FROSTBITE

The Problems of Management and a Review of 200 Cases

William J. Mills, Jr. M.D.
Anchorage, Alaska
Contract NON–R–3183(00)
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INTRODUCTION

The importance of cold injury as a military problem is undeniable. Over one million cases have been recorded during the two World Wars and the Korean War, excluding Soviet and Chinese casualties. But, since cases may be scattered and escape compilation, it is not always appreciated that cold injury is a significant medical problem during peace time as well, particularly in subarctic areas of the world.

Two major categories of cold injury are recognized: non-freezing injuries of the immersion or trench-foot type and the more acute, freezing injury, properly designated as frostbite. Much of the cold injury seen during wartime is of the immersion foot, non-freezing type. Exposure is of many hours or days and the result is an injury noted for its extensive edema, pain and slow recovery, and its long-lasting sequelae of pain, hyperbidrosis and sensitivity to cold. An additional late problem may be intermittent local ulceration or chronic infection.

Most civilian injuries, on the other hand, result from brief, more acute exposure to subfreezing temperatures. The sequence of events seen in a typical case of acute frostbite is as follows. Prior to thawing, the part is hard, cold, usually white

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and anesthetic, appearing solidly frozen even in areas where freezing may actually be superficial. Thawing is generally painful, particularly when accomplished rapidly. Delay in thawing is associated with less pain and may account for the popularity of ice, snow or ice water as thawing media in many areas where self care is practiced. Following thawing, the part becomes flushed, often with an ominous purple hue.

The injured extremity is usually edematous with large serum-filled blisters developing an hour to several days following thawing. Unless accidentally broken, the blebs will remain intact until the fourth to tenth day when resorbtion of fluid begins and spontaneous rupture of the bleb may occur. As the blebs dry, a hard eschar develops on the injured surface. This eschar may be quite black, giving a false impression of deep gangrene. However, within three to four weeks, the eschar begins to separate spontaneously, revealing delicate but healthy tissue below.

When injury is so severe as to preclude tissue recovery, blebs are absent and the tissue remains cyanotic and cold. These areas, usually the distal phalanges, will show evidence of beginning mummification, often within a few days. Over a period of days, weeks or months, demarcation between healthy and dead tissue becomes more pronounced; the viable tissues separate and retract from the mummified until spontaneous amputation of the soft tissue is virtually complete.

It must be emphasized that the foregoing description is based on circumstances uncomplicated by infection or surgical intervention. Infection or premature debridement may lead to unnecessary tissue loss, osteomyelitis with successively higher

amputations, extensive skin grafting and prolonged hospitalization. The prevention of infection and the avoidance of unnecessary surgical intervention are essential for the preservation of the maximum amount of viable tissue.

The ultimate mechanism of tissue injury from freezing is unknown. However, it does appear that the extracellular ice crystals that form with the slow rates of freezing found in clinical frostbite do not cause mechanical injury sufficient to produce tissue death. The primary injury is presumed to be biochemical, resulting from the removal of water to form ice. Extreme dehydration is produced, with a concentration of solutes, particularly electrolytes.[1]

One of the most important effects of tissue freezing is the vascular stasis that develops following thawing. Quintanella, et al,[2] Lange, et al[3] and, more recently, Mundth,[4] have studied the microcirculation of experimental animals following freezing and thawing. Immediately following thawing the circulation is apparently unimpaired, but within a few minutes evidence of venular obstruction can be seen. Mundth reports that the obstruction appears to result from aggregations of platelets. Erythrocytes pile up behind them and stasis extends back through the capillary bed to the arterioles. Within two hours or less, there is complete irreversible stasis in the thawed tissue and the vessels are totally filled with a structureless, hyaline-like material. There is tissue edema and evidence of the extravasation of hemoglobin into the perivascular spaces.

On the basis of such observations, it was naturally assumed that much of the tissue loss in frostbite might well result from secondary vascular stasis and not from the primary effects of freezing.

Earlier attempts to reverse or prevent the stasis were generally unsuccessful, although some clinical benefit was reported by Lange, et al[5] using continuous heparin infusions. No satisfactory evidence existed that tissue cells were not irreversibly damaged by the primary freezing injury and might fail to survive even if the circulation were maintained.

Recently, however, Mundth, et al[4] investigated the use of low molecular weight Dextran following experimental freezing in rabbits. Observation of the microcirculation indicated that the Dextran did alleviate the post-thawing circulatory obstruction. Infusion of this material as late as two hours following thawing markedly reduced tissue loss in frozen rabbit feet. This is presumptive evidence that some of the injury from freezing is not necessarily irreversible and that maintenance of the circulation may permit the recovery of tissue otherwise doomed.

A number of workers, particularly Fuhrman and Crismon in 1947,[6] demonstrated impressive results by thawing experimentally frozen animal extremities, in water at 42° C. These studies were repeated with varying success by others.[2,7,8] Although some results could be questioned on the basis of uncontrolled duration of exposure to the frozen state,[1] where this factor was controlled, there did appear to be a very real reduction in tissue loss following rapid thawing in experimental animals.[8]

A wide variety of clinical approaches to frostbite have been reported in the literature and one can find examples of almost every conceivable therapeutic measure. Attempts to assess various treatments usually suffer from lack of diagnostic criteria and an insufficient

number of cases for statistical analysis. Much of the literature is concerned with problems of late treatment and sequelae. Of the promising early clinical procedures, one of the most encouraging has been that of Shumacker and associates[9,10] who used sympathectomy to improve and maintain circulation.

A highly successful therapeutic routine has also been developed by Campbell[11] and is used by the International Alpine Rescue Commission. Thawing is achieved in a bath initially at about 50° F. (10° C.) and gradually increased in temperature, reaching 104° F. (40° C) in about thirty minutes. This technique is reported to prevent the pain of thawing. An open, dry procedure is recommended with limited debridement of bleb coverings after their rupture or collapse, and the application of silver or aluminum foil over granulating areas.

In Alaska prior to 1955, frostbite was treated by a variety of methods including rubbing with snow, thawing in an ice or snow bath, spontaneous thawing indoors, or, rarely, immersion in warm fluid.[18] Subsequent care varied from total neglect to early surgery. Tissue loss was not uncommon and a distressing number of mid-foot and below-the-knee amputations had been reported. At this time, a series of studies was begun, in an effort to establish a uniform routine for both early and late treatment, to improve our own results and, in particular, to determine whether the beneficial results reported after rapid thawing of animal extremities could be duplicated in clinical injuries.

From Alaska, we are now able to report a series of 200 cases of frostbite of which 130 were treated throughout by us according to a fixed therapeutic routine and of which 48 were thawed in water at above body temperature. In addition, records are available for over 400 cases[17,19] treated by others according to our regimen. We have also

followed 68 patients who did not receive treatment according to our standard regimen but who were subsequently referred to us for late treatment.

METHOD OF TREATMENT

Patients seen prior to thawing of the extremity were at first thawed rapidly by immersion in well-agitated water maintained at between 100° and 112° F. (38° to 45° C.) Subsequent observations and second thoughts have resulted in a revision of the higher limit downward to 108° F. (42° C.) When thawing is conducted in the hospital, a whirlpool bath can be utilized for that purpose. Such rewarming is reserved only for patients seen prior to thawing. This treatment is considered useless and perhaps injurious to extremities no longer frozen.

On admission, a frozen extremity appears white, yellow-white, or mottled blue-white, hard, cold, insensitive, and presents the illusion of being frozen solid. Even a relatively shallow freezing may give this appearance and an estimate of the depth and severity of the injury is impossible at this time. Early in our investigation we discarded the conventional terminology of first through fourth degree frostbite as a prognostic impossibility and have attempted only to describe the injury as superficial or deep. Even so, such an estimate may be changed by the method of thawing. A presumed deep injury, rapidly thawed, may assume the appearance of a superficial injury, while a superficial injury, thawed in ice or snow bath or by other delaying means, may then appear as a deep injury, the viability of underlying structures presumably having been jeopardized.

Immersion of the frozen extremity in the thawing bath is painful to the patient and sedatives or analgesics are used as indicated. As thawing proceeds, flushing will progress distally down the extremity. Thawing is continued until the flush has extended to the tips of the extremities and the immersion is then promptly terminated. The flushing may be an ominous purple in color despite the excellent results that can be anticipated following this mode of thawing. This Burgundy hue is particularly associated with higher thawing temperatures. With rapid warming (100° to 112° F.) sensation returns to the affected part when thawing is complete. Sensation remains until the blebs develop and separate the surface layers. In no other method of thawing have we observed this. Sensation remains absent for weeks when frozen tissues are allowed to thaw spontaneously in air or by delayed means such as in an ice or snow bath.

Following thawing, the patient is hospitalized with complete sterile precautions. The extremities are kept on sterile sheets under cradles. Sterile cotton pledgets are placed between the toes. The patient is kept in strict isolation with attendants masked and gowned. No dressings, ointments or other applications are used. Treatment is completely open. As blebs appear, every precaution is taken to avoid their rupture. In addition to the sterile precautions, infection is controlled by cleansing the extremity for twenty minutes twice daily in a whirlpool bath at 90° to 98° F. A mild disinfectant soap is used in the bath*. Patients who have already thawed prior to admission are placed on the identical routine save that the initial thawing procedure is omitted.

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* We have used pHisoHex and Betadine.

Ideally, the blebs will remain intact and after five to ten days their serious contents begin to be resorbed. In some cases the blebs are accidentally ruptured and in other cases the patient may be admitted with blebs already ruptured. No attempt is made to debride. This is left to the motion of the whirlpool from which there is much less danger of separating tissues prematurely.

Of critical importance to the ultimate functional result is constant energetic active exercise of both large and small muscles and intermittent elevation of the extremity. As the blebs dry, hard, often black, eschars form. Where these prevent motion of joints they may be carefully split on the sides or dorsum of the digits. However, they are never removed but are allowed to be separated and gently debrided by the motion of the whirlpool. One of the many virtues of the whirlpool bath is the opportunity it affords for active exercise. The dried blebs and crusts are softened during the washing and the patients report greater ease and comfort of motion. The importance of active joint motion cannot be over-emphasized, particularly for the prevention of flexion-contractures of the hands, not an uncommon sequela of frostbite even when complete anatomical preservation is achieved.

The use of water and whirlpool is often criticized on the basis that it is a "wet" regimen, a total misunderstanding of its use since, within minutes of removal from the whirlpool bath, the parts are dry and exposed to the air under a protective cradle.

We have been greatly impressed by the ability of the whirlpool bath to cleanse gently, to debride, to promote circulation, to permit and encourage active motion and to impart a sense of well-being to the patient. We have been particularly impressed with the efficiency with

which whirlpool controls infection, even in cases that have come to us complicated by maceration and advanced wet gangrene. We wish to emphasize that whirlpool therapy is a central element in our therapeutic regime and responsible, in our opinion, for much of our success in minimizing tissue loss following severe injuries.

Antibiotics are rarely necessary save for deep infection. No narcotics are used in uncomplicated cases after initial thawing. Anti-tetanus therapy is used where indicated by associated trauma. Special problems related to concommitant fracture or other special situations will be discussed subsequently.

When the eschar has begun to slough in the whirlpool and healing is clearly on the way, sterile precautions are discontinued but whirlpool and active exercises are rigidly pursued. Where distal parts of the extremity are to be lost and the part remains black and cold, no debridement is done until spontaneous amputation of the soft tissue is virtually complete. This may require anywhere from one to four months. The mummified portion may then be surgically removed without danger of retraction, infection or the necessity of skin grafting or subsequent revision of the stump.

The therapeutic regime, in summary, consists of rapid thawing where possible, avoidance of infection, whirlpool, continual active exercise with periodic elevation, prohibition of surgical debridement and postponement of surgical intervention pending complete demarcation, with spontaneous amputation of soft tissues.

RESULTS

To date, 200 patients with a total of 413 cold-injured extremities have been treated according to the foregoing procedures.

Cases of wet-cold, non-freezing injury have been excluded from this series. The first 51 patients treated have been reported in detail in a previous paper[12] and Washburn[13] has summarized our methods and several of our cases in an article on arctic problems published in the New England Journal of Medicine.[14] Our series of cases was treated over the period of 1955 to 1965. During this interval, we also had 68 cases treated by others by other methods referred to us late in their recovery period. We have used these for comparison of treatment methods.

Probably the single greatest obstacle to a comparative analysis of frostbite therapy is the impossibility of making any quantitative assessment of the extent of injury prior to the institution of early therapy. In the past, all criteria by which frostbite was partitioned into degrees of injury have been based on ultimate outcome and tissue loss, even though theoretically used in initial diagnosis. In fact, no method or set of criteria exist for evaluating the injury prior to thawing. Histories are totally unreliable since freezing is generally insidious and clothing and special contributing factors prevent temperature and wind conditions from being directly proportional to the severity of the injury. Thus the direct comparison of individual clinical cases is meaningless, placing greater burden on clinical impression and requiring the assembly for statistical analysis of a larger number of cases than would be necessary for the study of a more quantitable disease.

No attempt, therefore, has been made to estimate degree of injury prior to therapy. Cases have simply been evaluated on the basis of end result, both functional and anatomical. Table I explains the

classifications used. Where a single individual has had multiple extremities involved, he has been classified on the basis of the most severly injured. Table II compares the results obtained in patients whose frostbitten extremities were treated throughout by our standard program including rapid thawing, with those receiving the same standard program without rapid thawing; those treated by others, by other methods, and only seen by us following the resolution of their frostbite; and with two cases which were rapidly thawed but treated by others by methods other than our standard routine. Table III illustrates the results achieved when injuries treated by our standard routine are compared on the basis of the method of thawing. Both functionally and anatomically the percentages of extremities with good to excellent outcome are nearly identical regardless of whether extremities received rapid or slow thawing. Although slowly thawed extremities apparently suffered more tissue loss than those rapidly thawed, this is in part explained by the fact that some of these suffered refreezing or were thawed by methods felt to be deleterious such as by ice and snow and excessive heat. Those extremities receiving neither rapid thawing nor our standard routine showed a very high percentage of tissue loss and major amputation, in our opinion largely due to uncontrolled infection and premature surgery.

Table IV illustrates the distribution of injury produced by refreezing or by deleterious methods of thawing. The preponderance of poor results is evident.

Table V illustrates the influence of infection or subsequent results. Only two of the cases without infection lost tissue, while 25 of those with superficial infection and 29 of those with deep

infection did. Seven patients in the "E" category, and one in the "F" category, received whirlpool therapy.

EVALUATION OF SYMPATHECTOMY

For the past two years we have studied the results of post-thaw lumbar and cervical sympathectomy in patients with apparent bilaterally similar injury to hands or feet, or both. The sympathectomy has been performed on one side only, utilizing the untreated extremity as a control.

Unilateral ganglionectomy has been performed as early as twelve hours and as late as three weeks in the acute cases. The results to date are interesting, somewhat different than expected, and quite definite. The effects of sympathectomy have been assayed on the basis of recordings of tissue temperature using thermisters superficially, intramuscularly and subcutaneously placed. Our results to date are somewhat similar to those reported by Isaacson and Harrell.[15] In almost all cases our patient was happy to have had the sympathectomy performed. This was so until approximately six months to one year had elapsed. Complaints then were often that the ganglionectomized extremity was "too dry". Regardless of the time of the procedure, relative to the date of thawing, it did not appear to preserve tissue. In fact, the extremity not subjected to ganglionectomy often showed more preservation of tissue.

However, there were favorable results which appeared to be associated with the procedure. Infection, if present, superficial, or deep, was almost always rapidly resolved, often within a forty-eight hour period. Edema rapidly diminished, and pain was usually much less

and often completely disappeared on the operated side. Hyperbidrosis soon disappeared and sensation appeared to return earlier on the sympathectomized side. We noted, as previously reported, that demarcation of the tissue appeared more rapidly on the side of the sympathectomy, but at this time cannot determine whether that in itself is beneficial. This more rapid demarcation may not indicate more ready healing, but instead, more intense and immediate vascular shunting with more rapid necrosis and mummification of the part distal to the shunt.

SILVER NITRATE

In the past year, after the method of Moyer, et al,[16] for burns, 0.5% silver nitrate has been intermittently lavaged over the area of frostbite using a contralateral hand or foot as control whenever the depth of injury appeared to be bilaterally similar. The end result has been comparable to that following the use of other soaks or cleansing agents; the epithelialization is similar whether skin or scar, but there is perhaps one outstanding effect noted. Pain is less, and infection, even superficial, appears less obvious. The handling of $AgNO_3$, staining of sheets, floors and hospital equipment is a mild problem making this method of care unpopular with Hospital Administrators and Nursing Supervisors. This problem is somewhat eased by the use of disposable supplies.

SKIN GRAFT PROCEDURES

To hasten healing, skin grafts have been utilized between the third to the twenty-first day and as a plastic procedure at any time thereafter. Split thickness skin and Reverdin pinch grafts have

been well received during the early stages of healing if the part to which the graft was applied was rapidly thawed. The split thickness and minute grafts have been irregularly successful when applied to extremities spontaneously thawed or thawed by delayed means with ice or snow. After three months or longer, all types of graft appeared effective in the absence of infection, once the denuded areas were well vascularized.

Split thickness skin cover in frostbite requires intermittent saline soaks to prevent maceration and infection. The procedure of grafting is worth a trial in many cases, often preventing exposure and necrosis of tendons, underlying fascia, and joint and surrounding joint structures. The procedure is benign and can be performed without difficulty under local anesthesia.

HYPOTHERMIA AND DEHYDRATION

Death from general body cooling is not uncommon in the arctic and subarctic. In the past three years we have had the opportunity to see and treat four patients in deep hypothermia. Only one, the last treated, survived.

All had sustained freezing of the extremities as well as general body cooling. Sudden accidental cooling of the body and depression of the normal core temperature is serious and often fatal. At rectal temperatures below 92° F. homothermic control is unstable, and, if cooling persists, may be lost altogether. Coma often develops early and cardiorespiratory failure may occur even above 88° F.

We recommend, in this mixed problem, the same resuscitation techniques which are followed when general hypothermia is used as an adjunct to surgical anesthesia. These techniques include rapid

warming with warm packs and blankets, intravenous infusion of glucose and water, and respiratory aids including intubation and oxygen if necessary. The possible need for cardiac defibrillation or tracheostomy should be anticipated. The process of recovery is often complicated by pre-existing anoxia, trauma with excessive blood loss, and alcoholic stupor.

Rapid warming in a water bath at 90° to 100° F. brings the patient quietly to a responsive state, alert and rational. However, the release of accumulated acid end products of metabolism can create a sudden metabolic acidosis with death by ventricular fibrillation in less than two to three hours following rewarming. Following slow spontaneous, or delayed rewarming, death may occur as much as twenty-four to forty-eight hours later.

It is essential that one or more intravenous routes be established in the hypothermic patients to enable electrolyte control with the determination of, at least, pH, pCO, and PO, and the administration as required of buffering agents such as sodium bicarbonate or THAM. EKG monitoring is indicated in view of the hazard of ventricular fibrillation. In rare instances the patient may be in alkalosis rather than acidosis as a result of gastric suction or vomiting or from the retention of potassium or sodium.

The irrational behaviour previously reported[12] in victims of freezing injury may actually represent post-traumatic phenomena secondary to pre-existing effects of water deprivation and dehydration. This is particularly likely in the survival victim rescued after days of wilderness exposure, often without food and water.

X-RAY EVALUATION OF EXTREMITIES

The roentgenographic examination of the involved extremity is usually negative when performed in the first ninety days, unless severe infection with osteomyelitis is present or amputation has occurred. Occasionally in the absence of a strenuous program of physiotherapy and digital exercises there may be osteoporosis of the involved digits and tarsi or carpal bones.

Between the third and sixth months, apparently related more to the depth of injury than the method of thawing, there appears fine, irregular lytic areas, generally in the metacarpal or metatarsal phalangeal or proximal or distal interphalangeal joint areas (Fig. 5). These punctate lesions are often juxta- or subarticular and occasionally extend into the joint space, usually a late occurrence. In most of the cases examined these punctate lesions may worsen over one to three years and then many may eventually decrease in size or fill completely. Our experience is similar to that reported by Vincent, et al,[14] who found no pattern for this change.

Biopsy of these areas on the few occasions permitted, demonstrated the lesions to consist of dense fibrous connective tissue, suggesting areas of chronic inflammation. Prominent vascular channels are seen on some sections in the indentations that extend into the subarticular tissues. These changes are somewhat similar to the "punched out" lesions of rheumatoid arthritis or gout. The soft tissues are fusiform and obviously swollen. The area most commonly involved in our series is that of the interphalangeal junction, usually the proximal interphalangeal joint, with the lesion most often at or near the articular margins. These X-ray changes are often

associated with the clinical appearance of volar fat pad loss, subcutaneous fat absence, the glossy appearance of skin over the digits, fusiform joints and contracture of the involved joints.

The changes seen in our group appeared earliest at six weeks in a patient thawed by rapid rewarming, and latest at eighteen months in a patient likewise rapidly thawed. Possible causes of the lesions are (1) disuse, (2) direct effect of cold, or (3) avascular necrosis as a result of thrombosis of the articular branches of the volar or dorsal digital arteries. Although we have no direct evidence, most of us feel that the lesion is an effect of thrombosis or blockage of the articular branch of the digital vessels, with further loss of nutriment to the less vascular subarticular cartilage.

TABLE I

Classification of degree of ultimate injury

A - No recorded or demonstrated residual

B - 1) Dysethesia

2) Intrinsic muscle atrophy

3) Skin loss requiring replacement skin cover

4) Volar fat pad (digital) atrophy or loss

5) Limitation of joint motion

6) Neurovascular sequellae (hyperhydrosis, hypesthesia, hyperesthesia, paresthesia, pain)

C - Distal phalangeal amputation, any level, any number

D - Mid or proximal phalangeal amputation, any level any number

E - Complete phalangeal loss at metacarpal or metatarsal phalangeal junction

F - Major amputation of extremity

TABLE II

Results of varying methods of treatment.
(Figures are percentage of patients in each category and figures in parentheses are numbers of patients)

	A	B	C	D	E	F	Total Patients
Full frostbite program (rapid thawing, whirlpool, P.T., open care)	9 (4)	87 (40)	0	4* (2)	0	0	(46)
Program as above except thawing by other than rapid	8 (7)	70 (58)	6 (5)	7 (6)	8 (7)	1 (1)	(84)
Other treatment programs not including P.T., whirlpool, or open care	9 (6)	39 (27)	12 (8)	12 (8)	9 (6)	19 (13)	(68)
Rapid thawing but with other treatment programs	50 (1)	50 (1)	0	0	0	0	(2)
All patients	9 (18)	63 (126)	6.5 (13)	8 (16)	6.5 (13)	7 (14)	(200)

* Case #19: 1st case of Rapid Rewarming by H_2O (100° F.) Loss due to premature surgical debridement. Also case #77: Loss of 5th finger complete following laceration of left wrist (ulnar arter incised) and laceration left antecubital fossa in suicide attempt prior to freezing episode (as part of suicide attempt).

TABLE III

Results of Standard Frostbite Program Applied to Patients with Injuries Thawed by Rapid, Slow or Delayed Means or by Excessive Heat
(Data presented as percentage of patients in each category. Figures in parentheses are number of patients)

	A	B	C	D	E	F	Total Patients
Rapid thawing in warm bath 100°-115° F.	10 (5)	86 (41)	0	4 (2)	0	0	(48)
Slow thawing, predominantly spontaneous in air at room temperature	9 (12)	61 (81)	8 (11)	6 (8)	5 (7)	10 (13)	(132)
Delayed thawing by ice, snow, or cold water bath	6 (1)	25 (4)	13 (2)	25 (4)	31 (5)	0	(16)
Thawed by excessive heat	0	0	0	50 (2)	25 (1)	25 (1)	(4)
All patients	9 (18)	63 (126)	6.5 (13)	8 (16)	6.5 (13)	7 (14)	(200)

TABLE IV

Results of Mixed Insult Including Freezing
(Figures indicate numbers of patients)

	A	B	C	D	E	F	Total
Refreeze (freeze-thaw-freeze, thaw by any means)	0	0	0	2	2	0	4
Immersion injury followed by freeze, thaw by any means	0	1*	0	0	1	7***	9
Fracture plus freeze	0	5**	0	0	0	3	8
Thaw by excessive heat (above 120° F.)	0	0	0	2	1	1	4
TOTAL	0	6	0	4	4	11	25

* Age 12, spontaneous thaw.

** Includes one patient, diagnosis diastasis tibia, fibula (distal), thawed spontaneously; one patient diagnosis metacarpal fracture, thawed spontaneously; two patients fracture of tibia, rapidly thawed; one fracture ulna, undisplaced, thawed spontaneously.

*** Exposure in all cases 5-7 days minimum.

TABLE V

Result Related to the Presence or Absence of Infection

	A	B	C	D	E	F	Total
None	16 (11)	81 (57)	3 (2)	0	0	0	(70)
Superficial Infection	7 (7)	68 (68)	7 (7)	10 (10)	6 (6)	2 (2)	(100)
Deep Infection	0	3 (1)	13 (4)	20 (6)	7 (23)	12 (40)	(30)
TOTAL	9 (18)	63 (126)	65 (13)	8 (16)	65 (13)	7 (14)	(200)

DISCUSSION

Evaluation of the effectiveness of rapid thawing or any other therapeutic procedure is hampered by the absence of diagnostic criteria of the severity of the initial injury. Initially in this study it was attempted to estimate the degree of injury on admission of the patient, but even when the estimate was limited to only two classifications, superficial or deep, twenty-one of the first fifty-one cases were found to have been erroneously classified when viewed in retrospect. Furthermore, it was found that early classification had no clinical usefulness since there was no evidence that any variety in treatment would be indicated on the basis of an estimate of the severity of injury.

Because of the absence of initial quantitative diagnosis, this data is presented solely on the basis of ultimate outcome. This is most unsatisfactory because of unique circumstances in individual cases. In Table II, for example, cases in D and E categories receiving routine treatment but not rapidly thawed were almost all thawed by excessive heat, ice and snow, or suffered refreeze, procedures known to aggravate the injury. Half of the cases receiving major amputation after "other" treatment suffered shipwreck and exposure to cold water immersion for several days with superimposed freezing. Although our cases are certainly random, wide variation in circumstances and depth of injury makes even the attempt to evaluate treatment on the basis of final outcome most uncertain despite the relatively large number of cases reported.

Regardless of the difficulties in interpreting the statistical data, there is an unqualified clinical impression of the

superiority of rapid thawing. Extremities rapidly thawed show flushing to the distal tufts of digits and the rapid appearance of normal pink color. Sensation to pin-prick is always present after rapid thawing until separation of blebs begins. Sensation was never found following other modes of thawing save in the most superficial injuries which do not go on to bleb formation. After rapid thawing blebs appear in one to eight hours. They are larger and more distal than after other thawing methods and are filled with clear serous fluid, never bloody. Bleb appearance may be delayed for two or three days after spontaneous thawing, seven or eight days after ice and snow thawing. These latter thawing methods produce smaller blebs which are often sero-sanguinous or black in color.

The hospital course appears smoother and shorter for rapidly thawed extremities. Patients generally can be discharged in six weeks or less. Rapidly thawed extremities dry sooner, have less superficial infection, and few complications. Recently, emboldened by past success, we have discharged our patients after bleb rupture and eschar formation, to be followed at home. There the "clean" hospital regimen is employed during the Jacuzzi home whirlpool, or an oscillating washing machine, even available gas operated in remote areas. There was an attempt, in analyzing this series, to correlate hospital days with thawing and treatment methods but found this impractical because of the intrusion of other factors. An early amputation, for example, results in a shorter hospitalization than a protracted effort to save the maximum tissue. Indigents with no home care convalesce in the hospital and patients in the Public Health Service Hospitals serving the Alaska native population stay longer than

those in private facilities. Discharge is often delayed pending the availability of transportation to distant or inaccessible homes.

It is felt that there is little question regarding the total destruction produced by freezing, thawing, and refreezing. These tissues become black, dry and shriveled or liquefy completely within seven to nine days with no evidence of viability at any time. Slightly less rapid development of gangrene is also seen in severe injury following ice and snow thawing or with concomittant fracture which interferes with circulation in the extremity. The superposition of a burn over cold injury from the use of uncontrolled dry or wet heat for thawing is self-evidently destructive.

In our Alaskan experience, poor prognostic signs during early treatment include the late appearance of small, dark colored blebs; the failure of blebs to extend down to the tips of the volar pads of the digits; cold cyanotic distal parts and, of course, obvious mummification. Good prognostic signs include sensation to pin-prick after thawing; good color, warm tissues, large clear blebs appearing early and extending to the tips of the digits.

In conclusion, based on comparisons of the results obtained with random cases, it is felt that the clean conservative routine herein described has produced substantially less tissue loss and functional disability than the various procedures previously used. In particular, the absence of amputations higher than the metacarpal or metatarsal-phalangeal joint in any patients receiving this routine treatment compares favorably with the periodic mid-foot, below and above knee amputations previously seen throughout Alaska. The clinical impression is that substantial benefit is incurred by rapid

thawing. This method will be continued as a recommendation for treatment, wherever extremities are seen prior to thawing. It is anticipated that the collection of increasing numbers of cases treated by rapid thawing will provide a stronger statistical base from which to draw more positive conclusions in the future.

SUMMARY

1. Two hundred cases of frostbite have been treated according to a standard hospital routine consisting of open, sterile care, whirlpool bath, intensive active physiotherapy, and postponement of surgical intervention. Twenty-one patients, or 10.5%, lost phalanges or portions of phalanges. There was one major amputation. Seventy additional cases with frostbitten extremities received other forms of treatment. Of these, thirty-five, or 50%, lost tissue. Thirteen patients, or 18.57%, had major amputations.
2. Of the cases treated, forty-eight were seen prior to thawing and were rewarmed in water at above body temperature. Two extremities lost a digit and one the tuft of the distal phalanx. Although the number of cases is insufficient to permit positive conclusions, the clinical results following rapid thawing appear to be superior to those following other means of thawing.

FIG. A

XRAY OF DIGITS,SEVERE FREEZING,THREE YEARS PREVIOUSLY. THAWING WAS BY RAPID REWARMING IN WARM WATER. ON THIS SECTION OF FILM IS THE FUSIFORM ENLARGEMENT OF THE PIP JOINTS AND THE SUB AND INTRA ARTICULAR LYTIC AREAS.

CASE HISTORIES

The following case histories are illustrative of the sequence of events that may be anticipated in typical severe frostbite treated by this standard routine.

CASE #187, EXCESSIVE HEAT

This seventy year old fisherman, hardy, and inured to Alaskan weather and winters, was exposed for four or five hours, winds fifteen knots, temperature -17° F., lost on a trail. He eventually was forced to crawl on hands and knees and was discovered by a nearby cabin dweller alerted by a barking dog. The patient was brought into a warm area, hands and arms were described as being in the full fist position, hard, frozen, white, and similar to two clubs. They were without sensation or motion. Thawing was begun with snow and ice water, and when this failed to rapidly thaw the part, the well-meaning first aid was applied by pouring scalding water over the frozen extremities until thawing occurred. The result was burn over previously frozen parts. (Fig. 18 - 21)

EXPLANATION OF FIGURES, CASE #187

Fig. #1: The extremity less than twenty-four hours after injury revealing the cyanotic, quite painful, and foul smelling hands, primarily lacking blebs, revealing the dusky changes of excessive heat applied to freezing injury. The patient, because of the severity of injury, had been brought to the operating room where controlled sympathectomy was performed.

Fig. #2: The tenth day following injury, revealing the unrelenting tissue demarcation and necrosis, with routine treatment still in effect, infection controlled by whirlpool and open treatment.

Fig. #3: At three weeks the digits are hard, rigid, soft tissue is completely mummified, absolute tissue death demonstrated. Again, there is evidence of infection, superficial only, at the area of tissue demarcation and amputation.

Fig. #4: Spontaneous amputation, bilateral, at the MP junction, at six weeks. The pattern is demonstrative of the hopelessness for recovery following the onslaught of gangrene when frozen tissues are cooked by excessive dry or wet heat.

CASE No. 187

THAWING BY EXCESSIVE HEAT

Fig. #1

Fig. #2

Fig. #3

Fig. #4

CASE #91: REFREEZE (Fig. 4)

This adult mountain climber, age thirty-one, sustained injury over a period of several days at temperatures from -18° F. to -35° F., wind fifteen to twenty knots, altitude approximately 17,000 to 18,200 feet. While attempting direct ascent to the summit at about the 18,000 foot level, boots in place twelve hours, he noted loss of sensation and eventually upon returning to his tent found his toes white, immobile, with the resolution of what appeared to be at least superficial freezing injury following massage and warming of extremities by the accepted mountaineers method of using heat from his companion. Another attempt was made several days later, this time successfully, the summit at 20,000 feet was attained, during which he had complete loss of sensation. Upon reaching the 17,000 foot level and again thawing the extremities, it was noted that there was no evidence of pain, but a gravelly sensation in the heel and the development of small dark serosanguinous blebs distal to the metatarsal phalangeal junctions. Temperatures on the second attempt had been in the range of -30° F., wind at forty knots. On the second descent, after the second freezing insult, obvious demarcation had been identified at the mid-arch.

Eventually the climber descended to the 14,000 foot level, and there was met by rescue aircraft. He was admitted to an Anchorage Hospital, and placed on the standard frostbite program during which he suffered rapid destruction of tissue commonly seen following this type of injury.

CASE #91

Fig. #5: Forty-eight hours post-thawing, in whirlpool bath. The distal areas and toes are dark, cyanotic, and demonstrate small proximal serosanguinous blebs. Pain quite marked at the demarcation line.

Fig. #6: Five days following thawing, the foot wet, edematous and insensitive; the forefoot markedly necrotic, demonstrating rapid demarcation and separation between injured and viable tissues.

Fig. #7: Seven days post-thawing, revealing rapid liquefaction necrosis of forefoot, separation of tissues with dissolution and liquefaction of ligaments, vessels, nerves, tendon and structures about the joint, the osseous structures held in place only by a skin envelope.

Fig. #8: This view, twelve days following thawing, demonstrates the irreversible tissue destruction common to freezing injury preceded by long immersion injury, or by thawing after a previous freezing. This appears to be a typical freeze-thaw-freeze-thaw pattern found frequently in mountaineers.

CASE No. 91

DEMONSTRATION OF REFREEZE

(FREEZE-THAW-FREEZE-THAW SYNDROME)

Fig. #5

Fig. #6

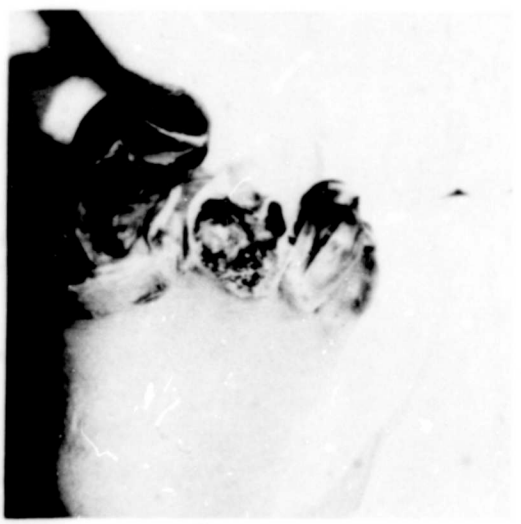


Fig. #7

Fig. #8

CASE #4: SPONTANEOUS THAWING (Fig. 2)

This patient, a seventy-five year old fisherman and trapper, was injured when out at extremely low temperatures, moderate wind, deep snow. Exposure time may have been as long as twelve to fourteen hours, the entire episode complicated by alcoholic excess. He crawled through deep snow drifts, eventually reached his own cabin where his badly frozen extremities thawed spontaneously. Following admission to a regional hospital, he was placed on a standard regime as described in this article. His case history is representative of the severe changes following spontaneous thawing, other patients with spontaneous thawing having had minimal or no loss. As with delayed thawing, the results of spontaneous thawing are unpredictable. When examined his radial pulse was adequate. His hospital course after three weeks resulted in demarcation at the mid-proximal phalangeal area, complete demarcation developing at approximately six weeks.

CASE #4: (Fig. 2)

Fig. #9 & 10: Demarcation with obvious complete necrosis and spontaneous amputation is seen at six weeks. Demarcation was equally bilaterally, infection superficial and minimal, silver nitrate lavage for comparison as a possible adjunct in controlling infection was utilized on the right.

Fig. #11 & 12: At three and a half months, he has adequate functional result for gross purpose, but poor anatomical result. Gross motion is permitted, the patient can feed and clothe himself, although with some difficulty, and has been discharged. He has, throughout the course, maintained an adequate and rigid program of physiotherapy. At the end of the treatment there appeared to be no significant benefit from silver nitrate soaks as compared to the open granulating method.

CASE No. 4

SPONTANEOUS THAWING

Fig. #9

Fig. #10

Fig. #11

Fig. #12

CASE #78: RAPID THAWING (Fig. 1)

This fourteen year old boy went hunting, walking twelve miles during his trip. The ambient temperature was -20° F., with little wind. He was wearing borrowed tight leather boots, covered with overshoes. One hour after leaving home his feet were noticeably cold and painful. Three hours later sensation was absent completely, the feet painless, and he continued hunting without pain, and therefore more comfortable. Six hours later he arrived home, overshoes filled with snow, and frozen to the boots. Foot gear was removed with difficulty, exposing cold, rigid, pale, yellow-white discolored feet, "solid to the ankle". He was taken to the nearest hospital. Examination there demonstrating an anesthetic foot, digits still in the "frozen" state, with collapse and compression of the volar pads. Forty-five minutes had elapsed since removal of the shoes and by this time a purple-red line of discoloration had developed at the line of demarcation between rigid and softer proximal tissues. The area involved was without sensation or motion.

The feet were thawed in water, temperature 110°F. until flushing of the distal pads was evident. The resulting "burgundy wine" hue of the distal foot persisted until the gradual development of blebs. His course was satisfactory, (Fig. 1) and he was discharged from the hospital for home care three weeks after injury. This represents a rapid hospital course for what was probably a severe injury, in our opinion, possibly only with rapid rewarming techniques.

CASE #78

Fig. #17: A cold rigid forefoot without sensation or digital motion. Tissue compression and sock marks are obvious. Treatment was whirlpool bath and thawing at 110° F. for approximately twenty minutes.

Fig. #13: Thawing was followed with an ominous burgundy hue. This has since been demonstrated in other cases, more often at temperatures greater than 110° F. The cyanosis remained for approximately six hours at which time small discrete blebs began to appear. Gross sensation was present after thawing and remained so until bleb development.

Fig. #19: Over the next forty-eight hours large clear blebs developed ultimately extending to the digital tips. Failure of distal bleb formation, in the presence of proximal blebs, is an ominous prognostic sign.

Fig. #20: Four months post-injury, the anatomy has been preserved, but the changes of deep injury are obvious, and include volar fat pad loss, subcutaneous fat loss, early IP joint contracture, nail changes, hypesthesia and hyperbidrosis. Epithelialization is complete. At the end of one year the extremity had adequate sensation, there was mild subcutaneous loss and interphalangeal contracture, with a few interphalangeal subarticular lesions present on X-ray examination. Increased sweating was present.

CASE No. 78

RAPID THAWING IN WARM WATER (110° F.)

Fig. #17

Fig. #18

Fig. #19

Fig. #20

CASE #135

Brought down after Helicopter engine failure in mid-winter on the Arctic Coast, this pilot walked out for help. He traveled for five hours, wearing felt 'bunny' boots, and lost sensation in his feet at the end of that time. Wind approximately 10 knots, temperature -30° F. He continued walking for another 7 hours and was finally rescued by another aircraft. He had minimal thawing by engine heat and was still demonstrating frozen tissues in the distal foot upon arrival at the Pt. Barrow Hospital. There he was thawed in a warm tub, 108° F., and within a few hours developed return of sensation and large distal blebs. His treatment was the regimen described in this paper, with the added procedure of lumbar sympathectomy on the left.

CASE #135

Fig. #24: Bilateral equal injury, 36 hours post-thawing by rapid rewarming in warm water. Patient complained of severe pain, bilateral, and agreed to a control sympathectomy on the left.

Fig. #25: Nine days post-lumbar sympathectomy. Note absence of superficial infection as compared to the right, or control, side. Tissues are dry and there is marked dimunition of edema on the left. Pain is absent on the left, present on the right.

Fig. #26: There is continued loss of edema and pain on the left, but some early demarcation of the tips of toes 2 and 3. Anhydrosis on the left as compared to hyperhydrosis on the right.

Fig. #27: Here, same data as Fig. #26, but appearance of a similar injury is much different. There is still some superficial infection (Pseudomonas); continued edema, and pain. At the sixth post injury week, both feet were similar in appearance except that there had been <u>greater</u> tissue loss on the left (part of volar tips 2 and 3).

CASE No. 135

FREEZING INJURY AND EARLY SYMPATHECTOMY

Fig. #24

Fig. #25

Fig. #26

Fig. #27

CASE #7

This case represents a very popular method of thawing the frozen extremity all over the world in the frigid zones -- that of immersion of the limb in ice water or a snow bath. This is popular presumably because the thawing is quite painless. The patient, a 54-year-old Eskimo, a trapper and hunter, was on the trail when a blizzard struck. His dog-team ran off, leaving him without food, water, or shelter, with the ambient temperatures between -15° F. and -20° F. He walked for six days, with no problem in his skin mukluk footgear until the latter part of the second day, when he lost sensation in his toes. His feet were "frozen solid" by the third day. He walked in the native village of Black River on the evening of the sixth day, having hiked an average of twenty to thirty miles daily, with only snow as oral intake. His feet were frozen for three to four days, according to history and he left them so without attempting to thaw the extremities in order to maintain them in the solid state for walking and to survive. Upon reaching the village, his feet were immersed in snow and ice water, and thawed by delay over a period of eight hours.

CASE #7

Fig. #13: The feet are approximately five days post-freezing and forty-eight hours post thawing. Here a very poor prognostic sign is evident. The blebs are all proximal, and are dark. The toes and distal tissues are without blebs or blistering, and are dusky, edematous, painless and insensitive. Phalangeal amputation is generally unavoidable with this pattern and may be anticipated from the date of admission -- as early as twenty-four hours post-thaw.

Fig. #14: The plantar aspect of the foot at the same period as Fig. 13 - the blebs are proximal and the plantar aspect of the foot without sensation. The pedal pulses are diminished but present.

Fig. #15: Three months post-thawing, with the superficial iniection at the junction of viable and gangrenous tissues held in control by whirlpool baths and aseptic care permitting the self-demarcation of the tissues, so that maximum length of foot is gained. Amputation is considered from this point on, once the tissue edema has subsided and there is no further tissue retraction.

Fig. #16: Amputation at the distal metatarsal level -- the patient was back in the Arctic the following winter and has been a trapper and hunter there for the past six years.

CASE No. 7

DELAYED THAWING BY ICE AND SNOW

Fig. #13

Fig. #14

Fig. #15

Fig. #16

CASE #45

This patient was on a caribou hunt in the Northwest coast area of Alaska when his small plane collided with a mountain at the 5,000 foot level. He sustained a fracture of the tibia, a fracture of the talus and was unconscious. His companion, equally severely injured, including a fracture of his lumbar spine, crawled 13 hours down to a settlement and eventually arrived at an Alaska Native Hospital. His thawing was in transport and was spontaneous. Temperatures in the area of the accident were well below xero and the winds were between 25 and 30 knots.

CASE #45

Fig. #21: Here the extremity demonstrates the cyanotic hue of the ischemic limb demonstrating vascular insufficiency. The pedal pulses are absent and the sensation is absent to the level of the malleoli. There are no blebs, proximal or distal, at this stage. This is a typical picture of extremity fracture or dislocation, thawed by other than rapid rewarming.

Fig. #22: On the fourteenth day there was only minimal bleb formation and these dark and serosanguinous. The foot was without sensation and the digits were obviously gangrenous.

Fig. #23: At the end of the third week after thawing, there was dry gangrenous change of most of the foot and the plantar pad. Tissue necrosis continued and the extremity was amputated at the level of the fracture.

CASE No. 45

EXTREMITY FRACTURE FOLLOWED BY FREEZING

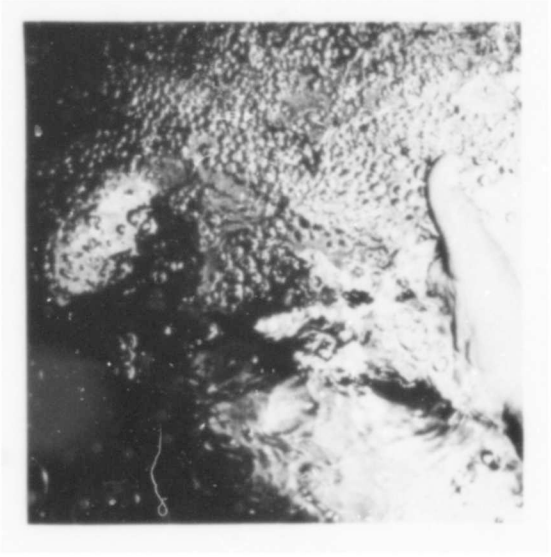
AND SPONTANEOUS THAWING

Fig. #21

Fig. #22

Fig. #23

SUMMARY

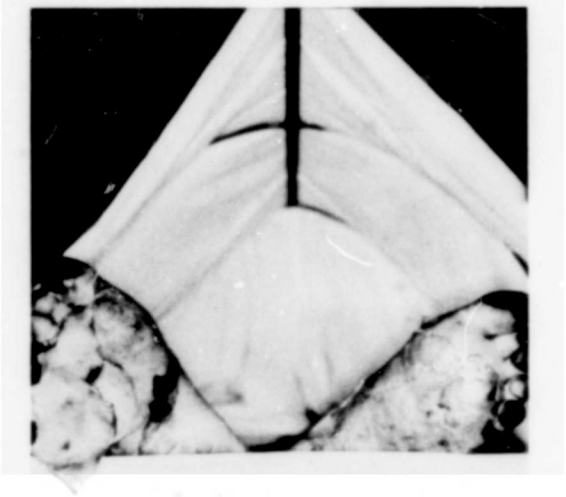


THAW RAPIDLY IN WARM WATER

(100 - 112° F.)

AVOID BLEB RUPTURE WHEN

TRANSPORTING PATIENT



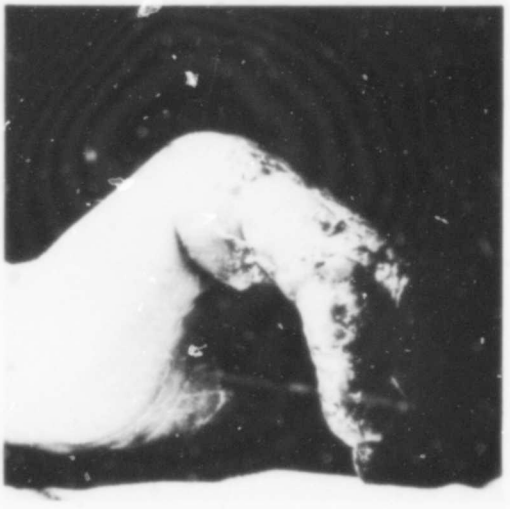
PROTECT INJURED PARTS

DURING BLEB STAGE

AVOID PREMATURE DEBRIDEMENT

OR SURGICAL INTERVENTION

SUMMARY (cont.)



DO INCISE CONSTRICTING ESCHAR WITH LATERAL OR DORSAL SLITS TO PERMIT IP JOINT MOVEMENT.

TWICE DAILY WHIRLPOOL BATH WILL PERMIT PHYSIOLOGICAL SEPARATION OF NECROTIC TISSUES FROM NEWLY FORMED EPITHELIUM BELOW

CONSTANT MP AND IP JOINT MOTION IS DEMANDED, FROM COMPLETION OF THAWING TO END OF TREATMENT

THAW THE INJURED EXTREMITY BY THE RAPID REWARMING METHOD AND DO AN IMMEDIATE REDUCTION OF THE FRACTURE OR DISLOCATION. AVOID FURTHER FREEZING CONSTRICTION BY CAST OR EXCESSIVE TRACTION. AVOID ALL NEUROVASCULAR TRAUMA.
(THE ABOVE INJURY DEMONSTRATES THE RESULT OF AN UNREDUCED FRACTURE-DISLOCATION OF THE TARSAL NAVICULAR AND SPONTANEOUS THAWING.)

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