MOUNTAIN FROSTBITE

International Society for Mountain Medicine Newsletter, **8** (3): 8-10 (July 1998)

Clinical Aspects

Frostbite is local tissue injury due to the direct action of cold below 0°C for a period of time. Frostbite injuries are usually classified in three (or four) degrees of severity according to their clinical aspect and evolution [1].

First degree is characterized by pallor or transitory cyanosis followed by erythema during rewarming, numbness, and complete healing within a few weeks. Superficial second degree is defined by the development of clear blisters in about 12 hours; the evolution is the same; the sensation problems can last longer. Deep second degree is characterized by complete anesthesia, some haemorragic blisters and proximal swelling. When deep frostbite results in necrosis, then amputation, it is classified as third degree.

Several conditions promote the development of frostbite: the external temperature, the wind (higher convective loss), the humidity (conduction), impairment of blood circulation (tight clothes and shoes, displaced fractures), the state of hydration of the patient, and high altitude hypoxia. All people are not equal in the face of frostbite; the classical risk factors are vasospastic disorders, autoimmune diseases, nicotine addiction and above all prior frostbite [1].

Clinical diagnosis is obvious, it is generally made by the patient himself, very rapidly for the fingers, more slowly for the toes. Chilblain are not frostbite, but a peripheral vascular disease presenting swelling and a pruritic erythema during rewarming.

At Chamonix hospital, we receive about 80 cases of frostbite a year. 75% of cases are superficial frostbite. For deep frostbite, the aim of treatment is to prevent amputation (8% of cases) but also neurovascular and trophic sequels. In our series, frostbitten feet represent 57% of cases (especially the big toe) and 46% of patients have frostbitten hands (but usually sparing the thumb). Finally, frostbite of the face is not rare (17%), especially of the nose and ears.

PATHOPHYSIOLOGY

Primary phase: cooling and frost effects

On cold exposure there is peripheral vasoconstriction whose magnitude depends on the intensity of cold and the vasomotor tone of the subject. This arterial and venous vasoconstriction with diversion of blood by arterio-venous bypass and shut down of pre-capillary sphincters causes a decrease of the capillary perfusion gradient and the development of local stagnation, hyperviscosity, hypoxia and acidosis. This vasoconstriction can be rhythmicaly interspersed with vasodilation periods due to the decrease of the vascular wall musculature sensitivity to adrenergic stimulation [2].

The distal parts, less perfused and more exposed to cold start to freeze when the

dermal temperature goes below the plasma point of freezing (-0.52°C). Meanwhile, cells can stay in a liquid state as low as -15°C. This phenomenom is due to some protective solutes in the cellular membrane and is called supercooling [3]. Thus, frostbite affects the extracellular space first. In this area, the growing of ice crystals causes an increase of osmolarity, and then an intracellular dehydration by passive diffusion of water through the membrane. Finally, the intracellular liquid freezes, at a temperature which depends on the type of cell: vascular endothelium, peripheral nerves and bone marrow are the first to become frozen [4].

The cause of cellular death depends on the rapidity of development of the lesions. Often due to the mechanical aggression of extracellular crystals, it can be caused by the ultimate effects of the dehydration mechanism [5].
In the case of fast cooling, crystals formed during the freezing are small and thermodynamically unstable. During slow rewarming, they tend to join others, in order to create bigger crystals but with a less superficial tension; these crystals are more damaging for cellular structures. Fast rewarming avoids this re-crystallisation phenomenom by melting crystals before they increase their size [3].

Second phase: thawing and progressive necrosis
During rewarming, arteriolar vasoconstriction is replaced by a reactional hyperaemia due to the local development of vasoactive molecules during the ischemic period. This hyperaemia facilitates the movement of fluid to the interstitium, which causes an increase in the blood viscosity followed by a slowing down of the microcirculatory flow. The desquamation of endothelial cells and the alteration of the basal membrane provoke an activation and adhesion of leucocytes which migrate to the interstitium, freeing cytokines and free radicals. The activation of the acid arachidonic cascade in platelets causes the release of thromboxane A2 [6]. This reperfusion injury [7] ends in total interruption of the microcirculation within a few hours. Finally, if cold is insufficient to cause cellular death, some vascular and nerve degenerative lesions can appear [8].

Initialy proven in rabbit ears or mouse legs, this progressive necrosis phase was confirmed in man by the evolution of the differents peaks of 31P (ATP, phosphocreatine, inorganic phosphate) in a patient with severe frostbitten legs by NMR spectroscopy at Chamonix hospital [9].

Late phase: permanent lesion
This is the most striking phase clinically (oedema, blisters, necrosis), it begins 48 hours after rewarming. The lesions are then irreversible and if treatment is begun only at this stage, the results are disappointing. The lesions in this stage are classified as follows [8]: a zone of coagulation where the action of the cold was maximum and where necrosis prevails from the first hours; a zone of stasis where irreversible damage is not noted initially, but which tends to be transformed into the zone of coagulation in 48 hours; a zone of hyperaemia, where the cold was less intense and where spontaneous recovery can be expected in less than 10 days.

Finally, the pathogenesis of frostbite spreads out between two extremes, which explains the diversity of the symptomatology, the evolution and the therapeutic effectiveness. For very cold temperatures the mechanism is primarily related to the

freezing of the cell and is characterized by the necrosis source of amputations. With the other extreme, with more lenient temperatures and a humid atmosphere, the lesions are more often vascular, with primarily functional and trophic sequels (trench foot) [8].

PROGNOSIS

The prognosis is difficult to establish clinically in the early stages. Three to four days are usually necessary to know if there is superficial or deep frostbite and, in this case, it is necessary to wait for the appearance of the line of demarcation, more than 30 days after injury, before the level of amputation is apparent. Waiting for the verdict is intolerable for the patient; fortunately Technetium 99 bone scanning makes it possible to shorten this delay[10] [11]. The examination should not be done too early because it can be falsely reassuring if the lesions of progressive necrosis have not had time to appear. The isotope bone scan appearance changes in three phases with an immediate or vascular phase, an early or tissue phase and a late phase or osseous (after 3 hours). In all of our series of 80 cases where the bone scan showed normal fixing of the isotope at the late phase, there was no amputation. On the contrary, if the late phase showed clear hypofixation, the patient had to have an amputation. A pilot study is underway in Chamonix to examine the role of MRI [12]which gives a much higher resolution than the isotope scanning, and thus permits a more precise estimate of the viability of injured tissues. The first results are encouraging.

Therapeutic Approaches

The treatment is based on pathophysiology: it is necessary to rewarm, to fight against vascular spasms, hyperviscosity, thrombosis and to prevent inflamation and infection.

Physical treatment

Rewarming is an emergency measure, usually achieved by immersion in a 38°C whirlpool water bath for a period of 30 minutes [1, 13].

All situations of decreased circulation, especially frostbite, impair the effectiveness of the physiologic hemodilution (the instant capillary hematocrit is on average 15%). The role of normovolemic hemodilution is to restore good distal rheologic conditions. An hematocrit of 30% allows optimal tissue oxygen delivery.

Pharmacological treatment

Given each day at low dose, aspirin irreversibly inhibits the platelet synthesis of thromboxane A_2 but lets the endothelial cells resume their prostacyclin synthesis quickly. It must be given as soon as possible.

For their anti-aggregating effects, the low molecular weight dextrans can be adopted; they also have an effect on the erythrocyte sedimentation rate.

Thrombolytic drugs allow the removal of thrombus which is formed during the first hours after the thawing of the tissues. Urokinase [14], streptokinase [15] and rTPA [15] have been successively used in pilot studies with encouraging results. This treatment is carried on with low molecular heparin, which is more practical and has

less of a platelet aggregating effect than heparin.

Several authors have reported the use of vasodilators in frostbite treatment [13], sometimes with contradictory results [17]. Ideally, the selected agent should be cytoprotective, anti-oedematous, and must have an anti-aggregating effect on platelets, leucocytes and erythrocytes. Above all, it must be a micro-circulation vasodilator in order to avoid a vascular theft effect by redirection of blood flow to larger more dilated vessels. Buflomedil, naftidrofuryl and pentoxifylline [18] can be used in this indication.

All non steroid anti-inflammatory drugs inhibit cyclooxygenase. These drugs are of interest because they decrease upstream oedema which, if it is circumferential, can impair the downstream circulation.

Iloprost is a stable analogue of prostacyclin, or PGI_2. By antagonising thromboxane A_2, it inhibits all the consequences of platelet activation, especially vascular wall aggregating and adhesive mechanisms. It is, by its direct relaxing effect on the smooth muscle cell, one of the most powerful vasodilators known today. It inhibits leucocyte activation and the freeing of cytotoxic factors. It is cytoprotective. So, it is, in theory, the ideal molecule [19]. We have used it in more than 40 cases with good results. In the same way, PGE_1 has been given arterially [20] or orally [21].

Different authors [6][18] have adopted aloe vera cream for its local inhibiting effect on the thromboxane synthetase and have reported its effectiveness in humans, associated with oral ibuprofen.

Other therapeutic approaches

Sympathic block is regularly recommended and sometimes criticized [23]. It may be either surgical (historical) or pharmacological, by means of spinal, plexic [22] or troncular blocks. It is more effective on large vessels, and its beneficial effect could be caused by the global increase of blood flow in the concerned territory. It may have a preventive action on the neuro-vascular sequelae.

Hyperbaric oxygen was often used at the end of the sixties [24] without proof of effectiveness.

Finally, neurospinal stimulation is proposed by the Zaragossa team. Its mechanism of action could be by autonomic nerve mediated vasodilation and the stimulation of prostacyclin production [25].

PRACTICAL MANAGEMENT

The most effective treatment is immediate thawing in warm water (38°). This treatment may be done in the mountain hut. After that, refreezing must be absolutely avoided. The oedema which appears generally prevents the patient from putting his shoes back on.

For first and superficial second degree frostbite, we also give aspirin (250 mg/day); buflomedil, for which the dosage increases according to the severity (up to 800 mg/day); and a non steroid anti-inflammatory drug.

For more severe cases, we use iloprost (up to 50 µg/day) for 5 to 7 days and sometimes rTPA (30 to 50 mg) at the time of admission (contraindicated in case of trauma). Anticoagulation is maintained by low molecular weight heparin. Aspirin is always mandatory. An appropriate blood volume is essential, as well as adherence to aseptic nursing rules. Frostbitten parts are kept elevated as long as the oedema persists (one week). Whirlpool antiseptic baths are repeated twice a day. They clean the wounds, kill the bacteria and promote soft excising. As soon as the oedema has disappeared, the patient must actively do excercise in the bath to prevent tendinous retractions. Blisters are left intact, unless they are constrictive or infected; in this case, antibiotics are prescribed. Tetanus prevention is routinely given.

Isotope bone scan is done in the first 48 hours, it can be repeated a week later to estimate the effectiveness of the treatment.

Surgery is started after the first week, with removal of blisters and superficial necrosis. Good nutrition and maintaining a positive psychological state are important. Except in the rare case of a compartment syndrome, aponevrotomy is never advised.

Amputation is delayed for as long as possible, in order to allow time for dry necrosis to settle, and to allow natural delimitation. Amputation is minimised, even if it means a later reintervention for plastic surgery. The wound closure is sometimes problematic [26] and must not be performed at any cost.

Sequelae
Sensitivity problems (pain, hypo or hyperesthesia), hyperhydrosis, finger ankylosis in flexion, skin and integument trophic troubles are regularly noted; they can persist for a long time. In the longer term (several years), osteoporosis and early arthrosis appear, caused by cartilage injuries [27]. In amputated patients, plastic surgery often allows a good functional recovery.

CONCLUSION
Prevention remains essential. In case of established frostbite, the sooner the correct treatment begins, the better the outcome. Rewarming by warm water is a therapeutic emergency. Intervention with inhibitors of the arachidonic acid cascade can then be considered, as well as micro-circulation vasodilators and antithrombotic drugs. Healing is always slow, amputations are rare, but the functional and trophic after effects can be disabling.

Bernard Marsigny (March 98). Chamonix, France

1. Foray J, Allamel G. - Les gelures. In : Encyclopédie Médico Chirurgicale. (Paris) 14-033-F-10.
2. Dana AS Jr, Rex IH Jr, Samitz MH - The hunting reaction. Arch Dermatol 1969 Apr;99(4):441-450.
3. Mazur P - Freezing of living cells : mechanisms and implications. Am. J. Physiol. 1984 247:125-142.
4. Trusal LR, Guzman AW, Barker CJ - Characterization of freeze-thaw induced

ultrastructural damage to endothelial cells in vitro. In Vitro 1984 Apr, 20(4):353-364.
5. Merymann HT - Freezing injury and its prevention in living cells. Annu Rev Biophys Bioeng, 1974, 3:341-363.
6. Heggers JP, Robson MC, Manavalen K, Weingarten MD, Carethers JM, Boertman JA, Smith DJ Jr, Sachs RJ - Experimental and clinical observations on frostbite. Ann Emerg Med 1987 Sep;16(9):1056-1062.
7. Manson PN, Jesudass R, Marzella L, Bulkley GB, Im MJ, Narayan KK - Evidence for an early free radical-mediated reperfusion injury in frostbite. Free Radic Biol Med 1991;10(1):7-11.
8. Morandeira JR - Estado actual de la fisiopatología de las congelaciones. In : Medicina de montaña. Pamplona, Graficas Xavier, 1994:15-21.
9. Kayser B, Binzoni T, Hoppeler H, Marsigny B, Mehier H, Gaillard E, Roussel B, Foray J - A case of severe frostbite on Mt-Blanc: a multi-technique approach. Journal of Wilderness Medicine 1993; 4: 167-174.
10. Lisbona R, Rosenthall J - Assessment of bone viability by scintiscanning in frostbite injuries. J Trauma 1976 Dec; 16(12):989-992.
11. Salimi Z, Wolverson MK, Herbold DR, Vas W - Frostbite: experimental assessment of tissue damage using Tc-99m pyrophosphate. Work in progress. Radiology 1986 Oct;161(1):227-231.
12. Barker JR, Haws MJ, Brown RE, Kucan JO, Moore WD - Magnetic resonance imaging of severe frostbite injuries. Ann Plast Surg 1997 Mar;38(3):275-279.
13. Mills WJ Jr - Comments on this issue of Alaska Medicine--from then (1960) until now (1993). Alaska Med 1993 Jan;35(1):70-87.
14. Zdeblick TA, Field GA, Shaffer JW - Treatment of experimental frostbite with urokinase. J Hand Surg [Am] 1988 Nov;13(6):948-953.
15. Salimi Z, Wolverson MK, Herbold DR, Vas W, Salimi A - Treatment of frostbite with i.v. streptokinase: an experimental study in rabbits. AJR Am J Roentgenol 1987 Oct;149(4):773-776 .
16. Skolnick AA - Early data suggest clot-dissolving drug may help save frostbitten limbs from amputation. JAMA 1992 Apr 15;267(15):2008-2010.
17. Daum PS, Bowers WD Jr, Tejada J, Morehouse D, Hamlet MP - An evaluation of the ability of the peripheral vasodilator buflomedil to improve vascular patency after acute frostbite. Cryobiology 1989 Feb;26(1):85-92.
18. Miller MB, Koltai PJ - Treatment of experimental frostbite with pentoxifylline and aloe vera cream. Arch Otolaryngol Head Neck Surg 1995 Jun;121(6):678-680.
19. Groechenig E - Treatment of frostbite with iloprost. Lancet 1994 Oct 22;344(8930):1152-1153.
20. Yeager RA, Campion TW, Kerr JC, Hobson RW 2d, Lynch TG - Treatment of frostbite with intra-arterial prostaglandin E1. Am Surg 1983 Dec;49(12):665-667.
21. Saito S, Shimada H - Effect of prostaglandin E1 analogue administration on peripheral skin temperature at high altitude. Angiology 1994 Jun;45(6):455-460.
22. Koster U, Mutschler B, Hempel V - Treatment of frostbite of the extremities

by combined axillary plexus and peridural anesthesia: a case report including blood levels of bupivacaine. Reg Anaesth 1987 Jul;10(3):93-95.
23. Bouwman DL, Morrison S, Lucas CE, Ledgerwood AM - Early sympathetic blockade for frostbite--is it of value? J Trauma 1980 Sep;20(9):744-749.
24. Gage AA, Ishikawa H, Winter PM - Experimental frostbite. The effect of hyperbaric oxygenation on tissue survival. Cryobiology 1970 Jul;7(1):1-8.
25. Arregui R, Morandeira JR, Martinez G, Gomez A, Calatayud V - Epidural neurostimulation in the treatment of frostbite. Pacing Clin Electrophysiol 1989 Apr;12(4 Pt 2):713-717.
26. Martínez Villén G, Morandeira JR - Patología localizada por acción del frío: “congelaciones”. In : Manual Básico de medicina de montaña. Morandereira JR, Martínez Villén G, Masgrau L, Avellanas M. Ed. Prames, Zaragoza, 1996. 171-174.
27. Foray J, Kalt-Binder F, Lanoye P - Les séquelles des gelures de montagne. Chirurgie 1979 ; 105:37-46.

Content copyright© 1998 ISMM Last modified 20-Nov-2002