

THE SKIN IN THE COLD

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The skin may often be assessed as nonimportant, passive, cosmetical cover or frame of human being. As a living organ forming the surface of the human body towards the environment, the skin plays, however, an essential role in the perception of the environmental temperature and its changes. The skin also plays an active role in maintaining the thermal homeostasis of the body by many necessary structural and functional skin responses, mainly by regulating the dissipation of thermal energy to the environment. During the late phase of cooling of the body, the skin may partly turn into a passive insulative bark of the body diminishing thus the thermal loss to a minimum. In a recent dissertation the behaviour and thermophysiology of skin in the cold is reviewed (Lehmuskallio 2001).

*Eero Lehmuskallio¹,
Juhani Hassi²,
Päivi Kettunen²*

THE STRUCTURE AND FUNCTION OF THE SKIN IN THE COLD

The structure of the skin

The skin consists of three layers (Fig. 1).

Epidermis

This superficial renewable layer consists of epithelial cells with 15-20 dead corneal cell layers on the surface of living cell layers. There is no vasculature and only a few free nerve endings. Corneal layer forms the main barrier for keeping environmental chemicals and external water outside and tissue water inside the body.

¹*Santahamina Health Center,
Finnish Defence Forces, Helsinki, Finland,*

²*Center for Arctic Medicine,
Thule Institute, University of Oulu, Finland*

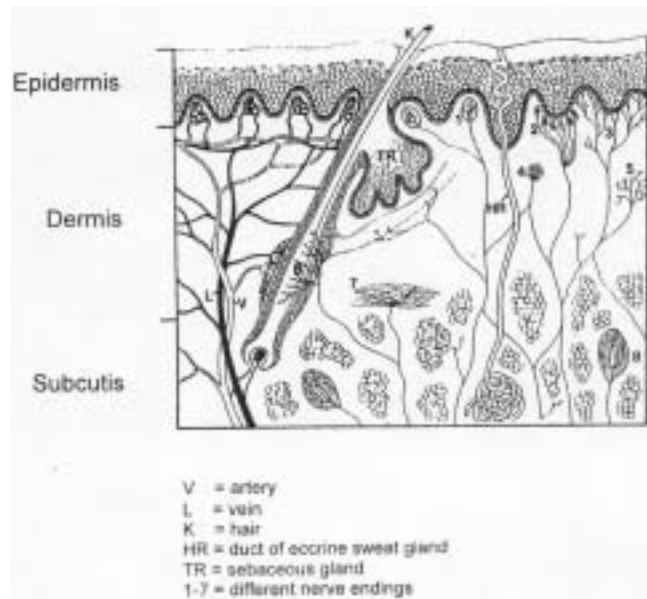


Fig. 1. The structure of normal skin.

Dermis

The middle, connective tissue layer with collagen and elastin fibers in ground substance, has a rich vasculature, contains nerves and most of the skin nerve receptors, etc. Dermis is responsible for the mechanical strength and elasticity of the skin.

Subcutis

The lowest, adipose tissue layer outside of muscular fasciae consists mainly of fat cells, some connective tissue and a few blood vessels and nerves, mostly passing through to and from the dermis.

The functions of the skin in the cold

Perception of the cold

As an organ forming the surface of the human body, the skin plays an essential role in the *perception of environmental temperature* (as well as touch, pain, etc.). There are specific neural receptors for cold and warmth, as well as for

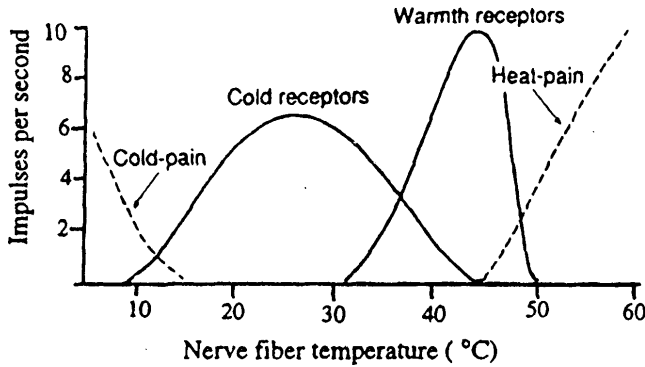


Fig. 2. The function of thermal receptors in different temperature levels. Frequencies of discharge by cold-pain, cold, warmth and heat pain-receptors (Chen 1997).

cold pain and heat pain (Fig. 2), although the interpretation of their integrated message in the brain leads to the perception.

Humans have no innate temperature sensation in the skin. Thermal perception in the skin is different when one enters the cold exposure straight from cold environment compared to the experience when coming from warm environment. The response to the environmental temperature depends not only on climatic conditions and physiological state of man but also on individual factors, such as past cold experience and previous thermal environment (Enander 1986). Personal cold adaptation is mainly caused by reduced intensity of thermal and cold pain perception, due to changes in the central nervous system.

Thermal receptors are most active during a change of temperature when their discharge is either increasing or decreasing (Fig. 2). Cold receptors are more prevalent than warmth receptors in the skin. The density of cold receptors is the highest in the face and upper body. In cold environment, clothing increases the importance of cold receptors in facial skin and upper respiratory membranes, as most of the skin elsewhere is usually covered by clothing. In the human skin, cold pain ceases when the tissue temperature lowers to an area between +15 - +10°C (Table I).

Insulative functions of the skin

Especially subcutis with its fat layer has a *passive* thermal insulative function similar to the subcutaneous fat and fur of arctic animals. The fat conducts distinctly less heat than

Table I. The skin sensations in the cold.

T °C of the skin *	Skin sensation
34-36	Thermal comfort
<29	Discomfort (cool)
<25	Discomfort (cold)
<18	Cold pain
<12	Numbness (gradual loss of tactile perception)
< 8	Loss of pain sensation

* The skin sensation depends on several other factors than skin temperature, such as the environmental temperature preceding the cold exposure, skin region, individual cold sensitivity, cold adaptation, etc.

tissues with higher water content, such as muscles or dermis (Elias & Jackson 1996).

The skin generally becomes warm when the body needs to dissipate excessive heat, and turns cold, when the body must preserve heat, becoming thus significantly more insulative. This *active* role in regulation of thermal insulation is managed specially by vascular responses in the dermis.

In furred animals, the piloerection reflex (raising of hair) increases the insulation of fur by trapping air inside this hairy layer. In man this phenomenon is only a rudimentary reminiscent from our more hairy past and is replaced by the use of adjustable, insulatory clothing.

Thermoregulatory mechanisms of skin in the cold (cold adaptation)

The skin is also an important *effector in maintaining thermal and fluid homeostasis*. In thermoregulation the skin carries out a major part of rapid autonomic thermophysiological responses (Table II) as the body adjusts the insulatory capacity of its surface. In normal conditions, over 90% of the total heat loss (radiation, conduction, convection and evaporation) occurs through or on the surface of the skin.

Circulatory reflexes

The arrangement and function of skin vasculature (Fig. 1) are the most important factors affecting thermal physiolo-

Table II. Thermoregulatory mechanisms in the cold.

Type of response	Specific response
Rapid autonomic responses of the skin	Circulatory reflexes - vasoconstriction (+Lewis vasodilatory waves) - opening of arteriovenous shunts Piloerection
Slow autonomic responses (development of cold tolerance)	Psychological adaptation Adaptation of central nervous system Cold acclimatization
Rapid and slow behavioural responses to cold	Avoidance of unnecessary cold exposure Protection by clothing and special outfit Cold habituation by learning, experience and tradition

gy of man. The skin circulation (about 450 ml/min in an adult in thermal comfort) is 10 times as much as is needed to supply the nutritive needs of the skin. This indicates that the primary function of the skin circulation concerns thermal balance, not nutrition. Skin blood flow may increase as much as 10-fold in maximal vasodilatation and decrease to almost a standstill level (30 ml/min) in extreme vasoconstriction (Elias & Jackson 1996). This means that the skin may either dissipate or conserve heat by its vasculatory regulation. Thermal conductivity of the skin in vasoconstricted state varies between 0.2-0.3 W/m²K and under vasodilatation 0.4-0.9 W/m²K.

The response of particularly the skin blood vessels by either vasodilatation or vasoconstriction makes evident that parts of the body are not truly homeothermic. In the cold the skin (and peripheral parts of the extremities) will adopt a new role as a "bark" or "shell". If the cold exposure lasts for a long time or is harsh enough, this "bark" will be rejected as unnecessary for the life of human being.

In special skin regions (especially in the fingers and toes), there is a vascular reaction called "hunting reflex of Lewis" to protect the tissues from rapid and permanent cold damage. This reflex works by opening the vasoconstricted vessels from time to time in a wave-like mode. After the skin temperature in hands and feet underlies +10°C, the arteriovenous anastomoses lose their vasoconstriction for a while to allow arterial blood to flush into the capillaries only to be followed by a new wave of vasoconstriction. This recurring phenomenon will maintain the life of skin in fingers and toes for tens of minutes.

Skin moisture

The moisture in the skin plays also an important role in thermal homeostasis of man. Skin is a large water reservoir that actively participates in the regulation of the fluid balance in the organism. Water enters the skin by ultrafiltration from capillaries. Although the principal function of the epidermal barrier is to prevent water from escaping from the body through the skin, there is a continuous passive outwards diffusion of some water across the skin layers. This leads both to humidification of stratum corneum and to thermal loss by evaporation of this "insensible" transepidermal water from the corneal surface. Naked adult rest-

ing in windless cabin at 27-29°C has an average transepidermal water loss (TEWL) of 400-500 g/day (Lamke et al. 1977).

When there is excess heat in the body, perspiration by 1.6 - 4.0 million eccrine sweat glands in the border between subcutis and dermis is excreted through the coil openings to the surface of the stratum corneum. The relatively high density of eccrine sweat glands in the head, upper body and upper extremities makes this area responsible for the majority of evaporative thermal loss in physical exertion. The sweat secretion may reach values as high as 3-4 kg/h for a short period in maximal physical performance in hot environment.

Whichever the origin of the evaporative water, TEWL or sweat, its evaporation causes an energy loss of 580 kcal/kg (672 Wh/kg) of water to the environment. The driving force of evaporation is the difference of absolute vapour pressure between the skin and the environment. Clothing diminishes the evaporative skin area and slows the evaporation capacity. The moisture is captured in the texture layers and affects the insulation of garments. The quality of clothing in use determines the behaviour and ultimate effect of water vapour inside the clothing.

As sweating may occur also in cold environment during physical exertion, its evaporation may cause a major loss of thermal energy in the cold, too. The role of the facial and head skin becomes more significant in this type of heat loss, as the body and extremities are usually covered by clothing.

ADVERSE EFFECTS OF THE COLD IN THE SKIN

“Normal” adverse effects

Uncomfortable skin sensations and functional deterioration

As the skin temperature gets lower the skin first perceives thermal discomfort, then cold and cold pain. At the same time the skin loses finer elements of tactile sensation, it feels numb and at the end of this development the skin does not sense even pain any more. Especially in distal parts of extremities, the cooling of deeper tissues, muscles, tendons and bones is adjoined with the cold induced functional problems in the skin. A gradual loss of muscular per-

formance together with weakened or lost tactile sensation leads to e.g. decreased manual dexterity, deterioration in physical performance and lowered working capacity.

Cold-related skin problems

Cold-related skin problems, e.g. winter xerosis of the hands and face together with dryness and chapping of the lips occur quite often during winter-time. This is at least partly due to the low atmospheric humidity both outdoors and indoors, where effective central-heating dries the air. The role of the cold in inducing skin dryness is obscure.

Local cold injuries and their sequelae

Local cold injuries may be divided into *non-freezing* and *freezing* injuries. Examples of the former group are immersion and trench foot, both skin problems developing as a reaction to a temperature of 0 - +10°C, often in combination with humid environment, immobility and constrictive clothing or foot-wear. It seems as if trench foot type of cold injuries were more frequent in British and US war statistics than in Nordic and Russian armies which have registered mainly classical frostbite injuries. This difference may be caused also by varying taxonomic traditions in separate nations.

The incidence of freezing injuries (frostbite) is quite high in countries with cold winters, as it has occurred in 44% (40% grade I and 12% more severe cold injuries) of Finnish conscripts already at the average age of 20 years. The frostbite incidence follows the geographical areas of cold exposure (Hassi *et al.* 1999). Mild frostbite ("frost-nip") injuries are most frequent, but their incidence can be found only in (self)reported questionnaires, not in clinical hospital or war statistics where deep frostbite injuries of extremities are predominant. The incidence of frostbite in different body locations varies according to the type and hardness of the cold exposure. Toes and feet are usually at the highest in the incidence list to be followed by ears, cheeks and nose, hands, etc. In Finnish reindeer herders the facial frostbite was ranked first in incidence forming 72% of all cold injury locations (Ervasti *et al.* 1991). The

reason was evident. Snowmobile riding caused a special cold exposure to the face.

Contact frostbite is a special type of freezing cold injury differing by its pathomechanism. The effect of the cold exposure by conductive heat loss in contact with a super-cold object, liquid (e.g. gasoline) or gas (e.g. evaporating liquid nitrogen) cools the contact area so rapidly, that there is no time for normal vasoconstrictive cold response. The skin freezes momentarily with crystallization of the intracellular fluid, and the cells die immediately. This mechanism is utilized in medical cryotherapy for warts and various skin tumours.

Abnormal skin responses to the cold

Vasoconstrictive hyperreactivity

There are many clinical entities with excessive or premature vasoconstrictive reaction of fingers and toes in the cold (Table III). These patients have cold (and often also moist) hands even in ordinary weather. They often use gloves, when other people do well without them, and their fingers turn pale or bluish when exposed to cold air or cool water. They feel discomfort, cold or even cold pain in fingers at temperatures at which the majority of people still feel themselves comfortable.

Cold urticaria

Cold urticaria is a group of hypersensitivity reaction types to the cold with cutaneous swellings, wheals and hives emerging after the skin has rewarmed after or during cold exposure (Neittaanmäki 1988). Systemic symptoms (vertigo, headache, tachycardia, dyspnea, or even anaphylactic shock) may emerge upon intense cold exposure. Cold ur-

Table III. Clinical entities with vasoconstrictive hyperreactivity in the cold.

-	Raynaud's syndrome (separate or as part of connective tissue or other systemic diseases)
-	white finger syndrome after prolonged use of vibrating tools
-	vasoconstrictive hyperreactivity to the cold after previous frostbite
-	acrocyanosis
-	erythrocyanosis, etc.

ticaria occurs quite rarely and is a sign of individual aberrant reactivity. It is related to other physical urticarias and responds often quite inadequately to medication with H₁-antihistamines. This disease invalidizes sometimes the patient heavily, as even a short visit outdoors in winter-time may cause severe symptoms. Cold urticaria disappears often after several years of disturbance. In its treatment, avoidance of cold exposure is the mainstay. Antihistamines, doxepin, UVB-therapy and desensitization have gained partial success.

Chilblains (perniosis)

Chilblains are localized, erythematous, swollen, tender and itching inflammatory lesions of the subcutaneous tissue and dermis, present often in acral extremities as an abnormal reaction to non-freezing cold temperature (at or below 16°C) in combination with high humidity. Chilblains occur most often in cold sensitive children and women with acrocyanosis and/or erythrocyanosis. The lesions are found usually in a bilateral, symmetrical distribution on the fingers and toes, heels, lower legs, thighs and face. Their course is typically self-limiting in about three weeks (perniosis acuta), although chronic cases also occur. Recurrence each winter for a few years is common, but complete recovery is usual. Prophylaxis with warm housing and adequate clothing is more important than different modalities of treatment (Dover *et al.* 1996, Dowd 1998).

COMMON DERMATOSES AND THE COLD

Very little information is available on the cold-induced differences in the incidence and prevalence of common dermatoses. The geographical and climatic variations sometimes found may be influenced by racial differences and many other parameters. Solar UV-radiation acts as an anti-inflammatory agent and causes seasonal differences in the severity of several dermatoses, such as atopic and seborrhoeic dermatitis, psoriasis and acne.

The problems of dry skin, including atopic dermatitis and psoriasis, are supposed to be more severe during the cold season. The effect of outdoor or indoor dry air can not, however, be clearly separated from the effect of the

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coldness.

The effect of the cold on the immunological functions on the skin has not been studied in detail. It is probable, that already the lowered circulation in the skin must disturb the capacity of the skin for immunological reactions. One aspect of this effect was found in a study of Halkier-Sörensen *et al.* 1995. Workers in fish-processing industry did not get hand dermatitis from long exposition to fish-liquid and water as long as their hands were cold, but hand eczema developed soon after they got their hands warm again. This was explained as a change in barrier function caused by the temperature. The study suggests that antigen-presenting to the immunologically active cells in living epidermis may be diminished by the cold. Recent positive experiments to treat rheumatic arthritis with exposures to very low temperature indicate an anti-inflammatory action by the cold.

Coldness (and coolness) has an antipruritic effect. Topical agents (e.g. ethanol, menthol, even water after showering) which evaporate easily cool the skin surface and have been traditionally used e.g. in urticarial pruritus, pruritus of healing varicella, etc. to relieve the unpleasant itch.

In cryotherapy, severe topical cold (often liquid nitrogen) is used for destroying different benign, premalignant and malignant skin tumours, such as verrucae, seborrhoic keratoses, basaliomas, etc. or cosmetically disturbing malformations.

Lehmuskallio Eero

Santahamina Health Center

POB 6, FIN-00861 Helsinki, Finland

lehmuska@nettilinja.fi