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Thermal responses during and after whole-body cryotherapy (−110°C)

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Abstract

The effect of whole-body cryotherapy (WBC) on rectal and skin temperatures was measured in healthy subjects before, during and after WBC exposure. WBC did not cause any significant change in rectal temperature. The lowest local skin temperatures were recorded in the forearm, 5.2 (2.8)°C, and in the calf, 5.3 (3.0)°C. WBC involves no risk for frostbites. After WBC, all skin temperatures recovered rapidly, indicating that the analgetic effects of WBC only occur during a limited period after the exposure.

Keywords: Whole-body cryotherapy (−110°C); Cryotherapy; Skin temperature; Rectal temperature; Thermal sensation

1. Introduction

Whole-body cryotherapy (WBC) is one mode of cold therapy, during which patients are exposed to very cold air (−110°C) in minimal clothing. It is primarily used to alleviate inflammation and pain in, for example, arthritis (Fricke, 1989; Samborski et al., 1992a; Wichmann and Fricke, 1997) and osteoarthritis (Metzger et al., 2000). It is also used for pain relief in fibromyalgia (Samborski et al., 1992b). In clinics, WBC has been used for to reduce spasticity in some neurological diseases. It may further have a sedative effect on psoriasis and neurodermatitis (Fricke, 1989). Experience has shown that lung function has improved in asthmatics after WBC (Fricke, 1989). It is believed to influence positively patients' mental state, resulting in an improvement of mood, relaxation, refreshment, comfort and euphoria (Rymaszewska et al., 2000). In Poland, WBC has been used in sports medicine to treat injuries and overuse syndromes (Zimmer and Zagrobelny, unpublished data, 2000).

The duration of WBC usually varies from 1 to 3 min. Patients wear bathing suits with their ears, hands and feet covered. A surgical mask is worn to protect the face. During a cold exposure, the thermoregulatory system attempts to maintain a constant core temperature (around 37°C) by means of skin vasoconstriction and by increasing the metabolic rate through shivering. During a severe cold exposure, such as WBC, skin temperature decreases rapidly due to vasoconstriction and direct skin cooling, most profoundly in the extremities. Local skin temperatures (e.g. fingers, toes) can be used as "safety limits" upon exposure to cold environments (Parsons, 2003).

Even though WBC is widely used in several countries and its beneficial effects have been recognised in clinics, only very limited data are available on actual body temperatures. Frostbites might be anticipated to occur when the human body is exposed to such a cold ambient temperature as −110°C. However, neither the literature nor clinical experience has reported frostbites during WBC. Taghawinejad et al. (1989) registered a slight

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decrease (0.38°C) in oral temperature after WBC (−100°C, 90 s).

The present study is part of a project undertaken to ensure the safety of WBC for patients and personnel. This study was designed to evaluate the effects of WBC (−110°C, 2 min) and the following recovery period on rectal and skin temperatures.

2. Methods and materials

2.1. Subjects

Nine sedentary and healthy females and one male agreed to participate after having been informed of the study requirements. Their mean age (mean ± SD) was 48 ± 9 years, height 163 ± 8 cm, weight 67 ± 10 kg and BMI 25 ± 3. None were on medication. Before the study, they had not practised regularly either WBC or winter swimming. The experimental protocol and procedures were approved by the Ethical Committee of the Hospital District.

2.2. Thermal exposure and temperature measurements

WBC is a specially built, temperature-controlled unit (Zimmer Elektromedizin), which consists of three chambers. Each subject was exposed to WBC (–110°C) for 2 min. The subjects passed through the first pre-chamber (−10°C) and the second pre-chamber (−60°C) before coming into the therapy-chamber. The actual temperature of the therapy-chamber was –110 to 113°C. The air in the therapy-chamber is dry and clear. The subjects were wearing a bathing suit, surgical mask, cap, gloves, socks and shoes. While in the therapy-chamber, the subjects were advised to slightly move their fingers and legs to avoid tension. During the 30-min recovery period, the subjects sat at room temperature (24°C) and were allowed to dress themselves as warmly as they wished to avoid a subjective sensation of cold. The thermal sensation was inquired ($n = 6$) before WBC, immediately after it and 10, 20 and 30 min after WBC, using a standard rating scale (ISO 10551) (Table 1). The instrumentation of the subjects lasted for approximately 20 min, which was considered an adequate stabilization period. At the end of the stabilization period, all subjects considered their thermal state to be neutral (0) on the ISO scale.

Rectal temperature (10 cm depth) (Yellow Springs Instrument, YSI 400 series) and local skin temperatures from nine sites (forehead, chest, lower back, upper arm, extensor side of lower arm, back of hand, front thigh, calf and foot) (Fig. 1) were recorded at 5 s intervals with a data logger (Squirrel 1200, Grant, UK) during WBC and the recovery period. The data logger was kept in a foam-filled bag, the leads were well protected, and the probes were taped (Durapore™ 3M) to the skin. Before the experiment, many pilot tests were done to avoid cooling of the probes. Previously, it has been found that if the temperature probes are in direct contact with cold air, they may yield a lower temperature reading compared to a similar probe (same measuring site) that is well protected, e.g. carefully taped to the skin. Therefore, extra precautions were taken to ensure maximal insulation of the probes by taping them well to the skin. The mean skin temperature was calculated by weighting the nine local skin temperatures by representative skin areas (Mitchell and Wyndham, 1969). The reference values for rectal temperature and

Table 1
Thermal sensation scale (ISO 10551) "How do you feel (at this precise moment)?"

Pole	Degree	Wording
Hot	+4	Very hot
	+3	Hot
	+2	Warm
	+1	Slightly warm
Indifference	0	Neutral
Cold	−1	Slightly cool
	−2	Cool
	−3	Cold
	−4	Very cold

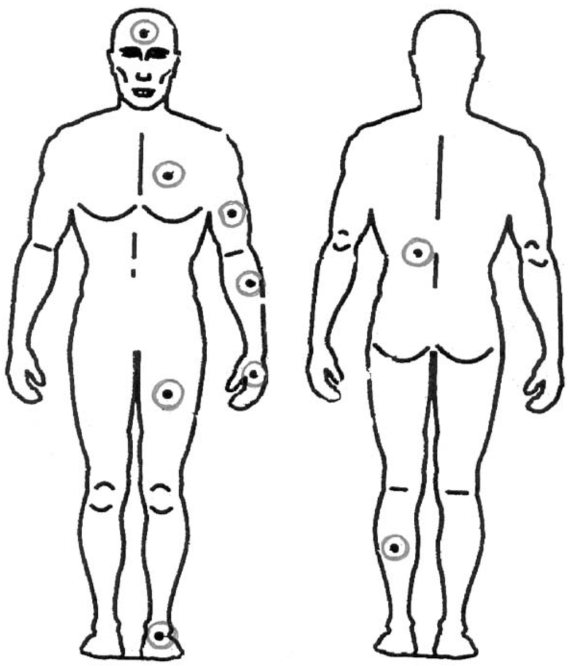

Fig. 1. Settings of the temperature probes.

skin temperature are the values measured 5 min before the beginning of WBC. During recovery, the difference between the reference value and the temperature measured at 30 min was analysed.

2.3. Statistics

The temperatures are reported as means at 1 min intervals before WBC, at 5 s intervals during WBC and until 5 min after WBC, at 1 min intervals from 5 to 30 min after WBC. The mean changes of temperatures (95% confidence interval) were calculated from the reference values to temperatures measured at 30 min.

3. Results

The mean rectal temperature did not change during the 2 min of WBC, but after WBC, there was a slight continuous decrease in rectal temperature (Fig. 2).

All skin temperatures decreased very rapidly during WBC (Figs. 3–7). The lowest skin temperatures (Table 2) were observed on the forearm and on the calf. The highest skin temperatures were recorded on the palm and on the foot, which were protected (gloves and socks). On unprotected areas, the highest skin temperature was recorded on the forehead. Immediately after WBC, all skin temperatures increased very rapidly for a couple of minutes, after which the increase was slower (Figs. 3–7). None of the temperatures reached the reference values during recovery (Table 2). The forehead skin temperature reached a plateau after 15 min, the upper arm values after 26 min, the lower arm values after 25 min and the foot values after 12 min. The values recorded at the other sites did not reach a plateau.

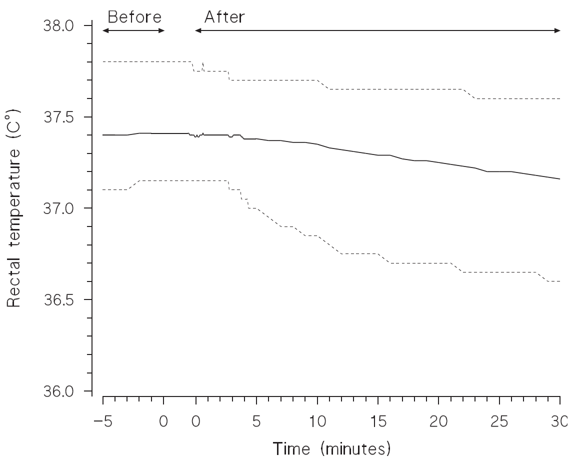

Fig. 2. Rectal temperature before (5 min), during (2 min) and after (30 min) WBC. Five minutes before WBC = −5 to 0, during (2 min) WBC = 0 to 0 and 30 min after WBC = 0–30. The values are means (SD) of 10 subjects.

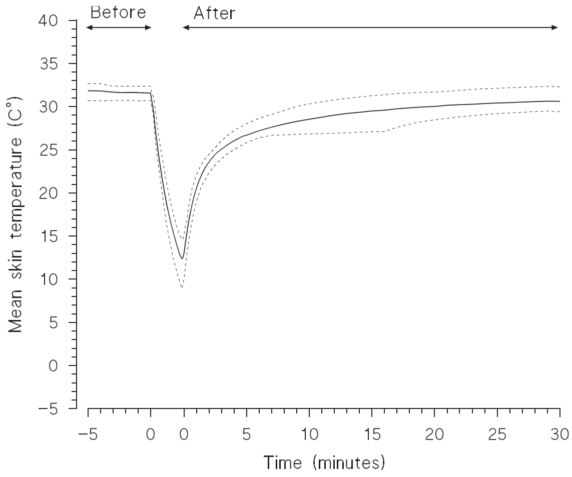

Fig. 3. Mean skin temperature before (5 min), during (2 min) and after (30 min) WBC. Five minutes before WBC = −5 to 0, during (2 min) WBC = 0–0 and 30 min after WBC = 0–30. The values are means (SD) of 10 subjects.

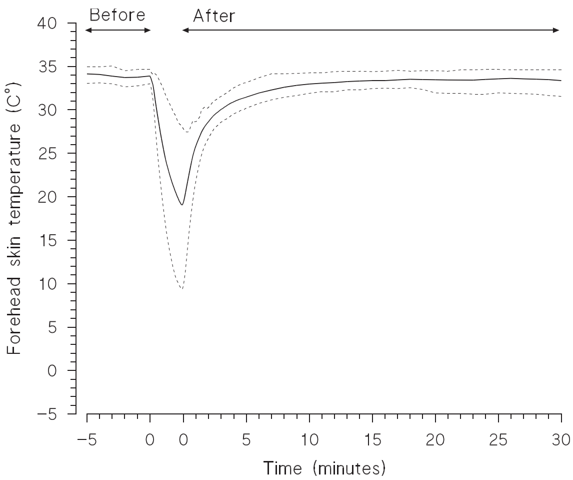

Fig. 4. Forehead skin temperature before (5 min), during (2 min) and after (30 min) WBC. Five minutes before WBC = −5 to 0, during (2 min) WBC = 0–0 and 30 min after WBC = 0–30. The values are means (SD) of 10 subjects.

The subjects thermal sensation immediately after WBC varied from cold (−3) to slightly cool (−1). During the recovery period at 10 min, they considered their thermal state to be neutral (0), this sensation lasted till the end of the recovery period. None reported pain during and after WBC.

4. Discussion

The present results showed that skin temperatures decreased very rapidly during WBC, but remained at

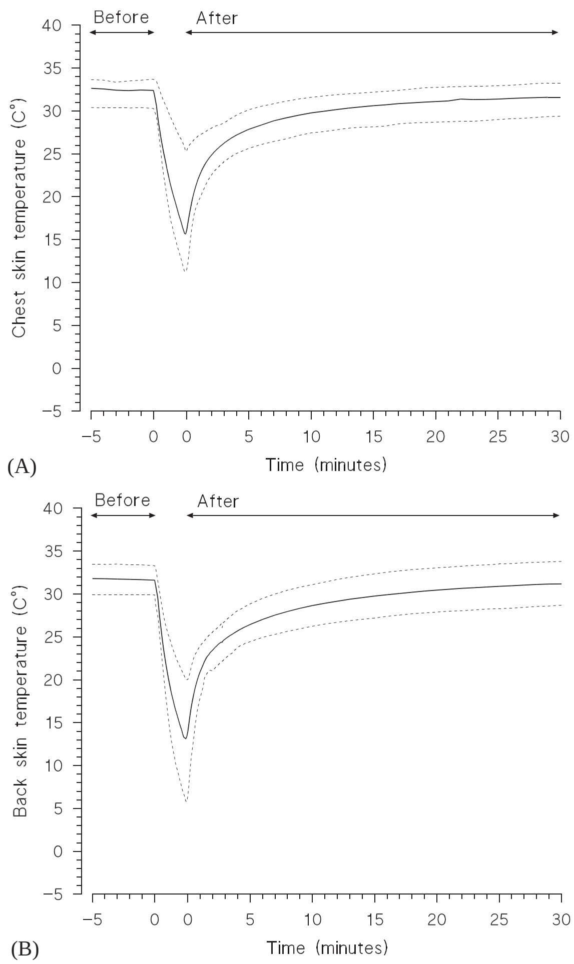

Fig. 5. Chest (A) and back (B) skin temperatures before (5 min), during (2 min) and after (30 min) WBC. Five minutes before WBC = −5 to 0, during (2 min) WBC = 0–0 and 30 min after WBC = 0–30. The values are means (SD) of nine subjects.

such a high level that there was no risk for frostbites. Immediately after WBC, skin temperatures increased very rapidly. The effects of WBC on rectal temperature were minimal.

Rectal temperature was unaffected by cooling, probably due to the short duration of WBC. At the beginning of the recovery period, we observed a slight, but continuous decrease in rectal temperature. This is a well-known phenomenon, called afterdrop, defined as continued cooling following the removal of cold stress. This means that two processes, called convective and conductive afterdrop, may operate simultaneously or separately (Steinman and Hayward, 1995). The convective afterdrop is thought to result from the venous return of cooler blood from the peripheral regions, particularly the extremities (Steinman and Hayward, 1995; Hayward et al., 1984). The conductive afterdrop

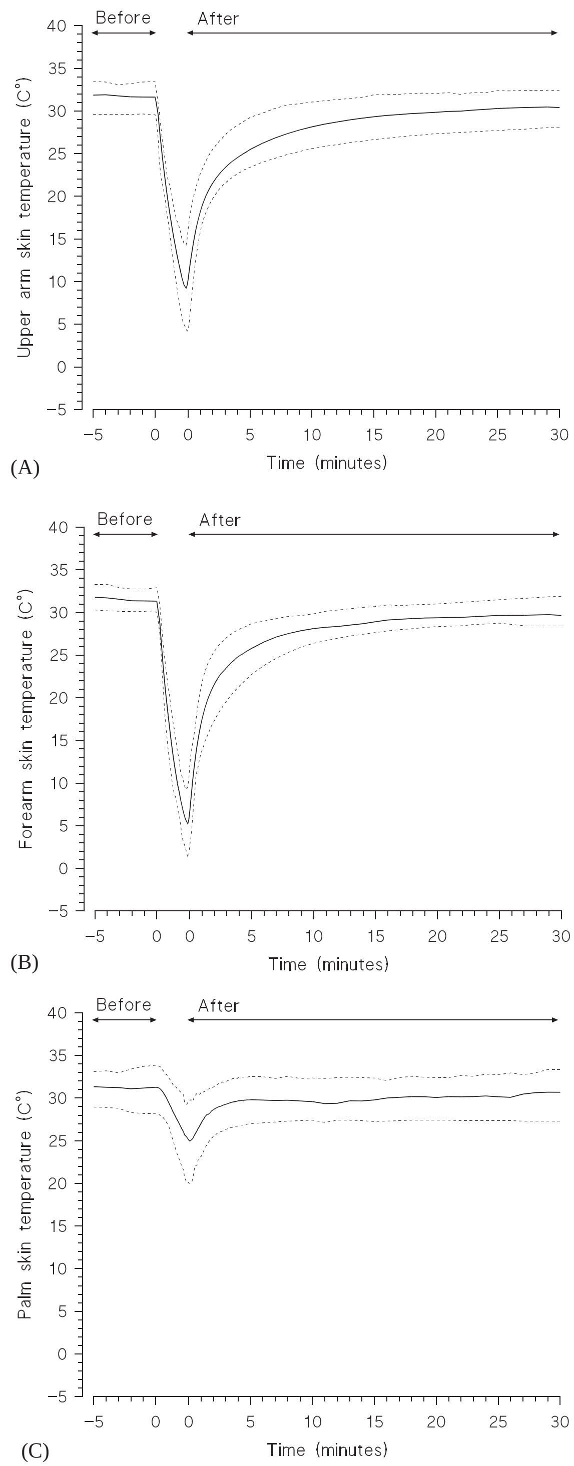

Fig. 6. Upper arm (A), forearm (B) and palm (C) skin temperatures before (5 min), during (2 min) and after (30 min) WBC. Five minutes before WBC = −5 to 0, during (2 min) WBC = 0–0 and 30 min after WBC = 0–30. The upper arm and palm skin temperature values are means (SD) of 10 subjects, and the forearm skin temperature values are means (SD) of nine subjects.

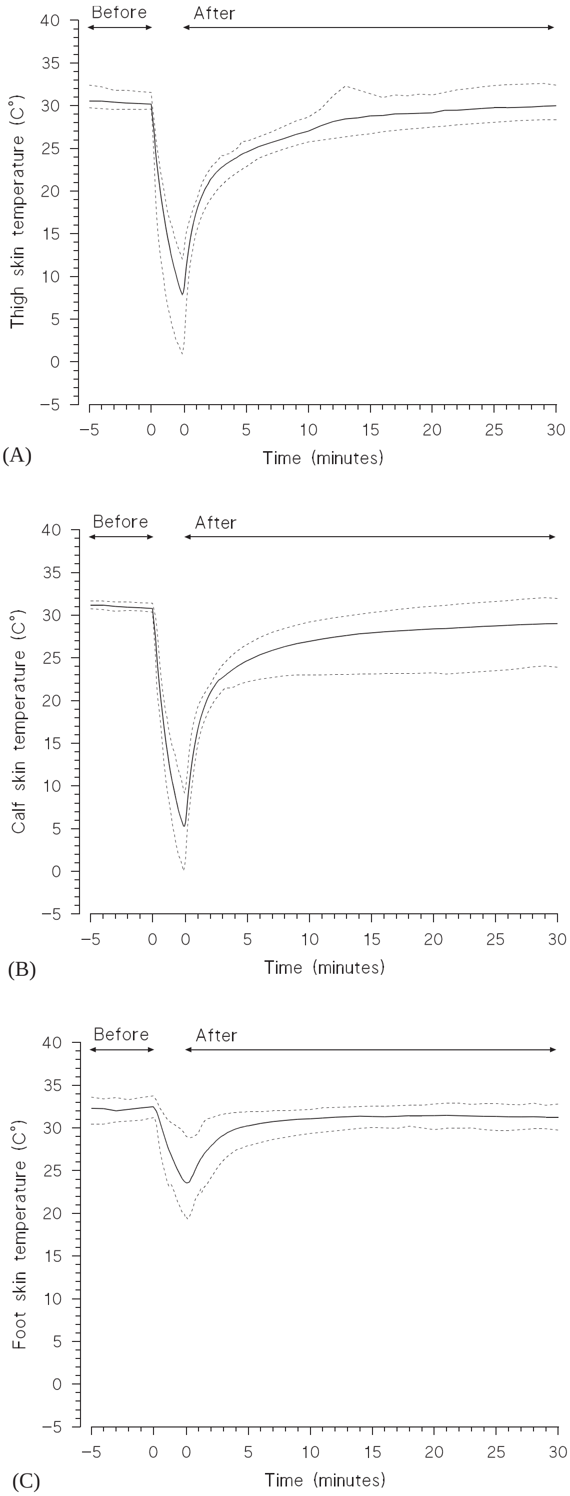

Fig. 7. Thigh (A), calf (B) and foot (C) skin temperatures before (5 min), during (2 min) and after (30 min) WBC. Five minutes before WBC = –5 to 0, during (2 min) WBC = 0–0 and 30 min after WBC = 0–30. The values are means (SD) of nine subjects.

refers to the conduction of heat down a thermal gradient from a relatively warm core to a relatively cold periphery (Steinman and Hayward, 1995; Webb, 1986). This type of afterdrop is thought to be particularly prevalent in the rectal region, because of the surrounding large mass of cooler adipose and musculoskeletal tissue (Steinman and Hayward, 1995). Rectal temperature was not restored during the recovery period because the subjects were inactive. However, rectal temperature remained within the thermoneutral zone.

Scant data are available about thermal responses to WBC. Taghawinejad et al. (1989) found a slight decrease of 0.38°C in oral temperature, indicating that 90 s at −100°C does not affect core temperature. They did not mention any values before or after WBC. When oral temperature is used, the ambient conditions may have a great influence on the result, whereas rectal temperature measurements are more reliable. However, the results of the aforesaid study agreed with our results concerning rectal temperature.

Skin temperatures decreased very rapidly, especially in unprotected extremities, but they also increased rapidly within a couple of min after WBC. Because the literature contains no reported data on skin temperatures during WBC, we can only compare our results with studies on local cold therapy. The comparison indicates that WBC is a more intensive exposure than local therapies (Table 3). The most effective local cold therapy of the lower extremities is ice massage. In our study, the calf skin temperature decreased from 31.2°C to 5.3°C. The drop of skin temperature in 2 min during WBC was of approximately the same magnitude as that achieved by Bugaj (1975) with ice massage in 10 min.

It is important to note the large variation in the individual responses to cold in this study. Chesterton et al. (2002) found the same phenomenon in their study with local cold therapy. This variation is due to such factors as body size, fitness level, amount of subcutaneous fat and gender. Large body size and good aerobic capacity slow down the rate of body cooling. Leaner subjects have higher skin temperatures and lower muscle temperatures after whole-body cooling than subjects with more subcutaneous fat (Buskirk and Kollias, 1969; Oksa et al., 1993; Keatinge, 1961). Females usually have lower cold tolerance compared to men because of their lower aerobic capacity. On the other hand, they have more subcutaneous fat, which serves as a thermal insulator. Chesterton et al. (2002) questioned whether generic application protocols and times always ensure clinically effective cooling of tissue. This should also be considered when using WBC as a clinical treatment method.

The attainment of a clinically optimal physiologic response by using cryotherapy requires the skin tissue to be cooled effectively. A number of studies have been performed to establish the critical level of tissue cooling

Table 2
Rectal, mean skin and local skin temperatures 5 min before WBC (reference value), the lowest value recorded during WBC and the change from the reference value to 30 min (recovery)[a]

Region	Reference value (°C)	Lowest value (°C) during WBC	Change (°C) from reference value to 30 min mean (95% CI)
Rectal	37.4 (0.25)	37.4 (0.24)	−0.24 (−0.39 to −0.10)
Mean skin temperature	31.8 (0.65)	12.4 (1.8)	−1.2 (−1.8 to −0.68)
Forehead	34.1 (0.65)	19.1 (5.6)	−0.78 (−1.3 to −0.28)
Chest	32.6 (1.1)	15.7 (4.4)	−1.0 (−1.7 to −0.43)
Back	31.8 (1.3)	13.1 (4.1)	−0.62 (−1.4 to 0.17)
Upper arm	31.9 (1.2)	9.2 (2.9)	−1.5 (−2.0 to −0.91)
Forearm	31.8 (0.88)	5.2 (2.8)	−2.1 (−2.7 to −1.6)
Palm	31.3 (1.3)	25.3 (2.4)	−0.66 (−1.9 to 0.63)
Thigh	30.5 (0.87)	7.9 (3.9)	−0.54 (−1.4 to 0.34)
Calf	31.2 (0.35)	5.3 (3.0)	−2.2 (−3.7 to −0.64)
Foot	32.3 (0.97)	23.6 (3.4)	−1.0 (−1.8 to −0.26)

[a] The values are means (SD) of 10 subjects, except those for the chest, back, forearm, thigh, calf and foot, $n = 9$.

Table 3
Skin temperatures of the lower extremities after different cold therapies in healthy subjects

Study	Method	Body part	Application time (min)	Skin temperature (°C)	
				Baseline	Minimum
Chesterton et al. (2002)	Frozen gel Pack	Thigh	10/20	30.2–30.7	14.5
	Frozen peas	Thigh	10	30.2–30.7	12.3
	Frozen peas	Thigh	20	30.2–30.7	10.8
Belitsky et al. (1987)	Wet ice	Calf	15	29.5–30.0	17.9
	Dry ice	Calf	15	29.5–30.0	20.1
	Cryogen Packs	Calf	15	29.5–30.0	20.1
Bugaj (1975)	Ice massage	Calf	10	32.4	5.8

required for specific effects. Localized analgesia requires a skin temperature below 13.6°C, and the explanation for the analgesic effect is that cold reduces the nerve conduction velocity (Bugaj, 1975). Cooling the skin below 20°C causes a marked reduction in the production of acetylcholine and in the rate of conduction along cooled nerves, which varies according to the size of fibres, thus producing asynchrony of impulses (Clarke et al., 1958). In our study, skin temperatures dropped below 13.6°C in the back, upper arm, forearm, thigh and calf. In clinical applications (e.g. as therapy for rheumatoid arthritis), WBC is used to alleviate pain, so that the patients can do therapeutic exercises after WBC. To reduce nerve conduction velocity by approximately 10%, a temperature of 12.5°C is required (Knight, 1976; McMeeken et al., 1984), and to lower metabolic enzyme activity by approximately 50%, skin temperatures between 10°C and 11°C are suggested (Knight, 1976; Zachariassen, 1991). These two critical levels were reached in the upper arm, forearm, thigh and calf in this study.

Hollander and Horvath (1950) and Hollander et al. (1951) demonstrated that normal knee joints had temperatures of 30.5–33°C, whereas joints with active synovitis had temperatures between 34°C and 37.6°C. Oosterveld et al. (1992) and Oosterveld and Rasker (1994) reported skin and intra-articular temperatures of the knee joint in healthy subjects and in patients with arthritis after cold therapy with ice chips (0°C) in a plastic bag for 30 min and nitrogen-cooled air (−160°C) for 6.5 min (Table 4). It is not easy to compare these results with ours because of the differences between the measuring sites. Skin temperatures in the extremities in this study were lower than those observed by Oosterveld et al. (1992) and Oosterveld and Rasker (1994) in the knee area. Therefore, it seems probable that, in our study, intra-articular temperatures decreased at least equally much as in their study. It should be pointed out in this connection that Oosterveld and Rasker (1994) found different cold applications to have different effects on joint and skin temperatures in healthy subjects and patients with arthritis.

Table 4
Skin and intra-articular temperature after cold therapy in healthy subjects and in patients with arthritis (Oosterveld et al., 1992; Oosterveld and Rasker, 1994)

Treatment	Skin temperature (°C)		Intra-articular temperature (°C)	
	Baseline	Minimum	Baseline	Minimum
Healthy				
Ice chips	27.9	11.5	31.9	22.5
Nitrogen	28.8	13.8	32.9	28.8
Patients				
Ice chips	32.2	16.0	35.5	29.1
Nitrogen	32.6	9.8	35.8	32.5

Cooling reduces the sensitivity of muscle spindles to stretch (Eldred et al., 1960; Mense, 1978) which reduces hyper-reflexia in spasticity (Bell and Lehmann, 1987). Harlaar et al. (2001) indicated that superficial cooling eliminated at the most hyper-reflexia and ankle clonus for 2 h. Based on our results we could also postulate that WBC decreases temporarily hypertonia in spasticity.

The recovery of skin temperatures was quick within a couple of min. At 30 min the skin temperatures had not yet reached the reference value, but they were higher than those required for an analgesic effect. Therefore, in clinical application, exercises and mobilization should be started as soon as possible after the exposure, as Belitsky et al. (1987) have suggested concerning local cryotherapy.

In conclusion, WBC is a safe form of cold therapy, as it involves no risk for frostbites. After WBC, all skin temperatures recovered rapidly, which is why the possible therapeutic exercises should be done immediately after WBC.

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