administration in the USA and ten times the dose recommended in Australia. As a result methoxyflurane was withdrawn from use in New Zealand. However an application is being made to re-register methoxyflurane for use in New Zealand.

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Dr David Komesaroff, FANZCA, is a Honorary Consultant Physician at the Royal Melbourne Hospital. He is Medical Director of Medical Developments Australia Pty. Ltd., Factory 7, 56 Smith Road, Springvale, Victoria 3171, Australia. Phone +61-(03)-9547-1888. Fax +61-(03)-9547-0262. E-mail mda@onaustralia.com.au .

IMMERSION HYPOTHERMIA

James Francis

Key Words

Accidents, first aid, thermal problems, treatment.

Introduction

I have a feeling that I was asked to do this because I hail from the "frozen north" although, looking around at some of the divers this week, hypothermia is not necessarily an exclusive problem for those north of the equator!

As we all know, the temperature of the body is determined by the balance between heat gained and heat lost. I am not going to address the thermal input side of the equation today, but will focus on the problems associated with heat loss.

Routes for heat loss

There are four routes for heat loss. Most important for divers is conduction. Water conducts heat away from the skin much more effectively than air, which is one of the reasons a dry suit affords better insulation that a wet suit. Heat loss from the head, largely via conduction, is particularly important because the blood vessels of the scalp do not vasoconstrict in response to cold in the same way as they do in other parts of the body.

Convection is also an important route for heat loss when diving. Convective heat loss is minimised by the use of wetsuits, which substantially reduce the convective currents which cause the replacement of the warm boundary layer with cold water in unprotected, stationary divers, and more or less eliminated by dry suits.

Evaporation is not an important route for heat loss while in the water, except possibly via the respiratory tract when breathing very dry, cold air or mixed gas, particularly on deep dives, in which case conduction also plays a part. But it does become an important route for heat loss once the diver is out of the water, even before getting out of the wetsuit. The fabric cover of most wet suits retains a lot of water which will evaporate and cool both the suit and the diver inside it. Once the wet suit is removed, evaporation will proceed until the skin is dry or an impermeable layer is donned. This can result in a very substantial loss of heat and this has to be considered during the management of an injured diver.

Finally, radiation is a negligible component of heat loss in the diving and most other settings.

Thermoneutral water

Thermoneutrality of sea water is between 33 and 35°C. It varies a bit between individuals. In water that is much below 30°C, the diver will be more or less fully vasoconstricted.

Thermal conductivity

Table 1 shows the thermal conductivity of various things which interest us. Water conducts heat well, as does muscle. Skin is, alarmingly, a good conductor of heat. Then we get down to the more comfortable zone of fat, which is a much poorer conductor of heat, sufficiently so to be classed as an insulator. Wool is a pretty good insulator and neoprene foam is even better. Air is an excellent insulator, which is one of the reasons why dry suits are so effective.

TABLE 1

THERMAL CONDUCTIVITY (kcal.cm/m^2.h)

Water	52
Muscle	35
Skin	28
Fat	16
Wool	8
Neoprene foam	5
Air	2

There are two sorts of hypothermia which can result if the diver is without insulation or the insulation is inadequate, or one has the misfortune of being in a cooling situation. These are local and whole body hypothermia.

Local hypothermia

Local hypothermia is more commonly known as freezing injury or frostbite, in which ice crystals form in tissues. More commonly in the diving situation tissues do not freeze and the hypothermia is in the form of a non-freezing injury (NFCI). Non-freezing cold injury is most unusual in exposures to 5°C water for less than about 60 minutes.

There is a protective mechanism against cold injury, cold-induced vasodilatation. This is a response that, after a period of maximal vasoconstriction, such as follows putting a hand in ice-cold water for about 10 minutes, causes a gradual relaxation of the arteriolar vasculature, allowing a brief restoration of circulation to the cooled part. Then the vasoconstriction reasserts itself. This "hunting reaction of Lewis", named after the man who first described it, provides a minimal level of blood flow, even in circumstances of maximal vasoconstriction. This reaction can be overridden under some circumstances. It is reduced in whole body hypothermia and it can also be reduced in situations where there is a high vasomotor tone. A scared and cold person is at greater risk of NFCI than one who is more relaxed.

It is unusual for divers to get NFCI, although there are some exceptions. In the Royal Navy and the US Navy, some clandestine operations, and the training for them, requires extremely long dives in very cold water, such as up to 9 or 10 hours in water which is only 1 or 2°C. These people do have a problem with NFCI and in order to undertake these operations they need active thermal protection for their hands and feet.

Whole body hypothermia

Hypothermia is defined as a rectal temperature below 35°C. It has been, to some extent arbitrarily, divided into mild, moderate and severe. Mild being between about 35° and 32°C, moderate 32° down to 28°C and severe hypothermia below 28°C.

Rescue from the water

As we saw in the boat the other day, recovery from the water ought to be done, if possible, with the casualty horizontal. There are a number of steps in the reasoning for this.

1 Both immersion and exposure to cold results in a movement of blood from the periphery, into the core

2 Both stimuli also result in a diuresis, which reduces blood volume. This does not matter while the individual is immersed in water and the circulation is supported by hydrostatic pressure, but it matters once the victim is removed from the water.

3 Once local tissue temperatures get below about 12°C (peripheral, not core temperature) there is a loss of autonomic control of the peripheral vasculature and a loss of vasomotor tone.

4 With even modest hypothermia, the central baroreceptors and hypothalamus work less effectively than under conditions of normothermia.

5 As a hypothermic diver, who will have a reduced blood volume from diuresis due to immersion, is removed from the water vertically the central blood pool is rapidly distributed to the dependent periphery, which has been freed from the water pressure which had kept the veins compressed, resulting in a massive reduction in venous return and central venous pressure (CVP). This results in a fall in cardiac output and, because there is little or no venous return due to depression of both central and peripheral vascular control mechanisms, a fall in systemic arterial blood pressure occurs.

It is thought that this sequence of events may underlie the sudden death of people who have survived a prolonged immersion in cold water but who die shortly after being rescued. The objective of removing the victims of immersion hypothermia from the water horizontally is to preserve the CVP and cardiac output.

Mild hypothermia

In mild hypothermia, both the victim, who is conscious, and any observer will notice that the diver is shivering. Shivering usually starts at a core temperature of about 36°C. It becomes maximal at 35°C to 34°C, and then gradually begin to decrease. At a core temperature of 35°C, the skin will feel very cold to the touch.

Even if the diver has not been trying to rehydrate himself inappropriately, there may be slurred speech and poor co-ordination. This sort of person will sit down in the corner and ignore everyone else, becoming a bit morose and introverted. This development is a danger sign, particularly in a normally gregarious person.

At 34°C, nobody should miss that something is wrong. The diver is going to be shaking like a leaf with teeth chattering for most of the time. Along with that, there may be a measure of amnesia, which is probably a good thing, as no one is going to enjoy life at this stage.

By a core temperature of 33°C, the shivering becomes less intense and less frequent. At this stage cardiac arrhythmias can develop. The myocardium is particularly sensitive to cooling and arrhythmias are one feature of this as is bradycardia.

At a core temperature of 32°C shivering is further reduced and may even cease. Shivering is very variable between individuals and varies with the rate of cooling. Rapid cooling causing more shivering that a gradual loss of core temperature. In most cases shivering will cease once the core temperature reaches 31°C, although one cannot be dogmatic about it. At the border between mild and moderate hypothermia the victim will look blue, will have a respiratory alkalosis, the metabolic rate will be well down and there may be some muscular rigidity and pupillary dilatation. It may be difficult to measure the blood pressure using a cuff.

Moderate hypothermia

Once shivering ceases, the victim has entered the realm of moderate hypothermia in which the battle to maintain the core temperature by increasing thermogenesis has effectively been abandoned and the condition is generally progressive without external intervention. The other feature of this stage is that, generally, the victim can still be roused. Hypoventilation sets in and these people may have virtually undetectable breathing patterns. Rather than a respiratory alkalosis the biochemical pattern changes to a lactic (metabolic) acidosis. A ‘J’-wave may be observed on an ECG.

With further cooling the victim may appear to be dead. There is a decrease in renal function which may exacerbate the dehydration which has already been caused by both cold and immersion.

At about 29°C there may be a loss of deep tendon reflexes and once a core temperature of 28°C is reached the victim is in serious trouble. The heart muscle is irritable, ventricular ectopics are not at all uncommon and spontaneous ventricular fibrillation (VF) is possible. There may be evidence of bronchorrhea and signs of pulmonary oedema. But they are still rousable.

Severe hypothermia

Once hypothermia victims become unrousable it is evidence of severe hypothermia. They have stopped shivering. They have a clinically dead appearance with fixed, dilated pupils. Muscles which have been increasingly rigid will start to relax. Further cooling produces hypotension and spontaneous VF. All thermo-regulation is lost.

Apnoea occurs at around about 24°C and cardiac arrest around about 21°C. The lowest ever recorded core temperature from accidental cooling, where the patient survived, was 18°C. Controlled experimental lowering of core temperature has been survived at 9°C.

A very important point.

Severely, and even some mildly, hypothermic people appear to all intents and purposes to be DEAD when they may NOT be. Nobody should be declared dead until they are warm and dead. In other words, one should take active measures to rewarm apparent fatalities from hypothermia before declaring them dead.

Treatment

Most important, and the first line of treatment in the field, is to prevent any further heat loss. The most effective measure is to protect the diver from the wind since evaporative cooling is the major cause of heat loss. Even a moist wet wetsuit provides thermal protection once the wind is prevented from evaporating water from its surface. Removal of the wetsuit and its replacement by dry clothing (insulation) and then providing protection from the wind is even more effective. However, removing a wetsuit requires a lot of movement, even if it is cut away from the casualty, and this is risky in a moderately or severely hypothermic person. Furthermore, not all dive boats have storage space for dry clothes. So, wrapping cold divers in plastic of some sort is probably the best and safest measure. Mylar space blankets, which reflect little heat back into the casualty, are effective at preventing loss of heat by evaporation. Plastic bin liners are even better, as they are well sealed and allow the generation of a microclimate within them. And above all, cover the head. Something like 60 to 70% of all heat loss will occur from an unprotected head because of lack of scalp vasoconstriction.

Cardiopulmonary resuscitation

This is a very awkward and controversial area. One thing I think everybody has agreed on is that the hypothermic person needs to be treated gently. They have an irritable myocardium and it is very easy to trip them into arrhythmias, especially ventricular tachycardia (VT) or VF. If one is going to provide CPR in the field, it is a good idea to have monitoring available. That is, of course, a joke, as in most circumstances it will not be available. Of more practical application, if CPR is going to be initiated there should be sufficient people to keep it going until the victim gets to a medical facility. The decision to start CPR on a severely hypothermic person is not one to be taken lightly. My view is that if the rescuers consider that they are able to maintain effective CPR until reaching a hospital, then it is probably worth doing. Otherwise leave the person alone.

Evacuation should be arranged as soon as possible. Assessment of the level of hypothermia is important to allow the receiving facility to make adequate preparations. As few people carry a low reading clinical thermometer, it is necessary to be able to assess the mild, moderate and severe hypothermias from the physical signs.

Rewarming

What can one do in the field beyond drying the victim, insulating with dry clothing, protecting from the wind and allowing the victim's sluggish metabolism to rewarm him or her? There are a number of options.

Hot water bottles are cheap, readily available and simple to use. But one must get the water temperature right. If the water in these bottles above about 40°C, the patient's skin will be burnt. The heat will warm the skin, unfortunately these people have very little skin blood flow, so the extra heat is not carried away and the skin in contact with the bottle rapidly reaches the same temperature as the bottle. It is best to start with cooler water and refill the bottles frequently as the peripheral circulation improves. The boat's engine cooling water is a ready source of hot water.

The same applies to chemical heat packs. They are easy to use, but their temperature control is not good and they have caused burns. They are also rather expensive.

Shared body heat has been widely promoted but, unfortunately, it is largely ineffective. Even if the heat donor is immediately adjacent to the victim in a double sleeping bag, little heat is actually exchanged.

One of the most dangerous things one can do to a really cold person is the hot shower. Do not, no matter what the grade of hypothermia, usher this individual into the shower, whack on the water as warm as you can tolerate, and say "Just stand there and you'll be warm in no time" and then leave them alone while you read the paper. Because, next thing you know, they will have fainted and collapsed, with a good chance of injury on the taps on the way down.. Because showers have a small base the victim is going to slump head up against the side of the shower recess, with the brain still deprived of oxygen. If one is to use a shower to get a person warm, and it will make them feel warm, always sit them down. Unfortunately, in the normal run of things, a shower is unlikely to be available on the dive boat.

Another technique, which is unlikely to be available on the dive boat, but has been used, is to breathe warm, humid oxygen. A closed circuit oxygen rebreather is the usual source. It actually delivers very little heat. However, the heat is delivered directly into the chest, and may warm the myocardium, which is the organ that one is most concerned about. It almost certainly will not do any harm and it may actually do some good. Also it is a simple and safe thing to do. Even if it does the diver little good it will make you feel a lot better.

What about a bath? A bath is unlikely to be available on the dive boat. Once ashore a bath is good treatment for mild hypothermia of rapid onset. With moderate or severe hypothermia, the rewarming should be undertaken in a medical facility. They are not candidates for a warm bath at home.

Warm baths have their problems. What is a comfortable temperature to a warm hand is excruciatingly hot to a cold hand. One must start with cool water, acceptable to the casualty, and gradually add more warm water after the patient is in the bath. The casualty will be the best judge of how rapidly the bath should be warmed. There has been much controversy over the years about whether the limbs should be in the water. It turns out that it does not make any difference. The theory of having the limbs out of the water was that what one did not want to warm up the periphery so that a large amount of cold peripheral blood was returned to the fragile myocardium. It appears this does not happen.

Rehydration

All hypothermic divers are volume-depleted. Vasodilators, which will have the effect of dropping the blood pressure are therefore inappropriate and that includes alcohol. But warm, sweet drinks are probably a good idea if the person can protect their own airway. There is no point forcing oral fluids into someone who is not able to protect their airway.

Heated IV saline or dextrose saline can be used. It not going to transmit much heat this way but if the victim is in need of intravenous rehydration, which they probably will be if they are anything other than mildly hypothermic, it is a good idea to warm the fluids before administering them. It is actually more comfortable for the patient and the drip will flow better when the fluid is warm. Do not heat the fluid more than about 40°C because it could then start to coagulate proteins. It is probably not a good idea to use Ringer's Lactate (Hartmann's Solution), which is a commonly used fluid in North America, as in moderate and severe hypothermia, liver function is reduced and will not metabolise the lactate.

Any more adventurous therapy should be undertaken in a medical facility, which is beyond this dissertation. Furthermore, there are enough anaesthetists here to address this, so I stop here.

Discussion

Unknown speaker

Do you mean all those nice St Bernard dogs are out of a job?

James Francis

Afraid so.

Bill Day, Wellington

Are you not concerned about the speed of rewarming?

James Francis

I am talking about acute mild to moderate hypothermia who can safely rewarmed rapidly. People with long onset hypothermia, particularly the elderly and drunks who have been out in cold weather for a long time should be rewarmed in a medical facility. Do not dunk them in warm water. They will be very volume depleted and resuscitating them requires a lot of attention to central venous pressure CVP and blood volume.

Bill Day, Wellington

In the first aid setting, what is your view on giving oxygen if it is not warmed and humidified. Just oxygen as most of us have, or some of us have, at dive sites.

James Francis

I do not think it will do any harm. I cannot see it is of any practical benefit, but it will not do any harm. If you can warm it, so much the better.

Dr T J R Francis, MSc, PhD, Dip DHM, one of the Guest Speakers at the 1997 Annual Scientific Meeting, was Head of Undersea Medicine at the Institute of Naval Medicine, Alverstoke, Gosport, Hampshire PO12 2DL, England. His address is now Naval Submarine Medical Research Laboratory, Naval Submarine Base, New London, Groton, Connecticut 06349-5900, USA. Telephone +1-860-694-4005. Fax +1-860-449-2523. E-mail francis@nsmrl.navy.mil .