SURGERY OF MODERN WARFARE

EDITED BY

HAMILTON BAILEY

PART TWO

THIRD EDITION

E. & S. LIVINGSTONE

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MODERN WARFARE

EDITED BY

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PART II

With 146 Illustrations

Many in Colour

Third Edition

(*Complete in Six Parts*)

EDINBURGH

E. & S. LIVINGSTONE

16 AND 17 TEVIOT PLACE

1944

SURGERY OF MODERN WARFARE

CONTENTS—PART II—*continued*

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PART III

SECTION VIII—Wounds of Blood Vessels

SECTION IX—Methods of Immobilizing the Limbs

SECTION III

FROST-BITE, BURNS AND SKIN GRAFTING

CHAPTER XV

FROST-BITE AND TRENCH FOOT

FROST-BITE

WHEN the body, as a whole or in part, is exposed to cold the pathological effects which ensue are best understood if they are divided into two sections, general and local, with the recognition that general effects may follow total or partial exposure and local effects may have general ones superimposed.

The maintenance of an appropriate body temperature is a prime necessity of all forms of warm-blooded life, and so efficient are the means adopted to this end that very prolonged exposure to severe cold is necessary before the balance between heat production and conservation and heat loss becomes disturbed, so that the body temperature falls.

General effects of exposure to cold can be subdivided into two categories : (1) those which occur when the exposure is not severe enough to lower the general temperature ; (2) those which follow when the body temperature continuously falls.

In the former group are placed some of those illnesses which occur chiefly in the winter months and which mainly affect the respiratory tract. Many of these are primarily infective conditions, and what part cold plays in their incidence is not sufficiently determined.

In the common winter cold, for instance, it is possible that the inspiration of cold air renders the nasal and other respiratory mucosæ less able to withstand the attack of the invading organisms or viruses ; in other examples of " winter complaints " there may be some general lowering of vitality and of resistance to infection, but undoubtedly other factors than cold, *i.e.*, lack of sunshine and fresh air, here play their part.

When the exposure is so severe that it produces a heat debt and the body temperature falls, a set of much more urgent and serious symptoms arises. According to those who have had an opportunity of observing such cases, there is at the onset a loss of energy and a feeling of great fatigue ; this is often associated with a loss of the normal urge to struggle for life, so that the victim resigns himself to his fate. When the body temperature falls to about 68° F. there is an overpowering desire to sleep, and coma shortly supervenes. Those few who have survived these experiences state that the sensations are not unpleasant. Apparently life may be maintained for some time in this state, for recovery has been shown to be possible after several hours' unconsciousness. This agrees with observations on animals found " frozen " which revive when the temperature is raised.

Experiments on animals subjected to severe general cold show that respiration, after an initial quickening, slows and finally ceases, while at a slightly later period the heart-beats (ventricular) also slow and stop. Such animals are not beyond resuscitation, even after several hours, and may be apparently unaffected by their experience. Below a certain temperature the thermal controlling centres fail and the internal temperature follows that of the surroundings, like a cold-blooded animal (poikilothermic). In some normally hibernating species there are indications of the same process at work.

Exposures as extensive, prolonged, and severe as those employed in animal experiments can arise but rarely in human experience, but nevertheless authentic reports from the recent Finnish and Russian campaigns reveal that large numbers of men have been found completely frozen, and similar records are received of shipwreck survivors exposed to icy cold wind and sea. In all these cases it is to be suspected that there were powerful predisposing factors at work, since it is well recognized that lack of food, debility, hæmorrhage, and toxæmia from wounds undermine the ability of the body to maintain its normal temperature.

The various mechanisms by which the body attempts to maintain a general temperature compatible with full vitality are all protective of the individual, although not of necessity equally so of the exposed part or region. Indeed, as the local changes associated with exposure to cold are studied, it becomes increasingly obvious that the body is often compelled to sacrifice the local tissues in the efforts it makes to preserve general vitality. This is possibly a novel conception of the process, but the underlying principle of local sacrifice to conserve the whole is one which can be applied to other pathological processes and is, of course, in complete accord with biological philosophy both in the colonies of cells which constitute the individual and in the larger colonies of individuals which form the families, tribes, herds, and other aggregations of life throughout the animal and vegetable world.

These mechanisms vary in importance ; there is even some evidence that in minor exposures to cold the reactions are directed only to local protection, the incident being too insignificant to call the general means of protection into play. Possibly this is the real meaning of the periodic local dilatation which Lewis has described and which he attributed to an axon reflex, since it remained after the nerve had been divided, but not if sufficient time had elapsed for the nerve to degenerate peripherally.

Against more severe [1] exposures protection is achieved in the following ways :—

1. The skin is normally covered with a thin layer of greasy sebaceous material which acts as a bad conductor, but, more importantly, tends to induce supercooling, the benefits of which will be described later.

2. The subcutaneous fat imposes another thermal barrier between the surface and the deep structures.

3. The superficial vessels contract so that less blood is delivered to the cold skin surface. With severe exposures the deep vessels will subsequently be affected, but owing to difficulties of observation it cannot be stated that they respond in the same manner ; as is well known, there is usually a reciprocal relationship between the deep and superficial blood supplies.

4. Sweating is reduced or abolished with a corresponding saving of the heat loss both in secretion and evaporation. Related to this is the cooling effect of the inspired air which is said to amount to 15 to 25 per cent. of the total heat loss. As already noted in animal experiments, respiration is

[1] The term "severe" is here used to include the temperature fall as well as the length of exposure (which, as would be expected, is an important factor). Thus severe exposure may mean exposure to intense degrees of cold or more prolonged exposure to lesser degrees.

slowed, but in human experience this is unlikely to occur until a late stage on account of other factors (such as the rarefied air in mountaineering).

5. In the earlier stages, shivering occurs in an attempt to increase heat production.

6. Contraction of the pilomotor muscles is obviously a very minor aid to heat conservation in man, although in animals it has this effect by making the hairy covering thicker.

7. There is increased heat production in the body generally by several means which need not be elaborated here; they include stimulation of the adrenals and the thyroid, liberation of glycogen from the liver, etc.

8. It will be noted that many of these effects depend upon the sympathetic nervous system for their development. This accords with Cannon's observations upon his sympathetically denervated dogs which were unable to withstand cold and became practically poikilothermic.

The effect of the circulation in distributing temperature changes is well seen (Fig. 166) by comparing the cooling curve of the corpse with that of the anæsthetized living animal. The importance to the body of restriction of the superficial circulation by vasoconstriction is thus emphasized.

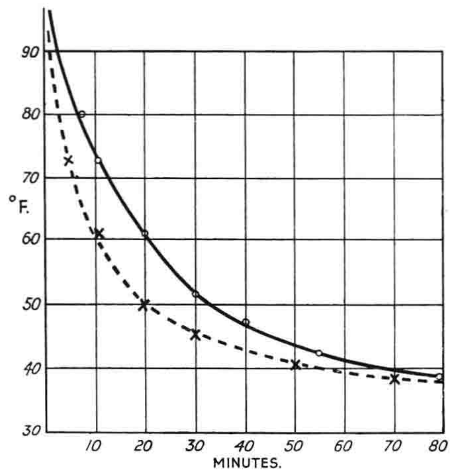

FIG. 166

Rates of cooling, when exposed to cold, of kitten corpse and of living anæsthetized kitten, compared. Continuous line is corpse, broken line is living animal. The initial rate of fall is much greater in the living animal owing to superficial circulation of the blood. As the circulation slows and fails, however, the rates are equalized.

When an animal *dies* as a result of severe exposure to cold its condition is really one of suspension of animation, so that it is not surprising that resuscitation should be possible when the temperature is raised. The plentiful stories of animal resuscitation are thus confirmed in the laboratory; there are, however, certain secondary problems which have to be overcome, such as the initial raising of the blood pressure, which becomes increasingly difficult as the age of the animal increases. The body of an animal which has died of cold (provided a certain critical temperature has not been passed) is comparable with an internal combustion engine in perfect condition and having plenty of available fuel which will never start spontaneously but requires an initial turn of the crankshaft to produce the first explosion. In the case of animals there is no residual blood pressure during the state of suspension of animation, and so when thawing out it is necessary to raise it artificially in order that the heart may receive its initial impulses. On occasions in very young animals the heart has been seen to start spontaneously and recovery has followed without artificial aid. It is unlikely, however, at present that attempts at resuscitation of frozen human beings would meet with success, for not only are the technical difficulties great but in most instances the frozen state has been preceded by such serious predisposing conditions as wounds, loss of blood, starvation, general debility, etc. The general effects of cold, while of great experimental interest, are therefore of little practical importance.

Local effects of cold—The local effects of cold, especially in times of war, have been recognized and studied for many years. Napoleon's surgeon, Baron Larrey, described the ravages of cold during the ill fated attack on Moscow. He was the first to recognize the condition which is now known as "trench foot," and showed that it was not extreme cold which was responsible but lesser degrees associated with wet. Again, in the "Medical History of the Crimean War" (1854), it is pointed out that it was in cold wet weather that these troubles became prevalent. A clear distinction is here made between true frost-bite and the gangrene due to cold and debility when the temperature was always above zero. From this time to the commencement of the last war, articles in similar vein appeared as a result of experiences in the Tibet Mission Force and the Balkan wars. On the whole, however, the armies engaged in 1914 were unprepared for the great number of cases which the special circumstances of static trench warfare produced. The magnitude of the problem is indicated by the fact that no fewer than 85,000 cases are reported in the "Official History of the War" to have occurred in the British Army alone. This number would be enormously increased if the figures of the French, Russian, and German armies were added. These alarming figures naturally commanded investigation; as a result a large number of articles were written, and a good deal of experimental work was carried out which increased both our knowledge of the pathology of the condition and our ability to suggest methods of prevention and treatment. Since no description of the clinical aspects of trench foot and frost-bite can mean much unless the underlying pathology is understood, it is necessary to give a brief survey of this work, which forms the basis of our present knowledge and which has been extended in the inter-war period, with general confirmation of the earlier findings and with certain important additions.

In 1915 Smith, Ritchie and Dawson published an account of their experimental production of a condition closely resembling trench foot by exposing rabbits to wet and cold under varying circumstances. It must first be noted that they found it difficult to produce any pathological change; this should remind us that great caution and reserve must be exercised in comparing clinical experiences and experimental work on animals which not only have a pronograde posture but also exceptionally well-developed defence mechanisms. The conclusion of these observers was that the main effect of cold was on the blood vessels, which, after exposure, allowed tremendous transudation; upon this the subsequent changes depended. They also formed the opinion that the effects of mild, wet cold over a long time were different only in degree from those of short exposures to severe dry cold. A further important point was their demonstration of the bad effects of slight constriction by rubber bands, an observation entirely in agreement with clinical observation in the trenches.

At this time, while engaged in certain experiments upon the growth of tissues *in vitro* (with an entirely different end in view), I found that individual tissues and growths *in vitro* appeared to be unaffected even by prolonged exposure to cold, providing actual freezing was avoided. Thus portions of explanted heart, growing and pulsating vigorously *in vitro*, could be stored at a temperature of 0° C. for several days (sometimes for weeks) in complete inactivity, to resume active growth and pulsation when the temperature was again raised to that appropriate for the animal concerned. Similarly, growth occurred more readily in explants obtained from tissues which had been stored for several days in the ice chest than in those obtained freshly from the animal. I am informed that the same observation applies to human corneal grafting—cold-stored grafts take even better than fresh ones.

By various means the vitality of these cold-stored explants was tested and the results showed that there was no diminution; they could in no way be distinguished from those in which life had been maintained at full flow in the incubator. In other words, there was true suspension of animation. The conclusion was justified that when cells were isolated from vascular, nervous, chemical, and physical influences which their connection with the body normally entails, they remain unaffected by moderate degrees of cold. Since trench foot, therefore, could not be due to any direct effect of cold upon the cells it must in some way be due to one or other of these possible influences, and as all of them would be very depressed or totally abolished about 0° C., it seemed likely that the harm was done chiefly during the thawing-out period. When the vascular and nervous responses were investigated in the intact animal it was found that division of the somatic or the perivascular sympathetic nerve supply failed to prevent the effects of exposure—indeed in the latter case the manifestations of trench foot were even more severe than in the controls. The vascular experiments were more productive, and it quickly became obvious that any means of restricting the blood supply during the thaw period was of value.

Local vasoconstrictors of various sorts were successfully used, and ultimately the paradoxical conclusion was reached that frost-bite gangrene of the skin of an animal's foot could be consistently prevented by tying the main artery to the limb. In human experiments the effects of experimental frost-bite were often completely abolished by the use of local vasoconstrictors (adrenalin, etc.), while in the control areas the skin sloughed and left permanent scarring.

In all the successful experiments the vascular transudation was absent, so that it was clearly this which, by cutting off the blood supply locally, led to gangrene. That this idea of the pathology was probable received support from the observation that multiple incisions or punctures which allowed the exudation to escape also prevented gangrene. At the time it was believed that the vascular phenomena were physical in nature, but in the light of Lewis' subsequent demonstration of the H substance it seems probable that the effect is really a chemical one.

CRITICAL TEMPERATURE

It was well known that exposures to very severe dry cold could produce immediate (or very rapid) death of tissues, and it therefore appeared that there might be a critical temperature beyond which tissue recovery was impossible. To determine this, tissues growing *in vitro* were again used. It was found that exposures to temperatures in the region of $-5°$ to $-7°$ C.

produced immediate death. This was the point of solidification of the cellular protoplasm (the tissue fluids may freeze at a higher temperature), and intimate observation of intracellular structure after such exposures showed that the protoplasmic framework was disrupted. It must be emphasized that the mere exposure of parts of the body to these severe degrees of cold does not warrant the assumption that the tissues themselves have reached the critical temperature, so responsive are the protective mechanisms and so great is the insulating power of the tissues. When care was taken to ensure that these temperatures had been surpassed in animals and in man, death of the particular tissue invariably occurred. This critical temperature of − 5° to − 7° C. was far below that expected from the known

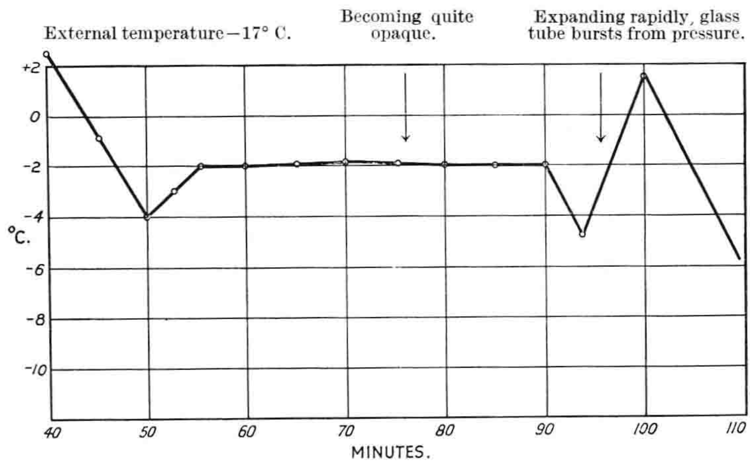

FIG. 167

Lower portion of cooling curve of 10 per cent. gelatin in water. At 50 min. supercooling is displayed, followed by a slow rise in the temperature to − 2, at which it remains while certain physical changes occur. At 75 min. the whole loses its translucency, and after 90 min. there is explosive expansion which breaks the containing tube. The erratic behaviour of the curve here is probably due to direct pressure effects upon the bulb of the thermometer. The slow rise after supercooling is explained by the fact that the more fluid phase of the gel is the disperse one. This should be compared with Fig. 168.

crystalloid and colloid content of protoplasm, but a further series of investigations on the cooling curves of different tissues showed that the discrepancy was due to the invariable exhibition of the phenomenon of supercooling when substances in the colloidal state are frozen. Somewhat similar curves could be obtained from many natural colloids, such as gelatin (Fig. 167), the ultra-microscopic structure of which was known, so that, comparing these with the tissue curves (Fig. 168), it became possible to hazard a guess as to the ultimate structure of the protoplasmic colloids.

The fact of supercooling must be recognized in the interpretation of the effects of cold on tissues; it is undoubtedly the explanation of some of the apparently discordant results which different experimenters have obtained. Lewis and Love subsequently reached the very important practical conclusion that supercooling may be abolished in skin by soaking it in water, or facilitated by leaving the natural sebaceous secretions intact, or by rubbing in oils. It is worthy of note that supercooling introduces a time factor into the question of clinical frost-bite which is not revealed in *in vitro* experiments owing to the small mass of tissue concerned.

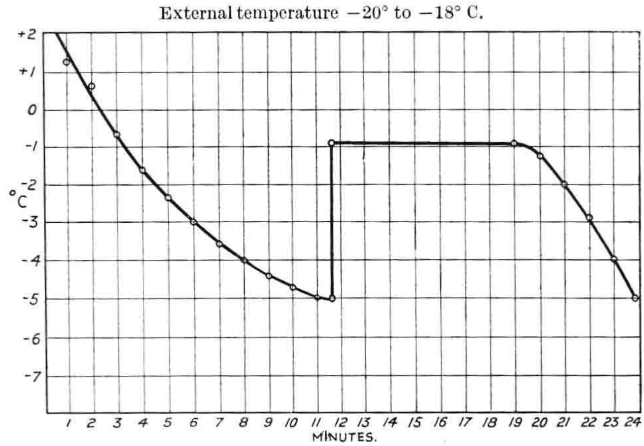

FIG. 168

Lower portion of cooling curve of fresh rabbit muscle. Supercooling is displayed between 3 and 11 min. when the temperature reaches −5. Then there is a sudden rise to the theoretical freezing-point and the protoplasmic structure is disrupted. This quick rise suggests that in muscle protoplasm the more fluid phase of the colloid is the continuous one, *i.e.*, that it is an emulsoid. The explanation of supercooling rests with a study of molecular physics.

The effects of true frost-bite, therefore, are determined at the time of exposure (not subsequently during the thaw as in trench foot) and cannot be avoided by restricting the blood supply or other measures successful in trench foot. But while this is true, it must be realized that surrounding the frost-bitten area is a zone in which the critical temperature has not been surpassed, and that this region, usually of much greater extent and mass than the frost-bitten area, will display all the phenomena of transudation, etc., upon thawing. Clinically this violent reaction may completely mask the tissue destruction due to actual frost-bite.

A study of the survival periods of living tissues at different temperatures (Fig. 170) will help to complete and explain the pathological picture. This curve was obtained from experiments upon isolated tissues growing *in vitro* ; one of its most interesting features is the depression between 25° and 10° C. The probable explanation is that metabolism is a two-sided process consisting of a building up (anabolism) and a breaking down (katabolism). The former, being absorptive of energy, will naturally cease earlier with fall of temperature than the latter, which gives out energy. As long as the temperature is above a certain limit life proceeds almost indefinitely, but as the temperature falls, anabolism ceases before katabolism, so that the period of survival is limited. At lower temperatures still, katabolism also ceases and the survival period increases until, from just above zero down to the critical temperature, life can be conserved for long periods again. When an exposed area is cooling this dangerous temperature zone must be traversed, and again in the reverse direction, and usually for a shorter time, during the thaw. The zone between 25° and 10° C. is thus passed through twice, the katabolic products then liberated (metabolites) accumulate in the tissue spaces owing to the vascular occlusion, and are responsible for the subsequent transudation. It will be seen that this conception fits in entirely with Lewis' work on the H substance, and it would suggest that if this zone could be traversed quickly there would be less metabolites to accumulate. There is some experimental support for this idea but it is not yet proved.

The histological changes in frost-bite of the two degrees were observed by Rischpler in 1900 and by Smith, Ritchie, Dawson and others. There was dilatation of the small vessels with swelling of the intima and some vacuolation of the muscle fibres of the media, but no thrombosis. The main effects were evidently upon the vessels, all the other changes seen, such as swelling and disintegration of fibrous tissues, etc., were to be explained by the tremendous exudation from the vessels. Some workers recorded thrombosis, but in these cases the critical temperature had possibly been passed.

Experimental work such as that described is of necessity somewhat academic; the handling and prevention of cases of frost-bite can be logical, however, only if founded upon sound pathological principles. These may be summarized as follows:—

1. Down to the critical temperature cold has no effect upon the individual cells of any tissue, but in consequence of the retention of metabolites a violent vascular response occurs during the thaw, which leads to excessive transudation of fluid from the vessels. This may be under pressure sufficiently great to obstruct the blood supply, especially to the superficial tissues, skin, etc., and lead to gangrene. In lesser degrees the transudation, which contains fibrinogen, ends in fibrosis of the skin and subcutaneous tissues with permanent hardening and loss of elasticity and with constriction of blood vessels, which renders the victim prone to all the manifestations of imperfect blood supply.

2. The critical temperature appears to be in the region of $-5°$ to $-7°$ C.; it is not absolutely constant owing to the display of supercooling. The external temperature necessary to bring about reduction of the tissue to the critical temperature will, of course, be much lower and will depend upon other climatic conditions, such as wind, etc. Rarely will the exposure be severe enough to affect more than the superficial structures, skin, etc., the deeper parts being protected by the heat of the body, the poor conduction through the fatty layer and the slowness of supercooling. Nor is mere solidification of a part sufficient evidence that the cells have also solidified, for it is probable that the tissue fluids between the cells freeze at a higher temperature than the colloidal protoplasm.

Below the critical temperature cellular life is destroyed and no recovery is possible. In practice the effects of true frost-bite are usually very limited in extent and are often completely masked by the reaction occurring in the surrounding parts which have not been below the critical temperature. In passing it may be noted that in certain modified forms, *i.e.*, the inspissated state of the spores of bacteria, protoplasm will withstand much lower temperatures than those here mentioned, which apply only to the succulent living cells of warm-blooded animals.

3. Experimentally the effects of the changes described in (1) can be prevented by restricting the blood supply to the part and to a lesser degree by drawing off the transudation as it occurs. The effects of true frost-bite (2) are determined at the time of exposure and thus cannot be avoided.

During the 1914-18 war many theories were advanced to account for trench foot. Some observers believed it to be infective, due to bacteria or fungi, others to changes similar to acidosis, or to the effects of water. It is now generally agreed that cold is the primary factor and that any others are purely subsidiary.

DETERMINING CONDITIONS

The conditions under which the effects of exposure to cold are likely to be encountered are very varied. For special reasons military undertakings are particularly liable to suffer, especially in certain regions and at certain seasons. Mention has already been made of the devastating effects of cold upon Napoleon's armies in their march to and from Moscow ; the records of the Crimean War give ample accounts of its incidence there, and there were an enormous number of cases during the last Great War. It should not be overlooked that similar conditions occur in sea warfare, mainly among shipwrecked men, and in aerial warfare. Polar expeditions and mountaineering exploits add to the possible circumstances, but the conditions are, of course, constantly met with in those parts of the world where the temperatures reach exceptionally low levels, such as Siberia and Canada.

The reasons why military operations are so important in this respect are (*a*) the large number of men involved, (*b*) the general circumstances of warfare in which efficient preventive measures become difficult and sometimes impossible to apply, and in particular the special conditions of static trench warfare, from which the term " trench foot " arose.

TRUE FROST-BITE

There are naturally many fewer victims of this form than of trench foot, and the parts affected are different. At the temperatures at which true frost-bite occurs all water has been converted to ice and so the surroundings are completely dry. Those parts of the body which are normally clothed, including the feet, are thus largely protected, but the hands, face, nose and ears are frequently involved. Raymond Greene, whose experiences on the Kamet and Everest expeditions were unique, thus describes the onset : " Sudden frost-bite develops in exceptionally cold weather, especially in a high wind or when exposed skin is brought into contact with cold metal. A sting like that of a wasp is usually felt, but sometimes it is painless. The skin is white and crystalline. If it is observed at once and a warm hand clapped on it, no harm may be done. During thawing a red area appears around the frozen patch which gradually invades it. The surroundings gradually return to normal, leaving the patch red and sharply defined.

Shortly afterwards itching and swelling begin. The wheal may take many hours to subside, or blistering may follow and even deep gangrene of the skin. Gradual frost-bite may occur on exposed skin or on well-clothed parts. The burning sensation of extreme cold dies away and a pleasant numbness takes its place. At this stage the skin may appear normal or may be white and waxy. If freezing continues there is destruction of tissue, blood vessels give way, œdema and hæmorrhages develop and the vitality of the tissues is destroyed—a course of events which may occasionally be delayed by cold so extreme that the normal contour of the part is preserved as in marble. A frost-bitten hand may have precisely the appearance of a hand in which the main arteries have been blocked by embolism."

FIG. 169

Gangrene of the toes due to frost-bite.

It must again be emphasized that usually only the most superficial tissues have passed the critical temperature, and so the permanent loss of substance by direct effect of cold is very limited in depth. The deeper structures have, however, been subjected to sufficient depression of temperature to produce the great transudation associated with chilling (*i.e.*, trench-foot conditions). Unless controlled this will cause further tissue loss on thawing. In severe cases the transudation is hæmorrhagic, the whole region becoming deep purple in colour, with blood-filled blisters and blebs. During the recovery stage the dead tissue, in the absence of infection, becomes dry and black, and slowly separates by the formation of a line of demarcation. If only the skin is affected this dry scab acts like the coagulum of a burn treated by tannic acid ; it is often surprising how much epithelialization can occur beneath it. The parts which recover remain swollen for a considerable time and there is obvious evidence of fibrosis and loss of elasticity. There is generally a long lasting disturbance of sensation in the form of anæsthesia, paræsthesia and hyperæsthesia. In the digits nail growth is interfered with ; the nail is usually lost and is replaced by a permanently deformed one. From the point of view of prognosis it is well to bear in mind that the frost-bitten part looks worse than it really is.

PREVENTION OF FROST-BITE

The prevention of true frost-bite has been learned in the hard school of practical experience in the various polar and mountaineering expeditions of the past, and also from a study of the methods universally practised by dwellers in Arctic regions, Esquimaux, etc. The clothing should be in as many layers as possible and made of a heat-retaining material, wool, despite certain artificial substitutes, being still the best. To retain the layers of air thus imprisoned it is essential to counteract the effects of wind, for whereas an external temperature of $-4{\cdot}5°$ C. will induce frost-bite in a high wind, temperatures well below the critical point, *i.e.*, $-13°$ C., may be reached without effect when the air is still (Brahdy). This is achieved by an outer layer of impervious material sufficiently robust to withstand wear, but light and flexible, to avoid embarrassment to the wearer. Leather is suitable (hence the fur-lined coat) but rather clumsy; other wind-proof materials, such as Grenfell cloth, proved very satisfactory on the Himalayan expeditions. Clothing must not be tight—particularly does this apply to socks and boots. Gloves and helmets should have the same characteristics, the former being slung round the neck so that the hands can be readily removed for essential purposes and as easily reinserted. For long the belief has been held that oiling the skin was a good preventive measure. It can scarcely be believed that such a thin film of oil can have much effect in insulating the tissues thermally, although some tests carried out in the last war, in which the legs and feet were exposed for an hour to cold water while the general body temperature was recorded, showed a fall of $1{\cdot}4°$ F. for bare legs but only $0{\cdot}2°$ F. when the legs and feet were well rubbed with oil (Yarrow). Lewis' observation that oiling the skin helped to induce supercooling, however, indicates that for severer exposures the method may be really protective. In this case the oil probably acts in the same way as the oily film often used in the laboratory to cover a fluid in which it is desired to display supercooling. It is stated that animal or fish oils or semi-solids, such as vaselin, are better than vegetable oils; as is well known, whale oil is one of the favourites. This will be further considered under Trench Foot.

General debility and malnutrition were correctly recognized as predisposing factors as early as the Crimean War. Often debility is associated with a vitamin deficiency, especially of C, as in the Scott Antarctic Expedition. These are points which must not be overlooked in considering prevention (see "Trench Foot," later).

TREATMENT

The treatment of true frost-bite commences with the thawing of the part; this must be carried out slowly and gently. The means of thawing should be kept only slightly above the temperature of the frozen part and progressively raised in temperature just ahead of the reviving tissues. In many cases all that is needed is protection from further cold, the heat of the body itself being allowed to thaw the part out slowly. Greene stresses that there should be no rubbing, for "the skin of a frost-bitten limb is in a most delicate state, and the gentlest rubbing may well destroy its chance of survival." He also believes (anyhow in mountaineering experiences) that anoxæmia is an important contributing factor, and advocates the administration of oxygen during recovery. Whether this factor is equally important at lower altitudes is not yet known.

The mildest cases, after a reactionary period, may recover almost completely, perhaps with some superficial desquamation and transient disturbances of sensation. In severer cases the surface layers are already destroyed to a varying depth and will ultimately separate and come away. The problem of the reconstitution of the skin is now similar to that occurring in burns.

Where islets of epithelium, glands, hair follicles, etc., remain alive, extension of epithelium takes place under the dead layer, forming a new but structurally modified skin. In still more severe instances the process involves the deep tissues, leaving a raw area which will ultimately require skin grafting or amputation, depending upon its site. The terminal phalanges are particularly likely to suffer severely, and may finally undergo spontaneous amputation.

The treatment of these lesions is not peculiar to frost-bite once the period of thaw has passed, but is conducted upon the general principles applied to burns, etc. Secondary infections are not uncommon, and tetanus is stated to fulminate in frost-bite and trench foot so that antiserum must be used prophylactically. When tissue loss has been considerable the subsequent measures to restore function or appearance are carried out according to well-established orthopædic and plastic principles, but it is well to remember that the parts surrounding the lost tissue have themselves been subjected to severe cold, and in consequence they form poor material for the fashioning of flaps and are liable to delayed healing, easy infection and even further gangrene. A good time should therefore elapse before such secondary operations are undertaken, and every means must be taken to improve the condition of the tissues in the interval.

TRENCH FOOT

As in true frost-bite the essence of prevention is to avoid undue chilling of the tissues, but here we have the additional factor of wet to contend with, since the provocative temperature is round about, but not below, the freezing-point. Water is a good thermal conductor, so that if it is in direct contact with the skin it will be almost impossible to prevent such local heat loss as will reduce the temperature dangerously. It is necessary, therefore, not only to isolate the part thermally, as in true frost-bite, but also to render the whole waterproof. As the name implies, the state of trench foot is almost limited to the feet, although the experimental studies have shown that a similar condition exists in the tissues surrounding a region of true frost-bite. The wearing of long waterproof boots, extending well above the level of the water or slush and large enough to accommodate two or more pairs of socks or stockings, is obviously required. Leather, if kept well oiled, is waterproof, but rubber boots require less care and are more economical, so that gum-boots are now universally used for this purpose. The oiled silk stockings suggested by Délépine in the last war proved to be difficult to manufacture properly and to have very poor wearing properties. All watertight materials also retain perspiration, and if this be excessive will defeat their object, but in the static conditions of trench warfare sweating is unlikely to be excessive except in those few who normally suffer from hyperidrosis. The boots, however, should not be used for marching and, like the socks, should be quite dry when issued. Obviously, socks must be changed before they become wet and sodden, being replaced by fresh dry ones. For the shipwrecked it is suggested that dry socks might be stored in sealed canisters carried in the lifeboats. Socks wet with sea water are notoriously difficult to dry by such expedients as placing them inside the clothing of the wearer. When possible, trenches are to be kept dry by drainage; alternatively, the men can be provided with platforms, duck-boards, etc., to keep them above the water-line. This is particularly important when cold periods are followed by intermittent thaws. Since venous congestion and stagnation predispose, attempts must be made to avoid these; men should not rest with the feet dependent, and especially over the edge of a seat or fire-step; movements of the limbs are to be encouraged, and all tight clothing, such as puttees, prohibited. The relationship of heavy smoking to peripheral vascular spasm has been challenged recently, but it appears probable that there is such an effect in certain individuals, and that in consequence smoking is undesirable. Provided the limb is dry within its coverings, alcohol as a peripheral vasodilator would not seem to be contraindicated, but if the foot is wet the heat loss is accelerated, and once the condition has arisen vasodilators are definitely contraindicated.

To maintain the general heat of the body the food should be ample and of good calorific value. It should consist of a sufficiency of carbohydrate to provide a ready and easy source of heat, and of fat to maintain the fuel supply when the carbohydrate is exhausted. The high fat content of the foods which dwellers in Arctic regions, *e.g.*, the Esquimaux, have learned to consume has its obvious implications, and these have been followed in many polar and mountaineering expeditions with great advantage. The vitamin content of the food requires attention, for, as shown above, an adequate supply of C is essential. Possibly the A and P (if this be considered a separate entity) vitamins also play their part in prevention. Except in the case of aviators, artificial sources of heat, electrical clothing, chemical heaters, etc., are of course impracticable.

In cold trench warfare foot drills should be established and carried out at least daily. Working in pairs, each man removes his mate's boots and socks, and after washing the feet, when desirable (although this must not be thorough enough to remove the natural grease of the skin), they are inspected for minor abrasions or the first signs of any colour change or swelling. The feet are then gently rubbed with whale oil until good absorption has occurred, and clean dry socks and dry boots are again donned. It is stated that the quantity of oil thus needed is about 10 gals. a day per battalion.

There is no doubt that by the adoption of such measures the majority of cases of trench foot can be avoided, but on occasions conditions may be so difficult that prevention proves impossible. Wounded men, especially those who have lost blood, are particularly liable to attack, so that, if feasible, they should be removed from the provocative conditions as soon as possible.

Clinical course—The onset of trench foot is not always recognized by the victim, for although the initial exposure may produce uncomfortable sensations of coldness on the surface, as the deeper tissues are chilled the nerves are involved and the parts become relatively insensitive. This is not always the case, however, and some complain of great discomfort throughout. The pain of chilling is not to be compared in intensity with that of the subsequent thaw. In this numb state small traumata, which may have serious consequences later, will pass unnoticed—an additional reason for regular foot inspections. With a rise in the temperature, or removal from the causative conditions when a spell of duty is over, the first signs of the trouble reveal themselves in swelling, with a dusky blue pallor followed later by an intense flush. This is the stage of maximum pain and also the stage at which most harm can be done by wrongful handling of the case. If of slight severity, the swelling persists for several days and then commences to subside with a concurrent change of the colour to normal. The surface layers of the epidermis desquamate and peel off, paræsthesiæ are complained of and may remain for a time. In severer cases the swelling is more marked, so that the whole foot may resemble a shapeless pudding, blisters form and, especially in pressure areas, portions of the skin become gangrenous; to the uninitiated it appears that the whole foot is doomed. These cases are so prone to secondary infection that in the last war it was thought by some that the condition was primarily an infective one. In particular, fungoid organisms were isolated (Raymond and Parisot) both from the tissues and the mud of the trenches, but all types of secondary infecting organisms could be found if the case did not come under control until a surface lesion was already present. Such secondary infections often have a great influence on the outcome of the case. In the absence of complications a foot in this condition may ultimately recover, after a prolonged period and with some superficial loss of skin.

In the most severe cases the foot rapidly becomes a dark blue colour and swelling extends upwards to the leg. One or more toes may become black and gangrenous. In cases of "immersion foot" the circumstances of production, *e.g.*, water-logged boats, etc., are likely to persist for much longer periods than the exposures in trench warfare. In consequence the deeper tissues are involved and the subsequent gangrene affects the whole foot. Amputation through the leg is thus a common result, and as the condition is almost always bilateral, both feet may be lost. Even so, it must be recalled that the condition looks worse than it is, for if the foot is saved it is often found that the gangrene of the toes is only skin deep and that the deeper structures are still alive. When the gangrenous portions separate, the raw areas remaining are comparable with those left after a burn of corresponding severity and need similar treatment. Severe cases all require a very long time for recovery, which is frequently incomplete. Thus some anæsthesia or paræsthesiæ may remain permanently, the skin is sclerotic, white, with telangiectases here and there, and prone to break down under minimal stress. Movements of joints are restricted, and the subcutaneous tissues are thin and inelastic. The circulation continues to be very poor, with a greatly increased sensitivity to cold. Owing to the increased susceptibility which one attack produces (negative local immunity), even the milder cases are unfitted to withstand similar conditions on a second occasion. The occurrence of secondary infection in the earlier stages usually leads to a particularly virulent and widespread inflammation which often necessitates the sacrifice of parts otherwise capable of recovery.

TREATMENT

If a man is known to have been exposed to the provocative conditions the greatest of care must be taken during the thaw period. It is