Frostbite: epidemiology at high altitude in the Karakoram mountains

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During a 10-year period (December 1984 to December 1994), 1500 cases of frostbite were treated at a tertiary care medical facility. They were all males with their ages ranging from 17 to 43 years. All the patients sustained the frostbite injury in the northeastern part of Pakistan known as the Karakoram range of mountains. They included a large number of porters and guides employed by various mountaineering expeditions (approximately 250-300 expeditions per year) in that region, as well as local inhabitants. This retrospective study included the heights at which frostbite occurred (range 11 000-22 000 feet above sea level). Of the patients, 15% (n=225) got frostbitten within 1 h of exposure, whereas the majority (71%) had an exposure of 1-3 h. The effect of seasonal variations (relative hypothermia) on the extent and depth (degree) of frostbite and the distribution of lesions as per body surface subunits (areas) was noted and found to be statistically significant with P<0.05 for both. The occurrence of frostbite at various heights showed a very steep upward curve beyond a height of 17 000 feet above sea level. This has been termed the 'cut-off' point for frostbite by the authors, the increase depicting the true picture of 'high altitude frostbite'. Tobacco smoking and peripheral vascular disease were found to be important contributing factors. The feet were involved most frequently (64%) followed by the hands (32%), the head and neck region (3%) and the perineum (1%). Independent effects of the height (relative hypoxia) on the depth of frostbite lesion (degree) and on the involvement of multiple body areas (surface sub-units) showed significant correlation with P values well below 0.05 for each. Of cases, 92% (n=1386) had second- or third-degree frostbite necessitating definitive surgical intervention. Total frostbite-related mortality spanned over 10 years was 11%.

Frostbite can be important and disabling since it entails loss of extremities and gross morbidity. Cold injuries are common among people living in the Karakoram range of mountains bordering the northeastern parts of Pakistan (heights ranging from 10 000 to 28 000 feet above sea level) and are basically due to gross lack of awareness and education on the part of inhabitants of those areas. Frostbite remains one of the major health hazards at high altitudes, as we found its incidence to be 1.5 times that of all the high altitude related medical conditions considered together during the 10 year period of this study (Table I). Once the changes by freezing cold injury at cellular level set in, there is very little which can be done for the patient except adopting a wait and watch approach.

<table>
<thead>
<tr>
<th>Problems</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frostbite</td>
<td>1500</td>
</tr>
<tr>
<td>Acute mountain sickness</td>
<td>469</td>
</tr>
<tr>
<td>Exhaustion</td>
<td>299</td>
</tr>
<tr>
<td>Hypothermia</td>
<td>46</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>86</td>
</tr>
<tr>
<td>High altitude pulmonary oedema</td>
<td>255</td>
</tr>
<tr>
<td>High altitude cerebral oedema</td>
<td>95</td>
</tr>
</tbody>
</table>

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policy. Awareness and dedicated discipline regarding preventative measures are therefore of paramount importance. The purpose of this study is to highlight the epidemiological aspects of frostbite with special reference to the precipitating factors, the independent effects of the altitude and the season on the distribution and extent of the lesions.

Area, altitudes and inhabitants

The northern part of Pakistan adjoining China, Afghanistan and Kashmir is an area where the three great mountain ranges (Karakoram, Himalayas and Hindu Kush) have churred the area into peaks, passes and glaciers because of the process of Himalayan orogeny. The Karakoram rise to an average height of 20 000 feet above sea level, K2 (Godwin Austen) being its highest point at 28 000 feet. In fact, five out of eight peaks above 25 000 feet above sea level lie in this area of Pakistan and attract between 250 and 300 international mountaineering expeditions every year.

The climate of the Karakoram range is arid, liable to sudden variations of temperature with wind especially at heights over 15 000 feet above sea level. Despite the effect of solar radiation, the temperature can fall to -20°C to -25°C, and this 'wind-chill effect' is probably the most common factor causing frostbite at high altitude.

There are isolated pockets of population scattered in the valleys in the Karakoram range at heights between 10 000 and 12 000 feet, living on Yak and sheep grazing. These people are subjected to limited seasonal migration to low lands according to variations in snow line and the increasing number of climbing expeditions which have turned them by profession into high-altitude porters capable of carrying heavy loads to great heights. These porters normally wear clothes made of sheep or goat skin, but for expeditions use high-altitude clothing kits gifted to them or left over by members of returning expeditions. As they have no means of getting their kits, boots or gloves repaired locally, they tend to be more liable to frostbite while climbing with worn-out or damaged protective gear.

Patients and methods

During a period of 10 years (December 1984 to December 1994), a total of 1500 cases (averaging 150 cases per year) of frostbite were received from the northern areas of Pakistan and treated at a tertiary care referral hospital. These cases were studied by the authors retrospectively, noting the height at which frostbite occurred as well as any predisposing or precipitating factors which increased susceptibility. The lesions were divided into four degrees according to the extent and depth of tissue involvement and the reaction observed after rewarmin as classified by Dick (1). Third- and fourth-degree frostbite cases, having a similar prognostic outcome, were considered together and grouped as third degree.

The number of areas of the body affected in a patient (number of body surface subunits) were also noted in detail. The seasonal variation in the incidence of frostbite and the duration of exposure of tissues to freezing cold injury responsible for it were also considered.

On admission, all the patients underwent a thorough physical assessment for any previous peripheral vascular disease. An inquiry was made regarding smoking habit and/or the use of other drugs. Environmental factors which could predispose to this condition were also recorded. After admission, the patients were treated conservatively and mostly received symptomatic treatment. The dead areas were excised when a clear line of demarcation appeared. In the absence of infection, amputations were usually delayed to give all possible chance to the deeper tissues to recover spontaneously. Where feasible, reconstruction with web-deepening procedures and toe to hand transfers were performed. The data were analysed statistically for the correlation of various factors calculating \( \chi^2 \) and \( P \) values.

Results

All the patients were fit and healthy males with ages ranging from 17 to 43 years. Of the patients, 4\% (\( n = 66 \)) were under the age of 20 years, 78\% (\( n = 1173 \)) were between 20 and 30 years, 17\% (\( n = 258 \)) were 30-40 years of age, and 1\% (\( n = 3 \)) were over 40.

In 71\% of patients (\( n = 1065 \)), freezing cold exposure of 1-3 h was sufficient to cause frostbite to some extent. Those who were caught up in blizzards (15\%, \( n = 225 \)) were affected earlier (within 1 h). In 12\% of patients (\( n = 180 \)), cold exposure of 3-24 h was responsible for the lesion, whereas 2\% (\( n = 30 \)) of patients had an exposure of more than 24 h before becoming frostbitten. The last two categories of patients were those who had some kind of accident and could not be rescued in time. In the Karakoram range, the terrain is so hazardous and the weather so treacherous that only 2\% (\( n = 30 \)) of patients could be evacuated to the nearest hospital within 6 h. Nearly half of the patients could not be rescued before 48 h necessitating primary treatment at the site of occurrence.

Tobacco smoking and peripheral vascular disease were definite factors affecting the long-term prognosis. Of the patients, 80\% smoked 20-30 cigarettes per day; 10\% also admitted habitual smoking of charas or hashish (marijuana) to while away the time. Of the patients, 1% had some evidence of peripheral vascular disease making them more susceptible to frostbite.

Although the snow line in the Karakoram range starts at 12 000 feet above sea level, the incidence of frostbite showed a very interesting curve when plotted against variable heights (Fig. 1). Up to the height of 17 000 feet there was a flat curve comprising only 6\% of cases (\( n = 87 \)), followed by a sudden and steep rise in the incidence proportional to the height. In fact, 85\% of patients (\( n = 1269 \)) had frostbite between 17 000 and 21 000 feet. The decline shown in the graph beyond this
point was because of the fact that persons who went and stayed at those heights were confined to their shelters with very little movement, so were relatively spared.

Monthwise distribution of cases over 10 years (Fig. 2) showed the maximum number affected during the month of January \((n = 360)\) followed by December \((n = 246)\), November \((n = 210)\) and October \((n = 153)\). The reason was a sudden fall in atmospheric temperature during those months (to minus 30–35°C), and the ‘wind-chill effect’ \((2)\) during blizzards. Only 18% of cases \((n = 269)\) had frostbite during the summer months (April to September).

Feet were most frequently affected \((64\%, n = 960)\) most probably because of using substandard or damaged boots, non-adherence to the instructions regarding self-examination, neglect because of exhaustion and/or the effect of narcotic drugs where used. Hands were affected in 32% \((n = 480)\) of cases. Head and neck exposure usually involved nose and ears and was seen in 3\% \((n = 45)\) of patients. Fifteen patients \((1\%)\) suffered perineal frostbite and sustained the injury while evacuating their bowels.

Of the patients, 27% \((n = 411)\) had one body area (surface subunit) affected by frostbite. The majority \((60\%, n = 924)\) had two body surface subunits affected, and a significant number had involvement of three \((n = 69)\) or four \((n = 96)\) regions or areas of the body.

Independent effect of variables like height (ie relative hypoxia) on the number of surface subunits affected by frostbite revealed that up to the height of 17 000 feet involvement of more than one surface area was just a chance occurrence, beyond which there was a significant increase in the number of cases with involvement of two, three or four body surface units by frostbite with \(P < 0.001\) (Fig. 3). Similarly, independent effect of the season (ie relative hypothermia) on the multi-area involvement revealed a significant \(P < 0.01\) increase in the number of body surface subunits (areas) involved during winter months (October–March) than during summer with \(P < 0.01\) (Fig. 4).

In all, 114 patients \((8\%)\) suffered from first degree frostbite lesions, whereas 92\% of cases had second \((n = 606)\) or third degree \((n = 780)\) lesions needing skin debridement/amputations or skin grafting procedures. Correlation of independent effect of height on the degree of frostbite (Fig. 5) showed that height adversely affected the lesions beyond 17 000 feet with \(P < 0.001\). Winter season had a similar adverse, significant and independent effect on the degree of frostbite with a \(P\) value of \(< 0.0001\) (Fig. 6).
One factor, however, remained very constant, i.e. the early recognition of the disease was found to be directly proportional to the education of the patient. The more educated he was, the earlier was the pick-up rate and the lesser the degree of frostbite.

A total of 160 patients died in the area between 1984 and 1994. While considering frostbite-related mortality, the total number of deaths (year-wise) were plotted against the number of cases (Fig. 7) showing an inverse proportion between the two. It is quite safe to conclude that frostbite does not contribute towards mortality at high altitudes.

**Discussion**

The devastating effects of extremely low environmental temperature in winter have been known since Napoleon's Russian campaign. Americans had 30,000 cases of cold exposure in France during 1944–1945 (1). In our series, we had 1500 cases of frostbite over a period of 10 years against 1250 cases of high altitude related medical problems like acute mountain sickness, hypothermia, pneumonia, and high altitude cerebral and pulmonary oedema (Table I).

Frostbite is a form of cold injury, the degree and extent of which varies with the environmental conditions and precipitating factors. Being an accidental injury like burns, no uniform data regarding the true incidence are available despite many published reports (3,4), the largest series describing 1880 cases encountered during the Korean conflict of 1950–1951 (5). Green and Ouriel (6) have considered the type of frostbite occurring at high altitudes as a separate entity to that generally reported at low altitudes since these have a different aetiology. While considering frostbite at high altitudes in the Karakoram range, relative hypoxia and 'wind-chill effect' (2) played a major role. The sudden increase in the incidence noted in our series beyond 17,000 feet above sea level has not been mentioned or highlighted in the world literature; the reason being that most of the studies on frostbite have been done in areas at lower altitudes than 170,000 feet and the incidence mentioned in those reports (3,4) has been identical to our curve below that height. The authors would like to call this sudden rise in the incidence beyond the height of 17,000 feet the 'cut-off point' for high-altitude frostbite. This increased incidence could possibly be related to raised packed cell volume and viscosity of blood in addition to local tissue infiltration by plasma in response to damaged capillary wall (7). The resulting intravascular sludging and haemoconcentration could have affected the overall tissue nutrition leading to rapid necrosis (7), resulting in gangrene. The other possibilities for such a phenomenon could be progressively lowered oxygen uptake at higher altitudes resulting in decreased heat production (8).

The effects of hypoxia on cerebral function affecting slowing of protective reflexes, neuropsychological functions and effective behaviour has been well documented, especially at heights around 15,000 feet (7), and can not be over-emphasised while considering the aetiology of frostbite. The degree of cerebral impairment seems to have a direct bearing on the incidence of frostbite, as Urschel (4) noted 53% of his cases under the influence of alcohol and 16% with psychological traits. As alcohol consumption is against the law in Pakistan, such a correlation to alcohol could not be established. Of the patients, 10% did admit using marijuana (hashish) and this could have affected their judgement regarding adopting protective measures. Hypoxia itself could be responsible for a feeling of indifference and lack of appreciation of danger. No data of psychiatric illnesses were available.

Frostbite lesions are reversible within 6–8 h after the initial insult. Various methods of management have been mentioned in the literature, but basically amount to rapid rewarming of the frozen part with symptomatic support followed by a wait and watch policy (9,10) adopted in our cases. As noted previously, owing to the weather and terrain factors, early rescue and institution of treatment was only possible in 2% of our cases.

**References**


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**ERRATUM**

Blood loss during primary total hip arthroplasty: use of preoperative measurements to predict the need for transfusion

The authors have pointed out an error in the manuscript of the above article. The equation described by Gross at the top of page 439 should read:

\[ V_1 = EB(\frac{H_0 - H_t}{H_nv} \]