

# INVESTIGATIONS INTO THE PATHOPHYSIOLOGY OF MILD COLD INJURY IN HUMAN SUBJECTS

Surgeon Commander E. Howard N. Oakley and  
Lieutenant Chris J. Lloyd,  
Institute of Naval Medicine  
Alverstoke, Gosport, Hampshire PO12 2DL, UK

## INTRODUCTION

Although cold injury was first reported in about 400 BC, and has been studied in detail over the last 300 years, it is still capable of being responsible for 20% of all casualties even in well-trained well-equipped soldiers in relatively mild conditions'. Whilst some of these may be inevitable, the underlying pathophysiology of freezing and non-freezing forms and their sequelae remain poorly understood<sup>2,3</sup>. Following the Falklands Conflict Golden (unpublished) established protocols at INM by which those who had suffered cold injury could be investigated, particularly with regard to the often severe late intolerance to cold seen in even mild cases. Since then, about 500 investigations have been performed using his technique. In 1986, Oakley introduced a simple neurophysiological test; this paper analyses the first 100 consecutive attendances in which both techniques have been used, in the hope that the results may provide some insight into the mechanism of injury and its sequelae.

## METHODS

One hundred consecutive attendances by patients and others, consisting of a total of 75 different individuals, were analysed, spanning the three years to 1990. Subjects qualified for inclusion if they were referred for the investigation of cold injury, any other peripheral vascular disorder (including sequelae of trauma, Raynaud's Complex), or were taking part as volunteer subjects in the ongoing study of cold injury. Those who attended during the first six months, or had no clinical indications, gave informed consent in writing. Patients referred with fresh cold injuries were not seen until at least two months after injury.

Subjects clad in indoor clothing entered a climatic chamber maintained at 30 ± 1°C and still mixed air, and rested recumbent on an examination couch. Sensory thresholds were measured using the Middlesex Hospital Thermal Testing System<sup>5</sup> with the room quiet and minimal distraction. Thresholds to cool then warm thermal stimuli were recorded from the volar surfaces of the distal phalanges of digits 2-4 in the left hand, and the whole of the volar surfaces of digits 1-3 in the left foot. Following this, infra-red thermography was carried out. The right hand or foot was exposed and allowed to equilibrate with ambient. A control picture of the volar surface was then taken using an Agaema 870 solid-state infra-red camera connected to an IBM PC which displayed and stored the images. The hand or foot was then placed in a plastic bag and plunged into a bath containing stirred water at 15 ± 0.5°C, and kept there for 2 minutes. On removal, the plastic bag was discarded and a further infra-red picture taken. Five minutes after removal, the final infra-red picture was taken. Patients with unilateral lesions were tested on their injured side, with thermography being performed on a limb only if there were indications of abnormality or injury in that limb (or the subject was uninjured).

Subjects were then interviewed and examined clinically, and their test results graded by the same doctor, following which he made a recommendation as to their disposal. Results were graded subjectively: infra-red thermograms into normal, then mild to severe degrees of cold sensitisation, sensory thresholds into normal (< 3°C for fingers, < 4°C for toes) and abnormal.

## RESULTS

Two-thirds of all attendances were from Royal Marines, 12% each from a group of very experienced and exposed individuals within the Royal Marines, and civilians, and 9% from other UK Armed Forces. Average age was 28.7 years (range 14-56). Males formed 93% of the attendees. Clinical studies accounted for 86% of studies. A total of 20 of the 75 different individuals seen had sustained non-freezing cold injury during the Falklands Conflict, of whom several were presenting for the first time (up to 8 years subsequent to their original injury). Non-freezing cold injury (NFCI) of the feet was the primary diagnosis in 43 of the patients, 13 had other forms of mild cold injury, 16 were seen for other clinical causes, and 3 were found to be normal. None of those with NFCI had sustained any form of tissue loss, and only three of those who had suffered frostbite had any.

Infra-red thermography appeared to be abnormal in 31 of the 43 with NFCI of the feet, in 7 of the 13 with other cold injury, in 12 of the 16 others, but in none of the three normals. All those with normal infra-red thermography results returned to full and unrestricted duties following their last tests. Of the 18 patients seen on more than one occasion, one was never abnormal and three others returned to normal over the period of study.

Sensory thresholds were abnormal predominantly in the **warm modality**, and mostly in the **toes**. Of those with NFCL of the feet, one had an abnormally **high cool** threshold in the **fingers**, five had abnormal warm thresholds in the **fingers**, **13** had abnormal cool thresholds in the **toes**, and **32** abnormal **warm** thresholds in the **toes**. Figures for the other groups were not dissimilar, although none of those considered as normal had abnormal thresholds. All of those with normal thresholds returned to full and unrestricted duties following their last tests. All of those with multiple attendances except for one were abnormal, and only one other returned to normal during the study.

Outcomes were not good. Of the **56** with cold injury, only **26 (4.5%)** returned to full duty. When the highly experienced group is excluded (as they came from and returned to full duties), only **17** of **48** returned to full duty, i.e. **65%** remained in some employment restriction. Furthermore, **8 (17%)** had to be referred to a medical board to consider whether they should be invalidated as a result of their sequelae.

## CONCLUSIONS

The clinical picture of NFCL in the feet has been well described<sup>6</sup>, and cases may present during the hyperaemic phase or subsequently, the latter being when these tests were carried out. This post-hyperaemic phase appears to be one in which those with either form of cold injury commonly suffer cold sensitisation<sup>2,3</sup>. This study reaffirms the frequency with which this disabling consequence occurs, even in those with very mild cold injuries. The evidence is that this period of cold sensitisation may last almost indefinitely, and certainly be longer than eight years. Furthermore, anecdotal stories of impaired warm sensation following cold injury have been confirmed, which again appears to be long-lasting if not permanent. These results re-emphasise the dramatic human and performance consequences of even very mild cold injury, and the importance of enforcing conservative limitations on permissible peripheral skin temperatures during human cold exposure studies, lest injury occur inadvertently.

Neither of the techniques used in this study has been completely validated. Infra-red thermography is notoriously difficult to use in control populations, as many of those believed to be free from cold injury appear to be abnormal. However, very few active young men have not undergone the brief exposure necessary to sustain NFCL, and there is speculation that a not uncommon disease of childhood, Pink's disease, or deprivation hands and feet, is identical with NFCL. More intense assessments of subjects are now being undertaken using laser doppler techniques, and a longitudinal cohort study of those undertaking military training is also planned. Although sensory thresholds measured at other sites have been extensively validated, a similar study using these sites in controls is still in progress, although the criteria of abnormality used here are believed (after examination of over 20 controls) to be conservative.

Whilst the infra-red thermography test gives an indication of sympathetic (unmyelinated fibre) function, sensory thresholds relate to both myelinated (cool) and unmyelinated (warm) fibre function. Therefore these abnormalities are consistent with a pattern of lasting damage to fine and unmyelinated fibres, and there appear to be very few who suffer from lasting damage to larger and myelinated nerve fibres. They are also consistent with the hypothesis that cold sensitisation occurs as a result of denervation supersensitivity<sup>3</sup>. This is in contrast to the large number of animal studies, which suggest that at least in the acute stages, nerve fibre damage from cold injury occurs to all fibre types, or is even worse in myelinated axons<sup>4</sup>. It is suggested that the pattern reported here occurs as a result of disruption to the axons of fine and unmyelinated fibres at a high enough level to result in neuronal death or to prevent effective reinnervation. Whilst this could happen as a result of spasm in, or blockage to, the vasa nervorum, it is suggested that this is most likely due to prolonged disruption of axonal transport, which could then propagate up the axon. This may be the primary site of injury, particularly in NFCL, with its requisite period of prolonged relatively mild cooling. The apparent similarities between mild cold injury and diabetic peripheral neuropathy may also merit further investigation.

## REFERENCES

1. Francis, T. J. R., Non-freezing cold injury: a historical review. *J. Roy. Nav. Med. Serv.* **70**:134-139, 1984.
2. Riddell, D. I., Is frostnip important? *J. Roy. Nav. Med. Serv.* **70**:140-142, 1984.
3. Francis, T. J. R. and Golden, F. StC., Non-freezing cold injury: the pathogenesis. *J. Roy. Nav. Med. Serv.* **71**:3-8, 1985.
4. Oakley, E. E. N., Investigations of warm and cool sensory thresholds in Royal Marines following cold injury and control subjects. MSc Thesis, King's College, University of London, 1986.
5. Fowler, C. J., Carroll, M. B., Bums, D., Howe, N., and Robison, K., A portable system for measuring cutaneous thresholds for warming and cooling. *J. Neural. Neurosurg. Psychiatry* **50**:1211-1215, 1987.
6. Ungley, C. C., Channell, G. D. and Richards, R. L., The immersion foot syndrome. *Brit. J. Surg.* **33**:17-31, 1945.