Frost-bite

Michael Ward

Definition

Injury due to cold, may be either general or local.

In *general cold injury* the condition is called Hypothermia, or a person is said to be suffering from exposure.

Local cold injury may occur at temperatures above freezing, usually wet-cold conditions, when it is known as immersion foot or trench foot. These cases often arise when the feet are kept in cold water for long periods, as occurs in life-boat survivors or soldiers standing in trenches. At temperatures below freezing (dry-cold conditions), frost-bite occurs; the tissues freeze and ice crystals form in between the cells. It may or may not be associated with hypothermia (general cold injury).

Relevant physiological data

a Anatomy and physiology

The normal circulation of blood provides both warmth and oxygen and nutrition for the cells of the body. The larger blood vessels that carry blood that has been fully supplied with oxygen from the lungs are called arteries. As the extremities of the body are reached, these arteries become smaller in diameter and are called arterioles. Finally, these vessels become even smaller, the capillaries. In the capillaries, the walls are extremely thin, usually only one cell layer thick, and this means that oxygen and other substances can pass freely from the inside of the capillary to the tissue cells. Carbon dioxide, which is given off by the tissue cells, travels in the opposite way through the capillary wall into the blood. This blood, with the majority of its oxygen removed, together with other waste products of cell function, returns to the heart, first of all in very small vessels called venules, then larger ones, veins. Two large veins enter the right side of the heart, and the blood is pumped to the lungs, where the carbon dioxide is exhaled and oxygen is taken up again. The re-oxygenated blood is circulated to the left side of the heart and pumped through the body again.

The structure of artery, arteriole, capillary and vein differs. The arteriole has muscles in its wall, whereas the capillary has none. However, the movement of blood through the capillaries is not constant, due to small rings of muscle which are placed between the artery and capillary. These are called pre-capillary sphincters, and regulate the flow of blood to the capillary. The muscles of the arteriole are supplied by nerves, but a particular type of nerve which is controlled unconsciously by that part of the nervous system which is called the autonomic nervous system. This works 'automatically', as opposed

17 *Frost-bitten climber, Makalu, 1961.* This and next photo: Michael Ward

to the 'voluntary' nervous system, which is under voluntary control. The nerves of the autonomic nervous system control a myriad of functions, such as the secretion of glands and the reaction that we have to various outside stimuli such as fright, heat and cold. Thus, when a part of the body is chilled, the arteriole to the adjacent area contracts and the blood supply to the part diminishes, and loss of heat from the chilled area is prevented. If the chilling is brief, the blood flowing through the capillary slows down, or is naturally directed to other areas, where there is no chilling effect. If the chilling is intense, there is a complete constriction of the arteriole and no blood gets to the part. If the duration of the chill is short, no damage occurs, but if the duration is longer, the degree of damage depends on the length of time that the cold stimuli are present. Damage to both the arteriole and to the adjacent tissues may occur in these circumstances.

In fact, two reactions take place when tissue comes in contact with a very cold object. Firstly, the superficial tissue at the site of contact freezes to a depth which depends on the length of the contact and the degree of cold. Immediately below this zone, direct damage can occur to the wall of the blood vessels, and the fluid part of the blood may flow through the vessel wall, causing blisters. The remaining blood in the vessel becomes very viscous, with relatively more cells than plasma. If rewarming does not take place, constriction of the adjacent arteriole naturally continues, and there is a continued reduction in the flow of blood to the affected part. However, if the capillary is chilled to the point where blood-flow through it is stopped, shunts between the arteries and veins open up. This means that blood in the arterioles bypasses the affected area, and returns to the heart. These shunts are not kept open continuously, but open and close in cycles. However, if too much chilled blood is returned to the heart, the central core temperature of the body will fall, as the cold blood will circulate to the temperature-regulating centre of the brain. However, before this danger point is reached, and death occurs, the shunts between the artery and vein are closed completely and the affected part becomes completely avascular. In this way, the diseased part of the organism is sacrificed for the survival of the whole. Secondly, at the point of contact after the initial vascular spasm, ice crystals form in between the cells. These originate from the fluid normally present in between the cells, the interstitial fluid. Water is attracted from inside the cells to enable these crystals to enlarge. The osmotic pressure rises and at a critical point the enzyme mechanisms inside the cell become disturbed, and the cell dies. If enough cells are damaged the area becomes black; that is, gangrenous. Certain tissues are more resistant to frost-bite than others, thus muscles, nerves and blood vessels are highly susceptible, whilst tendons and bones are more resistant. Because of prolonged vascular spasm, cellular nutrition may be affected apart from dehydration and ice crystal formation. By the same token serious tissue damage can occur even at temperatures above freezing point if there is prolonged vascular spasm and slow down of the capillary circulation as occurs in trench foot and immersion foot.

b Temperature regulation

The body functions normally only within a relatively small temperature range. The normal central core temperature is around 37°C. Hypothermia or general cold injury occurs when the central core body temperature is lowered below an arbitrarily chosen level of 35°C. Elevation of the temperature of a few degrees, say to 39°C, will produce some impairment of function, as occurs in fever.

Whilst it is necessary for the central core temperature to be maintained within a few degrees either side of its normal, the temperature of the peripheral structures—that is, the muscles and skin, especially of the hands and feet—may be very much lower. Under normal conditions, at a room temperature of, say, 26°C, with a central core body temperature of 37°C, the skin temperature will be about 35°C. There is thus a gradient between the central body and peripheral temperatures. If the temperature of the peripheral structures falls to 0°C, then the tissues freeze, ice crystals form and frost-bite occurs. The control of body temperature within a few degrees of normal, depends on the interaction between the production of heat and its loss.

Heat production depends on the normal body metabolism, or function of the body. Under resting conditions, this is about 1700 calories per day, and with moderate physical activity it rises to 2500–3000 calories per day, whilst when individuals take a great deal of exercise the total heat output may rise to as much as 7000 calories per day. Short bursts of intense activity may increase heat production up to sixteen times the normal figure. Shivering, an involuntary muscular contraction, increases heat production and is the normal method of bringing this about in cold conditions. In addition to normal body function, heat may be gained by radiation from the sun. This factor is of great importance, especially in polar and mountainous regions, where the atmosphere is clear and the snow a good reflector of heat.

The body automatically adjusts to heat loss by varying the amount of blood-flow through the skin and by sweating. Removing or adding clothing also alters the degree of insulation, and therefore heat loss. Heat may be lost from the body by conduction, convection, evaporation or radiation. In mountain country the most important of these is convection, or the transfer of heat to gases or liquids. The air adjacent to the body is heated by it, and if the warmed, trapped air is allowed to be disturbed by the wind, considerable heat loss will occur. This is prevented by windproof clothing.

Loss of heat by conduction occurs when clothes become wet. Air is a poor conductor of heat, whilst water is a good one, thus, if clothes become wet, either due to sweat or rain, their insulating value is much decreased and the individual loses heat. In addition, a very large amount of heat is required to evaporate water, and the loss of body heat used in 'drying' wet clothes on the body may be very considerable. Loss or gain of heat by radiation depends on the temperature of the body relative to its surroundings. If the air temperature is greater than that of the body, the body will take up heat, but if it is less, the body will lose it. Heat production must depend on the ability of the cells of the body to function normally, and they are unable to do this without sufficient oxygen. Thus, at high altitudes adequate heat production may be difficult to maintain. Normally, mountaineers operate at about 60 per cent of working capacity; thus, if the normal maximum intake of oxygen is 3 litres per minute, they function at about 2 litres per minute. If for any reason the physical working capacity is lowered, the individual will have to work nearer his maximum capacity to keep warm, and if he is unable to keep up heat production, first the peripheral structures will cool down to the ambient, or air, temperature, which is often below freezing; then the central core body temperature will start to fall. Once this has happened, the individual may become gravely ill and die within two hours of the onset of symptoms.

Man and the environment

a Climate

There are two distinct types of cold climate: wet-cold and dry-cold. The wet-cold climate covers large areas of the world, the so-called temperate zones. In these areas the range of air temperature varies from between 10°C to freezing point or down to −5°C, and rain, sleet, mud and high winds are not uncommon.

In dry-cold regions, the temperature rarely rises above freezing point, so that water does not contribute to stress, whereas snow, ice and wind do. By definition, as frost-bite occurs when the tissues freeze, it can only occur in sub-zero temperatures; that is, in cold, dry conditions.

Cold air alone is not so dangerous a freezing factor as a combination of cold and wind. The table below is self-explanatory and summarises with brutal realism the effect of wind on temperature—the so-called wind-chill effect. However, a number of strange anomalies do occur, as for instance the case of a rear-gunner who fell from a height of 17,000 metres (10½ miles), in an ambient temperature of −50°C, before his parachute opened. He only suffered mild frost-bite of his fingers.

WIND-CHILL EFFECT: EQUIVALENT EFFECTIVE TEMPERATURE

Windspeed	Actual air temperature (°F)											
(mph)	50	40	30	20	10	0	−10	−20	−30	−40	−50	−60
5	48	36	27	17	−5	−5	−15	−25	−35	−46	−56	−66
10	40	29	18	5	−8	−20	−30	−43	−55	−68	−80	−93
15	35	23	10	−5	−18	−29	−42	−55	−70	−83	−97	−112
20	32	18	4	−10	−23	−34	−50	−64	−79	−94	−108	−121
25	30	15	−1	−15	−28	−38	−55	−72	−88	−105	−118	−130
30	28	13	−5	−18	−33	−44	−60	−76	−92	−109	−124	−134
35	27	11	−6	−20	−35	−48	−65	−80	−96	−113	−130	−137
40	26	10	−7	−21	−37	−52	−68	−83	−100	−117	−135	−140
45	25	9	−8	−22	−39	−54	−70	−86	−103	−120	−139	−143
50	25	8	−9	−23	−40	−55	−72	−88	−105	−123	−142	−145

The above table is reproduced by permission of the Museum of Science, Boston, U.S.A.

Note: This table gives the effective temperature which, due to the wind-chill effect, is equivalent to the actual temperature in still air. The zero wind condition is taken as the rate of chilling when one is walking through still air (an apparent wind of 4 mph).

The climate of mountainous areas is particularly prone to produce cold injury. In any event the temperature normally drops about 1 °C for every 180 m of ascent, and as a still day is rare, the wind-chill factor has always to be taken into account. Sudden changes in the climatic conditions with storms of rain, hail and snow and sudden drops in temperature are common, especially in periods of disturbed weather.

Cases of frost-bite and hypothermia can and do occur on normal Alpine routes in mid-summer and mountaineers can find themselves wearing all their spare clothing taken for a bivouac whilst actually climbing if the weather deteriorates. In Great Britain cold-dry conditions and frost-bite are rare, but some degree of hypothermia is probably more common than realised, as the combination of rain and wind can cause a considerable degree of heat loss.

b People at risk

Frost-bite is an uncommon condition in civilian life, despite the fact that large numbers of people live, at least for part of the year, in sub-zero temperatures. Populations of the order of at least a hundred million may be at risk in Siberia, Russia, Scandinavia, Canada and Alaska, while at least another ten million people live at altitudes exceeding 3600 m in South America and Central Asia. During warfare at sub-zero temperatures it is not uncommon for frost-bite to occur as a complication of wounds or disease. Frost-bite, for instance, was common amongst soldiers during Napoleon's campaign in Russia, during the Second World War in the winter in Northern Europe, and also in the more recent Korean campaign. It has occurred, too, amongst Indian and Chinese soldiers fighting in the Himalaya. Aircrews, especially air-gunners in the U.S. Air Force in the Second World War, were prone to frost-bite, and at one time during the winter of 1943 frost-bite injuries among U.S. heavy-bomber crews were greater than all other casualties combined. Most of these occurred in aircraft flying between 7500 and 10,500 m, in temperatures between −32°C and −43°C. The waist-gunner of these aircraft operated his machine guns through large waist ports, and the guns were fired directly into the frigid air rushing by at over 320 kph. Although well protected with sheepskin clothing and heavy mittens, the gunners, to work their guns more dextrously, often removed their gloves. Contact with the metal of the gun, which lasted only a few minutes, resulted in extremely severe frost-bite injuries. The interiors of the aircraft were not insulated, and rewarming hardly ever occurred. In addition to the extreme cold and wind, other factors, such as poor nourishment, low oxygen content of the air, fear and exhaustion, made frost-bite a near certainty.

Frost-bite occurs fairly frequently at high altitude, especially if oxygen is not used, though its occurrence is by no means inevitable. For instance, on the successful American Everest expedition four men bivouacked at 8500 m with little or no oxygen and two only were seriously affected. At 12,000 m men have only existed briefly in free-fall parachute drops, whilst at 18,000 m the blood boils at body temperature, because of the low atmospheric pressure, and man can exist only in an artificial environment.

At 8850 m, near the summit of Everest, men used oxygen in order to move, and although they have survived for up to one hour without its use while sitting still, it is unlikely that they could live for much longer at this altitude without supplementary oxygen, and loss of heat would contribute to their death.

Curious unexplained anomalies occur in the incidence of frost-bite. For instance, exposure of part of the body in the slipstream of an aircraft may result in complete loss of the affected organ, yet, as already mentioned, an airman who fell from approximately 17,000 m in an ambient temperature of −50°C before his parachute opened, only sustained mild frost-bite of the fingers. Polar travellers of the pre-1920 era, associated with the names of Scott and Shackleton, suffered severely from frost-bite, and it seems to have been a common and almost unremarkable condition. Now, however, in these regions it is uncommon, except in the case of accidents, and this lowered incidence is due to increased knowledge and its application. The use of improved clothing, a better diet (there is evidence that Scott's polar party suffered from scurvy) and improved living conditions with better protection from both wind and cold have resulted in frost-bite being an uncommon injury.

In civilian life, even in big cities, frost-bite is still encountered occasionally. In the winter of 1957 in Montreal, I treated a number of cases which occurred in men who had been found lying in the street unconscious, due to alcohol. In London, too, I have seen a man who, during a period of sub-zero temperatures, camped out for several days on a bombed site to avoid the police. When he was eventually arrested both lower limbs were so badly frost-bitten that they were amputated below the knee.

Mountaineers especially are exposed to conditions in which frost-bite can occur, and on early Everest expeditions mild degrees seem to have been common, and were accepted. However, at least two Sherpa members of these early pre-war Everest expeditions appear to have died from frost-bite. More recently, despite increase in knowledge and improvements in food and equip-

18 *Frost-bitten feet*

ment, the overall incidence of frost-bite on Himalayan expeditions does not appear to have fallen greatly, and this is because improvements in equipment have led to harder routes being attempted in more severe conditions at high altitudes than previously.

There is a difference, too, in the outlook in those who climb mountains and those who undertake polar travel, the only comparable activity carried out in a similar environment. Polar travellers live for long periods in sub-zero conditions, and on their continued fitness depends their ability to survive and work. Mountaineers who are engaged in climbing peaks rather than carrying out research in mountain regions for long periods, may, when attempting the summit, have to forego a number of precautions which will protect them from frost-bite, and this puts them at greater risk. When climbing a peak over 6000 m the margins of safety, already narrow due to high altitude, may have to be pared to the bone in order to complete the ascent, especially in uncertain weather. However, frost-bite is by no means inevitable at high altitude, though illness and injury do make it more likely. The majority of the highest peaks in the world have been climbed successfully without cold injury. On Everest, K2 and Kangchenjunga, the three highest, climbers who made the first ascent used oxygen, and all escaped any degree of cold injury. However, when attempts have been made without oxygen, the incidence of frost-bite has been high, as occurred on attempts on Nanga Parbat, the successful ascent of Annapurna and early attempts on Everest. The incidence, too, of other illnesses was increased. With care and preparation, frost-bite may be avoided. For example, Bradford Washburn has taken at least a hundred people into the high peaks of Alaska with only one mild case. However, in the summer of 1963 three out of five parties climbing Mount McKinley sustained frost-bite injury, and a number of cases required amputation. This was due in part to inadequate preparation and in part to a lack of high mountain experience. The recent popularity of winter climbing in the European Alps has resulted in an increase in the number of cases, despite great improvements in technique and clothing. Two of the surviving members of the team who climbed the North face of the Eiger in winter were frost-bitten, and a number of other cases have been reported.

c High altitude (*over 5500 m*)

At 5500 m a steady work rate of 2 litres per minute is difficult to maintain, as the individual is working nearer to capacity, and therefore the liability to cold injury is more common than at lower levels. Heat loss, too, from the lungs increases with the raised ventilation inevitable at high altitudes. If, due to inadequate oxygen intake or other reasons, heat production falls, the peripheral structures will cool to the ambient temperature, which is almost always below freezing, and frost-bite will inevitably occur.

This situation can arise whilst actually climbing, and a number of cases have been reported of individuals climbing at high altitude on Everest and elsewhere who, despite being fully clothed, have been unable to take in enough oxygen, with the result that the skin of their fingers and toes has cooled to below freezing point and they have sustained frost-bite.

If, due to illness, they become immobile, the peripheral tissues will cool even more rapidly to the ambient temperature and become frost-bitten.

Other factors at high altitude are low calorie intake, which is almost inevitable over 6500 m, and low fluid intake, which leads to dehydration and a decline in physical condition. A third factor is high-altitude deterioration, which is another word for the general effects of chronic oxygen lack. It would be fair to say that any illness at altitude may be associated with frost-bite. The most serious and immediate effect of low oxygen pressure is on the brain cells. This effect is insidious, and there is a diminution in the more sensitive functions of the brain, such as reasoning power and the ability to make correct judgements. There is also a tendency to become lazy and careless. Life generally at high altitude tends to increase the risk of frost-bite, as shelter is often inadequate and difficult to find, storms tend to be more violent and arise more rapidly, the cold is more extreme and the wind more vicious. Inadequate diet, lack of fluid intake and loss of sleep all contribute to greater body fatigue. Nervous tension, too, will be increased, especially during summit attempts. In this connection, it is well to recognise that many drugs taken to stimulate individuals to extreme physical exertion may cause constriction of the blood vessels, and therefore increase the liability to frost-bite. Certain drugs too, especially the hallucinogenic ones and opium derivatives, may cloud judgement, jeopardise the safety of the individual, and through him that of the whole party.

Considerable loss of heat may also occur from the lungs as a result of excessive respiration on exertion. Shivering, too, may be impaired due to oxygen lack. The use of oxygen at high altitude decreases the incidence of frost-bite, and on expeditions where oxygen has been used the incidence of frost-bite has been lower than when it has not. A number of trained observers, too, have noticed how warmth has been restored to frozen limbs by the use of oxygen.

A high-calorie diet is necessary in cold weather, and at high altitude in bad weather the preparation of appetising and digestible food may be extraordinarily difficult. A sufficient amount of food is essential for good health, and every effort must be made to cook and eat it. Adequate fluid intake too, is important. A good rule is to drink too much, enough to allay thirst is insufficient, as the sensation of thirst is blunted due to oxygen lack—as is the sensation of appetite. It is most important that adequate fuel must be taken to melt snow for water. If long periods are spent above the snow-line, and fresh food is not available, regular vitamin tablets should be taken. At low altitudes fat, which provides twice the number of calories for a given weight as carbohydrate, is easily digestible. At high altitudes, however, this is not the case, and Washburn cites the example of an expedition to Mount McKinley in 1912 which failed, due to its total reliance on a pemmican diet. This had been eaten successfully below 4200 m but it was totally repellent above 4900 m. Sweet substances are well tolerated at high altitude and sugar should be taken in very large quantities. Normal blood flow to the peripheral tissues may be decreased by some stimulant drugs, and also by smoking. Smoking, however, seems to have little effect on the incidence of frost-bite. Alcohol causes dilatation of the peripheral vessels, which means that more blood flows through the cool tissues, and therefore bathes the temperature-regulating centre of the brain at a low temperature. The whole central core temperature may, in this way, be lowered, and the patient becomes very ill. Although alcohol should not be drunk whilst outside, therefore, once in a sleeping bag inside a tent its effects can often be beneficial.

d Acclimatisation

Acclimatisation to cold is a little-understood phenomenon, but there is some evidence that people who work for long periods in the cold with bare fingers do get accustomed to low temperatures. These individuals are able to work for longer periods than those who are not used to this type of work, and it has been suggested, but not confirmed, that local vascular changes take place. Other observations have been made on individuals, especially those living in the Himalaya who are able to walk in bare feet in snow for long periods without their feet becoming frost-bitten. Investigations have been carried out on one or two cases, and these show that despite the below-zero temperature of the snow in which they have been walking, the temperature of the feet is well above freezing point. As a result, the tissues do not freeze, and thus frost-bite does not occur. It is thought, too, that these individuals have a higher metabolic rate and are less sensitive to the painful stimuli produced by cold.

Exposure to identical, or even similar, conditions does not, however, necessarily result in frost-bite in all cases, and marginal discrepancies may result in one person becoming frost-bitten where another is not affected.

Better shelter from the wind, due to intelligent foresight and use of available materials, better protective clothing, a more adequate digestion, a better peripheral circulation, lack of anxiety and a fitter individual may make a minimal yet significant contribution. At higher altitudes better acclimatisation, a higher respiratory capacity and a better cardiac output will also be important.

The part that acclimatisation to cold plays is as yet not fully understood, but unlike acclimatisation to high altitude it seems to be a relatively slow process, and it is possible that natural selection may, over the years, be important. It seems, therefore, that individuals who are both physically and mentally well-attuned to the environment and are in good training are less likely to suffer from frost-bite.

Description of injuries

a Frost-nip

Numbness of the toes, fingers or cheeks, followed by tingling on rewarming, does not constitute real frost-bite. Frost-bite is a pathological condition that damages the tissues, but it is sometimes difficult to be certain whether a person has a mild degree of frost-bite or, instead, so-called ‘frost-nip’.

In frost-nip the changes are reversible, and following treatment the affected person can continue to work in the cold environment. The skin blanches, and there is a sudden and complete cessation of cold or discomfort in the injured part, which may be followed later by a feeling of warmth. If treatment is started immediately frost-nip will not progress to frost-bite; however, it is only fair to add that many serious cases of frost-bitten feet have occurred after a period when there was no anaesthesia.

b Superficial frost-bite

The frozen part, though obviously white and frozen on the surface, is soft and pliable when pressed gently before thawing. Only the skin and subcutaneous tissue immediately adjacent are involved. After rewarming, the affected part becomes numb, mottled, blue or purple and it will then sting or burn and swell for a period.

Blisters may occur within twenty-four to thirty-six hours—depending, to a certain extent, on the site of the injury. Thus blistering is more common on the dorsum of the fingers and hand, where the skin is *less* closely applied to the subcutaneous tissues, than on the palm, where it is more closely applied.

The blisters slowly dry up, the skin then hardens and will become black, producing a thick, insensitive carapace of tissue. Some oedema or swelling of the injured part may occur, but will subside if the affected part is raised. Throbbing or aching may persist for several weeks. If there has been no loss of tissue, the part maintains a reasonably normal contour; if this contour is not maintained, however, and there is obvious loss of form, then it is reasonable to suppose that loss of tissue has occurred. When the black skin carapace finally separates, the tissues underneath are red, tender, unusually sensitive to cold and heat and may show evidence of abnormal sweating. Eventually, after some months, this tissue takes on the appearance of normal skin.

c Deep frost-bite

This is a more serious injury, and involves not only the skin and subcutaneous tissues, but also the deeper structures, including muscle, bone and tendons. Immediate blistering is not inevitable, and may take up to a week to develop. The entire hand and foot may remain swollen for months. The affected part becomes cold, mottled and blue or grey in colour. Initially, though often painless, shooting or throbbing pain can occur, and frequently abnormal sensations are encountered for up to two months. As the tendons are markedly resistant to cold injury, the patient will be able to move his fingers or toes for long periods. Muscles (abnormally sensitive to cold injury) which are responsible for moving the fingers or toes are placed a long way from the affected area, and this means that patients with even severe frost-bite can walk or use their fingers for crude movements, such as gripping.

The blisters finally dry up and the skin becomes black and sloughs off. Often a complete cast of the tip of the finger or toe, with nail attached, may separate, leaving red, abnormally sensitive skin underneath. In addition to abnormal sensation, the skin sweats abnormally and is oversensitive to temperature changes. Permanent loss of tissue is usually inevitable in deep frost-bite, especially at the tip of the injured area, i.e. the finger or toe, when it loses its normal contour and shrivels up. If left, and kept dry and uninfected, the shrivelled area separates at the 'line of demarcation'; that is, a line of tissue reaction between the dead and healthy tissue. However, even with deep frost-bite, a limb may return almost to normal, over a period of months, and this occurred in one patient of mine who had deep frost-bite of both legs. Unfortunately, because of residual gangrene of both heels, a bilateral below-knee amputation had to be carried out.

It must not be forgotten that frost-bite may be a local manifestation of a generalised disease (cold injury) and a patient who is frost-bitten may, in addition, be suffering from hypothermia. This condition may be recognised by temperature recordings or clinical observation, and must be treated also. Obviously, frost-bite in association with hypothermia is a much more serious condition than frost-bite without any evidence of hypothermia.

Treatment

a Preventive

Obviously, prevention is more effective, and preferable, to cure. This depends on a knowledge of the environment, good health, adequate clothing and shelter and adequate oxygen equipment. An intelligent appreciation of what is going to happen is the best prevention against frost-bite. It is only when the individual is exhausted, hungry, injured, ill or hypoxic that the chances of frost-bite are increased. Correct and intelligent use of clothing to maintain general body warmth is very necessary. Enormous amounts of heat may be lost through the face, head and neck and these parts should be protected adequately. Clothing should fit loosely; it is important that socks and boots should fit snugly, but not too tightly, otherwise the possibility of frost-bite is enhanced. Sweating should be avoided under conditions of extreme cold and clothing that allows adequate ventilation should be worn. The reason for this is that the amount of heat required to cause the evaporation of fluid from wet clothing is very considerable and can cause a fall in the central body temperature. The feet and hands should, if possible, be kept dry. The most difficult item of equipment on which to give advice is gloves. In cold weather, mittens should be worn instead of gloves, although it is often impossible to carry out specialised work requiring the use of complicated and delicate instruments unless one is actually wearing gloves. If the bare finger is placed against metal at very low temperature the skin will stick to it; therefore, thin silk or nylon gloves should be worn, and all metal parts that are touched frequently should be covered in tape. Alternatively, there should be no metal parts on instruments that are used in very cold weather. Extra socks and gloves should always be taken on climbs. It is probably unwise to shave the face under very cold conditions, as a beard helps to entrap a barrier layer of insulating air.

Enough food of the correct sort should be eaten to produce the maximum output of body heat, and the diet at low altitudes in cold weather should have a considerable amount of fat. As altitude increases, carbohydrates are more easily assimilated, and therefore more sugar should be included in the diet, as although fat produces twice as many calories per gramme as carbohydrates and protein, it is not well digested at high altitude. Care should be taken not to climb under too extreme weather conditions, especially at high altitude, or where one is exposed to the wind. It is often possible to find a sheltered route up a mountain or to place a camp in a sheltered spot if one inspects the mountain side intelligently.

The combination of high altitude and wind can be lethal, and considerable loss of heat can occur when overbreathing. This contributes to generalised hypothermia by washing out warm air from the lungs. It is therefore inadvisable to work, or climb, too vigorously in extreme cold. A slow steady pace that does not result in panting, or very deep breathing, is best. It is extremely important to dress for the temperature with which the limbs will be in contact, thus it is perfectly possible for the ambient air temperature to be above freezing whilst the temperature of the feet will be many degrees lower, especially in deep powder snow. Even the temperature of the ambient air may vary enormously, and variations of over 50°C can occur at sunset within a relatively short period.

b Curative

i *Field*

a Immediate. The only form of frost-bite that should be treated on the spot is frost-nip. This commonly occurs on the exposed portions of the body, such as the cheek or nose, and under these circumstances the 'buddy' system is important. By this is meant that each member of the party keeps a watch out for signs of superficial frost-bite occurring in other members of the party, and as soon as it is spotted it is treated. This is done by warming the affected part with the back of the hand, and it is best carried out sheltered from the wind. Once the part has been restored to normal colour consistency individuals may continue working.

b Camp. All cases of *bona fide* frost-bite should be treated either in hospital or at the best-equipped camp. Attempts to treat frost-bite at high camps are always ill-advised, and if it is not possible to evacuate the injured man to civilisation and hospital immediately, he should be taken to a camp where there are reasonable facilities, the temperature is equable and shelter adequate. A frost-bitten limb should not be rewarmed whilst climbing. Once a toe or foot is rewarmed the patient should be carried, and cannot therefore take any further part in his own rescue. No patient should be allowed to walk on thawed, or partially thawed, feet, as infection and serious loss of tissue may result. Therefore, it is better to continue walking on frost-bitten feet to a suitably placed camp or position from which evacuation is easy before starting any form of treatment. If a fracture has occurred the part should be splinted, and the splint should, if possible, be well padded, as any pressure will tend to impede the blood supply and make frost-bite more likely. The parts of the limb distal to the fracture or injury should be watched carefully, to see that the blood supply is adequate.

No attempt should be made to treat the frost-bitten part, except under maximal conditions, where treatment can be continued. In essence, this means a camp from which the patient can be flown out by helicopter or carried down without difficulty. Once the patient has reached the site from which he can be evacuated easily, treatment should start. This is directed at two levels: the whole individual and the affected part.

The whole individual. The patient's morale should be kept up, because after a long, possibly painful, and usually difficult descent, the prospect of a gradually blackening toe or finger is not pleasant to contemplate. This may be done by telling him that black fingers and toes do not necessarily mean that they are either going to drop off or that they are going to need amputating. Hot liquids should be given immediately, as this is a form of *active* rewarming, which is most important. Food, also, should be given, as food in itself tends to warm people up and cause dilatation of peripheral blood vessels. The body heat from his companions lying either beside him in a sleeping bag, or in the same sleeping bag, may also provide an extra source of heat. General rewarming may cause pain, and unless there is a doctor available it is wise only to give aspirin. The patient should *not* be allowed to cool down, and should be *kept* warm continuously. Antibiotics must be given prophylactically.

The affected part. Methods of treatment have changed in the last few decades. It is now recognised that rubbing the affected part with snow, as once advocated, is unwise as it does not raise the temperature and melt ice-crystals, but is liable to break the skin and lead to infection. Other forms of violent local therapy, such as beating, are open to the same objections.

The affected part should be warmed. Preferably, a container with water at 44°C should be used. As water that is too hot will damage the limb, a thermometer is useful. If this is not available the temperature can be tested with the finger. If it is too hot for comfort, more cold water should be added. If no container is handy, hot water poured over towels or cloth wrapped round the part can be used. Rewarming should last about twenty minutes, and the temperature of the water should be checked frequently to see that it does not fall below 42°C. Additional hot water should not be poured over the affected part. If rewarming by fluid is impossible, the part should be placed against a warm abdomen, armpit or held in the warm air. It should never be placed by an open fire, as a frost-bitten part is partially anaesthetic and can be burnt without pain. For the same reason, the temperature of the water should never be assessed by an affected finger. After rewarming either by wet or dry heat, the part should be cleaned gently with a very mild antiseptic or mild soap. It should not be scrubbed or rubbed. Dirt must be removed gradually and gently. The tissues are at this stage very friable and liable to infection. Once the protective covering of the skin is breached, organisms enter the subcutaneous tissue and breed at a great rate. Blisters should be left alone. They should not be pricked or removed, as they form a covering for the part. Often, however, blisters are broken and there is some loss of skin. In these cases soft, dry, absorbent dressings should be used to cover them. Similar dressings between the fingers and toes will diminish friction and prevent further damage, as even light pressure can cause pressure sores, infection and loss of tissue. So long as the affected part is warm and does not get rubbed, it may be kept exposed. To diminish swelling the part should be either raised or kept level. If it is not possible to send the patient to hospital, simple treatment must be continued along the following lines. Infection must be prevented by the use of broad spectrum antibiotics. Some of these have unpleasant side-effects, such as diarrhoea, and should be stopped temporarily if this occurs. No tissue should ever be removed, as even after many weeks it may be impossible to assess the depth of frost-bitten tissue. Movements of the joints should be carried out to stop them stiffening. This may be done only by the patient himself, as if the part remains totally immobile it may lead to serious or complete limitation of joint movement.

ii *Hospital*

Over the past few years, a considerable number of different forms of treatment have been used, and these are directed at the various stages of the pathological process.

1 *To melt ice crystals, by rewarming.* The part is immersed in water at 44°C.

2 *Increasing the blood supply.* This increases the nutrition and warmth taken by the blood to the affected cells. This can be carried out by warming. It may also be carried out by temporarily or permanently blocking those nerves of the autonomic nervous system which cause the peripheral blood vessels to contract. These denervated vessels remain widely open. This treatment may be carried out either by injection of a chemical or by surgical excision and removal of the nerve supplying the blood vessels. Drugs also can be used to cause temporary dilatation of the peripheral blood vessels. Blood vessels may, in addition, be dilated by a reflex method; that is, the unaffected arm or leg is placed in warm water, this causes dilatation of those blood vessels supplying the affected part.

3 *Prevention of the blood 'sludging' after the fluid has seeped through the blood vessel wall.* There are various different methods and a number of anticoagulant and other substances are used, including Heparin, Dicoumarol, Streptokinase, Low-Molecular-Weight Dextran and Rheomacrodex.

4 *Increasing the oxygen supply to the affected cells.* At high altitude, the use of supplementary oxygen increases the amount of oxygen transported to the cells and allows metabolism to proceed more normally. In partially damaged cells this may well tip the balance between cell death and survival. At sea-level, using the same principle, hyperbaric oxygen or oxygen under two or three 'atmospheres' pressure can be used. At sea-level the haemoglobin is normally saturated with oxygen under normal conditions, so that when hyperbaric treatment is used the extra oxygen is transported in the fluid part of the blood.

5 *Prevention of infection.* This is carried out by the use of antibiotics, preferably ones that affect a large number of different organisms. Cortisone and other anti-inflammatory agents may be given.

6 *Physiotherapy.* This is essential to keep the joints mobile, and a whirlpool bath may be useful.

7 *Surgical procedures.* These should only be used as a last resort, and include plastic repair and amputation.

After-effects of frost-bite

A part that has been frost-bitten once is likely to be frost-bitten again. The affected area is unduly sensitive to cold and heat, and is often moist. Some decalcification of the bone underneath the affected part may occur. The after-effects of frost-bite are due to injuries of both the nerves and blood vessels of the affected part and it is possible to distinguish between these, after simple medical tests have been carried out. From the practical point of view, however, it must be stressed that a part that has been frost-bitten once is liable to be frost-bitten again, and great care should therefore be taken to prevent this.

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