

Thermophysical Effects of Ointments in Cold: An Experimental Study with a Skin Model

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The use of emollients on the face is a traditional way to protect the skin against cold injuries in cold climate countries like Finland, but their preventive effect against frostbite has been questioned. The purpose of this investigation was to define the thermal insulation and occlusivity of ointments in cold by using a skin model with a sweating hot plate. The properties of four different emollients were studied in both dry and humid conditions simulating transepidermal water loss, sweating, and a combination of sweating and drying. The thermal insulation of ointments applied on a dry surface was minimal. Evaporation of water from an oil-in-water cream caused significant cooling for 40 min after its application. The diffusion of water through the applied emollients changed their thermal effects depending on their composition and on the amount of water. Low input of water increased and high input diminished slightly the thermal resistance of ointments. The minimal or even negative thermal insulation of emollients in varying conditions gives them at best only a negligible and at worst a disadvantageous physical effect against cold. Key words: emollients; frostbite; cold injury; prevention; protection.

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Outdoor work and winter sports are common risk situations for frostbite. Avoiding extreme cold exposure and wearing protective clothing are the most important measures in the protection of skin against cold injuries. Faces and earlobes are seldom covered by clothing, and therefore suffer quite often from mild frostbite (1–3). Mostly children and women use waterless ointments to protect their faces against cold. Some armies recommend their use in winter manoeuvres (4). However, recent epidemiological data indicate that the use of protective ointments in cold is a considerable risk factor for frostbite of the face and ears (3).

Water content of the keratin layer has a significant role in the living skin and its thermal behaviour. Transepidermal water loss (TEWL) and perspiration cause emission of body thermal energy and cool the skin. Occlusion by emollients can prevent the evaporation and cause accumulation of water under or in the ointment. The water in at least some oil-in-water emulsions evaporates quite freely (5). The total thermal effect of a cream or ointment on the skin in cold has not been studied. People living and working in cold environments would benefit from solving this contradiction between tradition and epidemiological data. The aim of this experimental study was to investigate the thermal resistance (insulation) and occlusivity of different non-medicated ointments by using a self-constructed skin model in a climatic box.

MATERIAL AND METHODS

Equipment

For years, the Oulu Regional Institute of Occupational Health has used a self-constructed plane skin model with a sweating hot plate in a climatic box for routine measuring of thermal resistance of clothing material. The equipment fulfils the demands of Finnish and international standards (SFS 5681 (6) and ISO DIS 11092 (7)), and its properties have been presented in detail in an earlier report (8). The structure of the device is presented in Fig. 1.

TEWL and perspiration were simulated in this sweating skin model by regulating the amount of water spread through several channels on the metal plate under a filter paper and a semipermeable membrane, on which the emollients were applied. The filter paper was needed in humid and wet tests to ensure an even diffusion of water from the pipe openings. A constant 1 m/s airflow parallel to the surface of the skin model flushed the evaporating humidity away.

The temperature of the skin model was 20°C in most tests, corresponding approximately to facial skin temperature in cold weather, and 25°C in dynamic tests. The temperature of the ambient air was –15°C. The humidity content of the ambient air in the cold box was kept constant (relative humidity 30 ± 5%) by condensation of the evaporated water on the cold metal surfaces of the device outside of the measurement area. The tests were continued for 60–240 min, depending on the time needed for stabilizing the power level.

Ointments

Four non-medicated emollients, A, B, C and D (Table I), differing considerably in their water and lipid content, were used in tests. Emollient A was an oil-in-water (o/w) emulsion cream, emollient B a water-in-oil (w/o) emulsion cream, while C and D were different waterless ointments.

The emollients (10 g/0.0511 m² ~ 196 g/m²) were applied on a synthetic semi-permeable membrane (Goretex[®], thickness 0.2 mm, water vapour resistance 4 m² Pa/W). The thickness of an ointment layer was chosen to exceed clearly an ordinary application of 9.9–24.2 g/m² (9, 10) on the skin to aid detection of any insulating effect. A 10-fold layer of ointment D was compared with the thinner application in dry tests. The ointments were applied at room temperature (20°C, relative humidity 65%). A few minutes after application, the membrane was taped on the skin model in the climatic box with a plastic supporter. The registration of parameters was started immediately.

Parameters

The consumption of electric heating power (P, in watts) used to keep the skin model temperature constant was measured continuously. In wet tests, the input of water (g/m²/h) was regulated and registered. The ointments, with the membrane and its support, were weighed before and after tests to measure the amount of water trapped within, and for calculation of the evaporated water from and/or through them. The emollient surface was studied visually before and after the tests to detect any macroscopic change caused by the experiment. The temperatures of the skin model and the ambient air in the climate box were continuously monitored.

The thermal resistance (R_{ct}, m²°C/W) of ointments can be calculated by comparing the heating power level (P) of the equipment with bare membrane with the power required when one of the emollients was applied to it (8). The following formula defines the dependence of

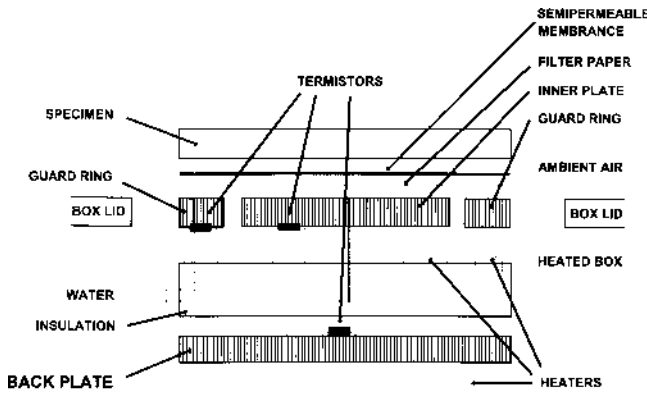


Fig. 1. The structure of the sweating skin model.

thermal resistance (R_{ct}) on other physical values:

$$R_{ct} = \frac{T_{sk} - T_a}{P} \times A$$

Where T_{sk} = "skin" temperature ($^{\circ}\text{C}$), T_a = temperature of the ambient air ($^{\circ}\text{C}$), P = heat power (W) and A = "skin" area tested (m^2).

Tests

Dry tests. The effect of test ointments A–D on the heating power (P) was compared with the results achieved with an untreated Goretex[®] membrane. The effect of the 10-fold thicker layer of ointment D was also measured. Dry tests were continued for at least 60 min. In addition, 4 TEWL measurements using an Evaporimeter[®] EPI (ServoMed AB, Sweden) were performed according to international guidelines (11) at room temperature with both o/w cream A and w/o cream B on the volar antebraial skin of 4 voluntary test subjects, in order to study the timing of the evaporation of water from the creams in warm surroundings.

Tests with water input. The low input of water was adjusted to 30 g/ m^2/h , about 5 g during each test. In high water input tests, water diffused at a rate of 100 g/ m^2/h , about 16 g during each test. Both series of tests lasted 180 min.

In dynamic tests, the first phase with high water input (100 g/ m^2/h for 120 min) was followed immediately by a drying phase (water input totally stopped) for another 120 min. These tests were included to simulate a working situation in cold: first "medium heavy work" causing perspiration, then "inactive rest" with drying up of the skin. In contrast to the other tests, the temperature of the skin model was adjusted to 25 $^{\circ}\text{C}$ to simulate the higher temperature of human facial skin during physical activity.

Precision of results

In repeatability tests with semipermeable membranes and white petrolatum, the margin of error of the apparatus was <1% for both. When applying emulsion creams and using water input, the distribution of

Table I. Properties of test ointments

Quality	Water content (%)	Lipid content	Trademark/Manufacturer
A. Emulsion cream o/w	65	Vegetable oils	Aqualan L [®] /Orion Pharma, Espoo
B. Emulsion cream w/o	30	White beeswax, liquid paraffin, white petrolatum	Neribase [®] /Leiras Co., Turku
C. Lipogel	0	Long-chain hydrocarbons	Ceridal [®] /Rhône-Poulenc Rorer A/S, Birkerød
D. White petrolatum	0	Vaselin. album	Manufactured <i>ad modum</i> Pharmaca Nordica in local pharmacy, Oulu

Table II. Thermal resistance (R_{ct}) of test emollients and evaporation of their water in cold. Dry tests

Ointment	Weight of ointment (g)	H ₂ O evaporated (%)	Energy of evaporation (W/h)	R_{ct} ($\text{m}^2\text{C}/\text{W}$)
None	0	0	0	–
A	10.8	59	3.3	0.001
B	10.8	0	0	0.001
C	11.0	0	0	0.001
D	10.5	0	0	0.001
D × 10*	100.1	0	0	0.014

Temperature of artificial skin 20 $^{\circ}\text{C}$, ambient temperature –15 $^{\circ}\text{C}$, measurement area 0.0511 m^2 , no water input, wind 1 m/s. Emollients A–D; see Table I.

* D × 10 = 10-fold layer of ointment D.

results in repeated tests was wider. The maximal error in the repeatability was always under 10%.

RESULTS

Dry tests

The results of the dry tests are shown in Table II. Cream A lost energy by evaporating almost all of its original water content in about 40 min (Fig. 2). During this period, the amount of extra energy needed was 11.9 kJ (3.3 W/h). At its highest in the first 10 min, the heating power required by cream A was 20–30% higher than that of the other emollients. At room temperature, water evaporation from cream A in TEWL measurements was faster, taking 20–25 min. Emollient B held most of its water in both cold and warm surroundings. After evaporation of the water from cream A, all emollients had a similar, very low thermal resistance of 0.001 $\text{m}^2\text{C}/\text{W}$ in cold. The thermal resistance of the 10-fold layer of D was 0.014 $\text{m}^2\text{C}/\text{W}$, in accordance with its thickness.

Tests with water input

The effect of emollients on water kinetics in different tests is shown in Table III. The input water penetrated the untreated membrane fairly freely in all tests. Cream A lost its own water and also let the input water diffuse easily through it. Emollient B lost $\frac{1}{4}$ – $\frac{1}{3}$ of the input water. Neither of the waterless ointments C and D let the water diffuse through them in low water input tests. In high water input tests, emollients B, C and D trapped most of the input water under and in them. This was

Table III. Occlusivity on input water and loss of own water by test emollients in dry, humid, wet and dynamic tests in the sweating skin model. Percentages are calculated from the total amount of input water during the test, in dry tests from the mass of the emollient

Ointment	Dry tests		Tests with low input of water			Tests with high input of water			Dynamic tests of water		
	E		E	A	t (min)	E	A	t (min)	E	A	t (min)
	%	t (min)	%	%	t (min)	%	%	t (min)	%	%	t (min)
None	0	100	91	6	180	89	8	80	97	2	120+120
A*	59	70	136	-43**	180	90	4	180	127	-30**	120+120
B*	0	70	32	61	180	24	70	180	35	65	120+120
C	0	70	3	92	180	28	67	180	18	78	120+120
D	0	70	2	95	180	12	85	180	9	88	120+120

E=H₂O evaporated. A=H₂O absorbed.

t=time period of measurements. Emollients A–D (see Table I).

* Results may include both input and own water. ** Negative results=loss of own water content.

also visually noted as water droplets under these particular ointments.

For over an hour, when the filter paper and emollients got wet in low water input tests, the insulating properties of emollients B, C and D increased a little. After stabilization of power consumption in 120–130 min, the thermal resistances of all emollients were somewhat higher ($R_{ct}=0.004-0.013 \text{ m}^2\text{C/W}$) than in dry tests.

The thermal resistance of all four emollients diminished (increase of 1.3–3.8 W in power) after saturation of the system after 60 min during the high input of water, and did not reach a totally stabilized state even after 180 min.

The results of dynamic tests are shown in Fig. 3. The thermal resistance of all ointments diminished again during the high water input phase following the results achieved in the former test series. When the input of water was stopped, there was a rapid 20–26% increase in thermal resistance (5.3–6.9 W decrease in power), increasing somewhat more during the drying phase. The untreated membrane behaved likewise. The thermal resistance of all emollients was minimal at the end of both the wet (0.001–0.003 $\text{m}^2\text{C/W}$) and dry phases (–0.001––0.006 $\text{m}^2\text{C/W}$).

DISCUSSION

Our device has proved its value in testing the thermal properties of winter clothing material (8). It can simulate normal skin functions (e.g. TEWL and perspiration) in varying conditions. We used a technique where the surface of the skin model was protected from the tested ointment by applying it to a semi-permeable membrane taped on the model. In water input tests, a sheet of filter paper was added to achieve even diffusion of water. Therefore, the power values in dry tests and tests with water input cannot be correlated.

TEWL has a marked role in evaporative thermal loss. It is influenced by ambient air and skin temperatures, region of skin, age, use of emollients and surfactants and pathological conditions of the skin, being high e.g. in eczematous and irritated skin (12). In addition, interindividual differences can be significant. Total daily TEWL of a resting naked adult at room temperature has been estimated at 400 ml (13). The average body TEWL calculated from this value is about 9 g/m²/h. Evaporimeter measurements with resting volunteers have

given TEWL values of 4–8 g/m²/h for volar antebrachial healthy skin (14). TEWL on the forehead is normally approximately 16.5 g/m²/h (15). The low water input (30 g/m²/h) used in our tests was thus somewhat higher than TEWL from human forehead skin. The high water input in wet tests (100 g/m²/h) was estimated to be near the mean water loss from the skin due to perspiration during moderate physical work.

The low relative and absolute ambient humidity, common in natural cold climates, increases the diffusion and evaporation gradients of water out of the skin. Emollients may occlude the evaporation of water; their water content has its own evaporative characteristics. Accumulation of water under occlusive ointment may influence the freezing of the skin. It has been shown that the freezing point of the stratum corneum becomes higher with increased water content (16). In our test procedure, freezing of the artificial skin was impossible because the sur-

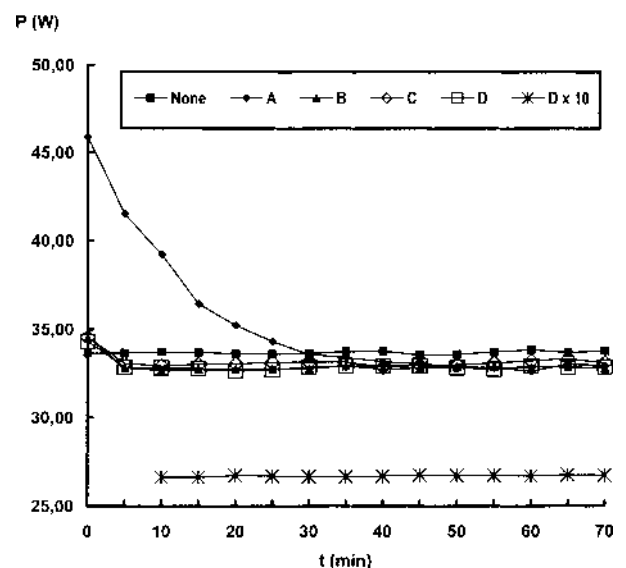


Fig. 2. The electric heating power (P) needed to keep temperature of the skin model constant, when test ointments A–D were applied on it in dry tests. Temperature of artificial skin 20°C, ambient temperature –15°C, measurement area 0.0511 m². No water input, wind 1 m/s. Emollients A–D (see Table I). D×10=10-fold layer of ointment D.

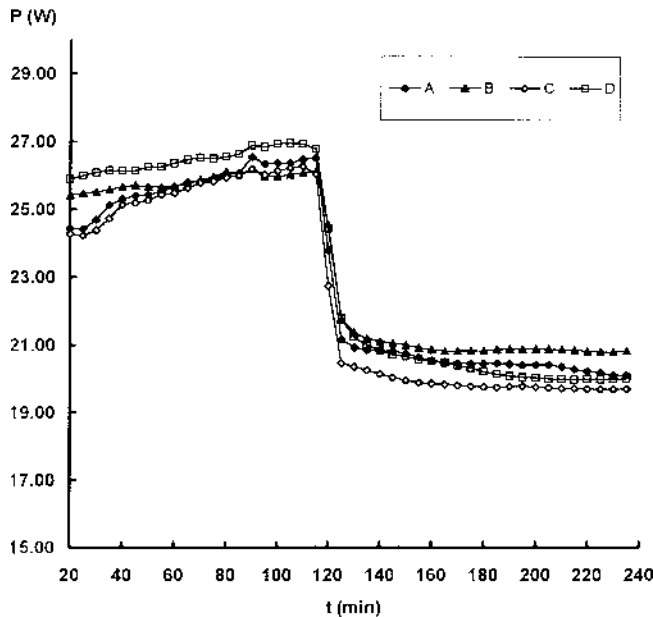


Fig. 3. The electric heating power (P) needed to keep the temperature of the skin model constant, when test ointments A–D were applied on it in dynamic tests. Temperature of artificial skin 25°C, ambient temperature –15°C, measurement area 0.0511 m². Water input 100 ml/m²/h for 120 min, then totally stopped, wind 1 m/s. Emollients A–D (see Table I).

face of the sweating skin model was kept at a constant, warm temperature.

After the evaporation of water from the o/w cream itself, all emollients studied had very low thermal resistance in cold conditions on a dry surface, with no distinctive inter-emollient variation. The insulative effect of a much thicker layer than is normally applied was very low: less than $\frac{1}{10}$ of a dry, thin, silky face mask, with R_{ct} of 0.02 m²°C/W (17).

In conditions simulating normal skin during rest and in work, the thermal resistance of emollients was influenced by the amount of water diffusing into and evaporating from them. Small amounts of water increased the thermal insulation of greasy ointments, probably by being occluded under or absorbed into them. Increased input of water caused “spilling over” of the water and cooling of the skin model. In natural conditions, however, where the skin is sweating in cold surroundings, increased circulation in the skin can be expected to eliminate the risk of frostbite.

This *in vitro* study was designed to investigate only the thermophysical (insulative and occlusive) actions of emollients. Their total thermal effects *in vivo* include, in addition, possible interactions with the dermal vasculature and with biochemical contents of skin layers, both of which can affect the freezing temperature of the skin. Our results, showing that the thermal insulation caused by the ointments tested was at best negligible and at worst disadvantageous, did not give thorough support to the epidemiological observation that the use of ointments in cold forms a considerable risk factor for frostbite of the face and ears.

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