Cold Environments

Edwin M. Kilbourne, M.D.
Centers for Disease Control

Background and Nature of Physical and Physiologic Aspects of Cold Exposure

Scope of the Problem

Unlike heat waves, periods of sustained, unusually cold winter weather do not characteristically cause a clear-cut rise in numbers of daily deaths from all causes Nevertheless, the cold causes mortality and severe morbidity of considerable public health importance. In fact, if one considers only U.S. deaths certified by physicians as being temperature-related, the average number of deaths attributed to the cold (about 700 yearly) is substantially higher than the average yearly number attributed to the heat (about 200) (1).

Physical and Meteorologic Factors

Air temperature, humidity, wind speed, and radiant heat energy are the four environmental factors of greatest importance in determining human heat stress; they also determine cold stress. However, these factors differ in relative importance in causing stress from heat and cold. Air movement is far more effective in facilitating convective heat loss from the body in cold conditions than in warm ones. On the other hand, since the regulation of perspiration is not an important physiologic mechanism for maintaining body temperature in the cold, changes in humidity do not affect cold stress as much as they do heat stress. Radiant heat emitted by indoor heating devices (e.g., stoves, radiators) may substantially ameliorate indoor cold stress. The sun, however, transmits radiant heat to the earth's surface less efficiently in winter than in summer, resulting in a relative decrease in the importance of outdoor variations in radiant heat in the determination of cold stress. Thus, for most purposes, air temperature and wind speed are the two factors most important in determining thermal stress under cold conditions, particularly outdoors (2,3)

A widely used "wind-chill" index formulated by Siple and Passel in 1945 relies only on air temperature and wind speed in predicting the cold stress resulting from specific meteorologic conditions (3). Although widely applied and generally useful, this index has inherent inaccuracies at the extremes of wind speeds, and alternative schemes have been proposed (4,5). A relatively standard wind-chill equivalent temperature guide is shown in Table 1.

Adaptive Mechanisms

The principal immediate adaptive physiologic responses to the cold are shivering and vasoconstriction Muscular activity related to shivering causes increased metabolic heat production. Peripheral vasoconstriction causes a rerouting of some blood away from cutaneous and other superficial vascular beds toward deeper tissues, where the blood's heat can be more readily retained. In addition, blood is rerouted from the superficial veins of the limbs to the venae comitantes of the major arteries. There, through a 'countercurrent" mechanism, arterial blood warms venous blood before its return to the core and cools arterial blood, so that it gives up less heat when it reaches the periphery. The result is a fall in the temperature of superficial body parts in defense of core temperature. The difference between skin and core temperatures is thus an approximate measure of the efficacy of vasoconstriction (6,7).

Cold Weather and Mortality

In the United States, mortality usually peaks in midwinter and reaches a low point in late summer (Figure 1). The amplitude of the cyclic rise and fall in mortality is quite large, resulting in the occurrence of tens of thousands more deaths in January than in September. Thus, the increased numbers of deaths in the winter substantially exceed the number of deaths certified each year as having resulted from the cold (1). A similar seasonal rise and fall in death rate occurs in other countries in the temperate regions of both the northern and southern hemispheres. Of course, the seasonal patterns of these two hemispheres are 6 months out of phase, the death rate being maximal in winter in each hemisphere (6). Nevertheless, winter "cold snaps" (several days or more of unusually cold weather) do not seem to cause the sudden, striking increases in overall mortality that summer heat waves cause. Therefore, investigators have had to use statistical analysis of daily temperature and mortality data to

TABLE 1. Wind-chill equivalent temperatures for a reference wind speed of 4 miles per hour (1.79 meters per second)

Temperature (Degrees F)	Actual wind speed (in miles per hour) 4	5	10	20	30	40	50
40	40	37	28	18	13	10	9
35	35	32	22	11	5	2	1
30	30	27	16	4	−2	−6	−7
25	25	22	10	−3	−10	−14	−15
20	20	16	4	−10	−18	−22	−23
15	15	11	−3	−18	−25	−29	−31
10	10	6	−9	−25	−33	−37	−39
5	5	1	−15	−32	−41	−45	−47
0	0	−5	−21	−39	−48	−53	−55
−5	−5	−10	−27	−46	−56	−61	−63
−10	−10	−15	−33	−53	−64	−69	−71
−15	−15	−20	−40	−60	−71	−77	−79
−20	−20	−26	−46	−67	−79	−85	−87

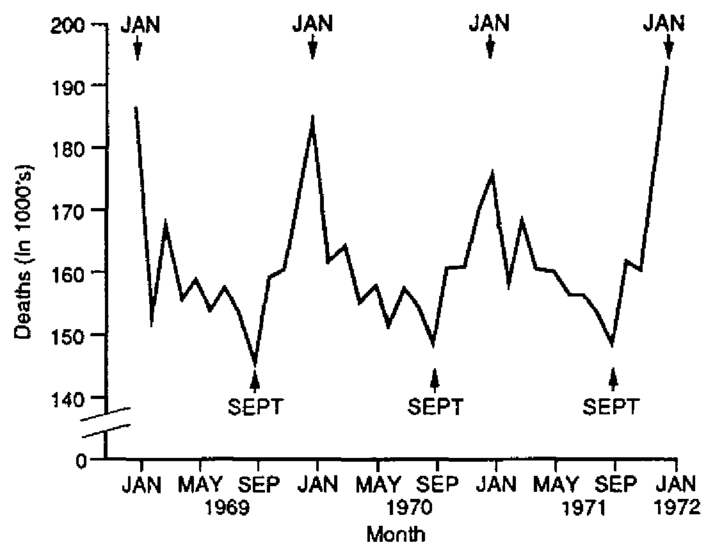
demonstrate the increase in numbers of deaths associated with the cold (8-11). This analysis is greatly complicated by the seasonal variation in mortality observed in countries of the temperate regions of both hemispheres.

The tendency for death to occur in the winter is most marked among the elderly and becomes increasingly prominent with increasing age. Moreover, for persons < 46 years of age the trend is reversed. For this group, death is more likely to occur in summer than in winter. Many of the major causes of death are associated with increases in mortality in the winter, among them diseases of the heart, cerebrovascular disease, pneumonia, influenza, and chronic obstructive pulmonary disease. In contrast, deaths from malignant neoplasms remain virtually constant throughout the year (12).

Because of the seasonal fluctuation in mortality, regression analyses based on daily observations show a significant negative correlation between mortality and temperature, that is, a direct association of high death rate with cold weather. The strength of this association does not necessarily imply that cold weather is the direct cause of all of the wintertime death increase. In fact several observations tend to indicate that this seasonal increase is not related to temperature. One is that the peaks and valleys in the U.S. mortality curve have not always appeared in January and September as they do now. In the early part of this century, the peak was usually in February or March and the nadir in June (13). Winter death increases occur even in states with relatively mild winters (e.g., Florida and Hawaii), and such increases are of approximately the same magnitude as those observed in states in which winter is characteristically harsh (e.g., Minnesota and Montana) (12). One epidemiologic analysis sought to control for the confounding effect of seasonal fluctations in mortality by limiting its observations to the months November through February. The death rate for men <65 years of age increased modestly on days with mean temperatures below the monthly mean, but there was little change in numbers of deaths among persons of both sexes ≥65 years of age, the group for which the seasonal mortality increase is most pronounced (12,14).

Nevertheless, the ability of the cold to cause severe illness and death should not be underestimated Deaths from stroke, ischemic heart disease, and pneumonia may all increase as a direct result of the cold (10,11). Cold-related increases in blood pressure and coagulability may cause the reported increases in deaths from stroke and ischemic heart disease (15,16).

FIGURE 1. U.S. deaths, by month, January 1969-January 1972



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Hypothermia

The term "hypothermia" refers either to the unintentional or purposeful lowering of core body temperature. Hypothermia has been purposefully induced to decrease oxygen consumption during certain surgical procedures (6,7).

Unintentional hypothermia is usually the result of overexposure to the cold and is a problem of considerable public health importance. The latter is the only type of hypothermia discussed below.

Hypothermia is the only known cold-related illness with a substantial death-to-case ratio. It is thus reasonable to suppose that cases of hypothermia account for the great majority of deaths for which exposure to cold is certified as the underlying cause (E901, *International Classification of Diseases, 9th Revision)*. However, this supposition has not yet been verified.

Most authorities agree that hypothermia is clinically significant when core body temperature falls to ≤ 95 F (35 C). As body temperature drops, consciousness becomes clouded, and the patient appears confused or disoriented. Pallor results from intense vasoconstriction. Shivering occurs at first, but decreases markedly in intensity as body temperature falls further and hypothermia itself impairs thermoregulation. With severe hypothermia (body temperature < 86 F or 30 C), consciousness is lost, respiration may become imperceptibly shallow, and the pulse may not be palpable. At such low temperatures, the myocardium becomes irritable, and ventricular fibrillation is common. The patient may appear dead even though s/he may yet be revived with proper treatment (6). Persons found apparently dead in circumstances suggesting hypothermia should be treated for hypothermia until death can be confirmed (17). In particular, the potential for recovery of apparent victims of cold-water drowning should not be underestimated, since there have been reports of virtually complete recovery of patients who were without an effective heartbeat for periods as long as 2.5 hours (18).

Hypothermia can be primary or can result from thermoregulatory failure caused by other illness—particularly sepsis, myocardial infarction, central-nervous-system damage, or metabolic derangements. Secondary hypothermia has a worse prognosis than does primary hypothermia, probably because of the severe nature of the concomitant illnesses capable of producing hypothermia (19).

Controversy exists regarding the optimal method(s) for rewarming patients with hypothermia. Advocates of slow external rewarming contend that relatively rapid rewarming causes an abrupt release of vasoconstriction in acral body parts, resulting in a sudden influx of cold, acidotic blood into the core, which exacerbates the metabolic derangements of hypothermia. Further, the release of vasoconstriction is said to result in a relative hypovolemia that may precipitate shock (7,20). Advocates of rapid external rewarming counter that volume deficits and acidosis can be rapidly corrected by infusion of fluids and sodium bicarbonate, and that the best way to treat any further deleterious effects of the cold is rewarming itself (21,22).

The treatment of hypothermia under extreme circumstances (e.g., when intractable ventricular fibrillation occurs) is more standardized. In such circumstances rapid, invasive "core" rewarming by such methods as peritoneal or open mediastinal lavage or cardiopulmonary bypass is generally advocated (17,23,24).

No matter what method of rewarming is used, all but very mild hypothermia cases require intensive care, including respiratory support, electrolyte and acid-base disturbance correction, and intravascular volume optimization. Hypoglycemia should be checked for and corrected. In addition, the patient must be treated for any predisposing medical condition.

Local Tissue Injury Produced by Cold

Frostbite is damage to local tissue caused by that tissue's being frozen. This damage results from the mechanical effects of ice crystals, the denaturation of intracellular proteins caused by hypertonicity of the unfrozen tissue fluid, and subsequent microvascular occlusion in the affected area. Acral body parts—including hands, feet, ears, and nose—are most frequently affected. In mild cases, recovery is usually complete. However, in severe cases tissue viability is affected, gangrene develops, and amputation of affected tissues may be required. Optimal treatment includes rapid rewarming in a water bath with a temperature of 42 C and subsequent supportive care (2).

Prolonged exposure to cold conditions at above-freezing temperatures may also cause tissue injury. "Trench foot" and "immersion foot" result from prolonged (days to weeks) exposure to wet and cold conditions. Affected persons develop paresthesia, hypersensitivity to cold, and muscle weakness or atrophy. In severe cases there may be superficial gangrene. Pernio (chilblain) is superficial ulceration occurring on body parts (especially the legs) subjected to prolonged exposure to dry cold. Both dry- and wet-cold nonfreezing injuries are thought to result from a prolonged vasoconstrictive response to cold and consequent circulatory inadequacy to affected body parts (2).

Determinants of the Risk of Hypothermia

Situational Factors

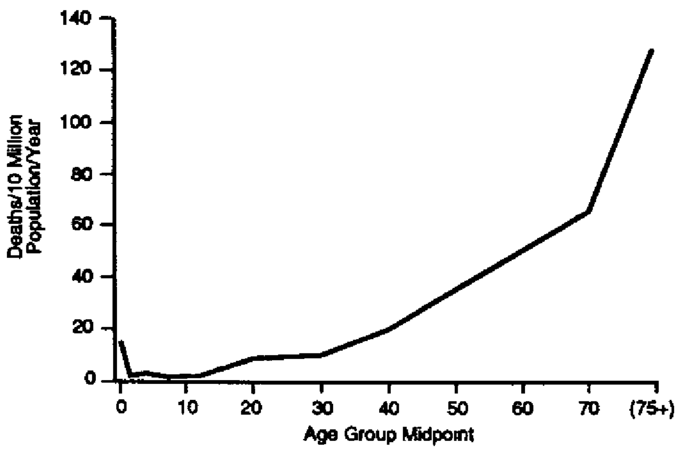
Unintentional hypothermia tends to arise in one of two sets of circumstances. One situation involves hypothermia affecting relatively young and generally healthy participants in outdoor sports that are often done in cold weather (e.g., hiking, camping, skiing). In this manner, an uncompromised host may be subjected to an overwhelming cold stress. Hypothermia may develop relatively rapidly, over a period of hours. Frostbite frequently accompanies hypothermia in this situation, since temperatures below freezing are generally involved. Factors that increase the likelihood of developing hypothermia include wearing insufficient clothing, getting clothing wet (which decreases its value as an insulator), and immersing oneself in cold water (in which the relatively high heat-conducting capability of water results in rapid loss of heat from the body). Hypothermia may impair the judgement of recreationists, causing them to remain in situations of dangerous cold stress or not to protect themselves adequately (6).

The second situation in which hypothermia commonly occurs involves a particularly vulnerable person who is subjected to only a moderate, indoor cold stress. A common example is that of an elderly person living in an inadequately heated home. In such circumstances hypothermia may not occur until days or weeks after the cold stress begins, and frostbite does not usually develop, since temperatures below freezing are not commonly involved (6). The risk factors in this situation are distinct from those involved in hypothermia among recreationists.

Hypothermia Involving the Elderly

The special vulnerability of elderly persons to hypothermia has been increasingly appreciated in recent years. After the first year of life, the rate of death due to effects of the cold increases with advancing age (Figure 2). In the United States, over half of the approximately 700 persons who die each year due to cold exposure are ≥ 60 years of age, although persons in this age group represent < 16% of the population (1,25).

FIGURE 2. Rates of death associated with cold (ICD E901), by age, United States, 1968-1980*



* *International Classification of Diseases*

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The extent of morbidity from hypothermia among the elderly is less easily measured. A national wintertime survey of 1,020 persons ≥ 65 years of age conducted in Great Britain found that relatively few (0.58%) had hypothermic (≤ 35 C) morning deep-body temperatures, and none had hypothermic evening temperatures. However, a substantial number (9%) had near-hypothermic temperatures (≥ 35.5 C but < 35 C) (26). In contrast, 3.6% of 467 patients > 65 years of age admitted to London hospitals in late winter and early spring had hypothermia (27). That hypothermia is relatively common among elderly persons admitted to hospitals—although virtually absent in the community—has been interpreted as showing that most elderly Britons with hypothermia are quickly hospitalized.

The apparent sensitivity to cold on the part of the elderly may be due to physiologic factors. Collins and others found that a high proportion of persons ≥ 65 years of age failed to experience physiologically significant vasoconstriction in response to a controlled cold environment and that the proportion of such persons increased with the age of the cohort examined. Elderly subjects with abnormal vasoconstriction tended to have relatively low core temperatures (28). The basal metabolic rate declines substantially with age, requiring elderly people to battle cold stress from a relatively low level of basal thermogenesis (29), and the shivering mechanism of some older persons may be impaired (30). Voluntary muscular activity also releases heat, but the elderly are more prone than younger persons to debilitating chronic illnesses that limit mobility. Brown fat, a type of tissue whose principal purpose seems to be the generation of metabolic heat, is less abundant in old people than in children and younger adults (31)

Elderly persons appear to perceive cold less well than younger persons and may voluntarily set thermostats to relatively low temperatures (32). In addition, the rising cost of energy in recent years, together with the relative poverty of some elderly people, may discourage their setting thermostats high enough to maintain adequate warmth.

Drugs Predisposing to Hypothermia

Ethanol ingestion is an important predisposing factor for hypothermia. The great majority of patients in many case series on hypothermia are middle-aged male alcoholics (33,34). Ethanol produces vasodilatation, interfering with the peripheral vasoconstriction that is an important physiologic defense against the cold (7). Although ethanol-containing beverages are sometimes taken in cold surroundings in order to obtain the subjective sense of warmth they produce, this practice is dangerous. Ethanol also predisposes persons to hypothermia indirectly, by inhibiting hepatic gluconeogenesis and causing carbohydrate-depleted persons (like many chronic alcoholics) to have hypoglycemia. Ethanol-induced hypoglycemia has been shown to cause healthy volunteers (35) to have hypoglycemia.

Ironically, ethanol treatment appears to improve survival from a hypothermic episode, an observation that may account for the relatively low mortality observed among alcoholics with hypothermia (36). Ethanol appears to delay the harm produced by impaired circulation and respiration by decreasing cellular metabolism, and thus, the requirement for oxygen—especially in the central nervous system (37). In addition, ethanol may reduce the tendency to ventricular fibrillation in association with hypothermia (36).

Treatment with neuroleptics (e.g., phenothiazines, butyrophenones, and thioxanthenes) also predisposes to hypothermia. Chlorpromazine, the prototype drug of this group, has been used to induce hypothermia pharmacologically (6,38). Chlorpromazine suppresses shivering, probably by a central mechanism, and causes vasodilatation (39). The hypothermic action of drugs of this class becomes more pronounced with decreasing ambient temperature (40).

Other Risk Factors

Infants < 1 year of age have a higher rate of death due to cold than do older children (Figure 2). Neonates, especially premature or small-for-dates babies, are at particularly high risk. Although the mechanisms for maintaining thermal homeostasis (vasoconstriction and thermogenesis by shivering) are present at birth, they seem to function less effectively than in older children. Infants have a relatively large ratio of heat-losing surface to heat-generating volume, and the layer of insulating subcutaneous fat is relatively thin. Perhaps most importantly, a young baby lacks the ability to control his or her own environment. Babies are totally dependent on others to care for their thermal needs, and if sufficient assistance is not forthcoming in a cold environment, hypothermia may result (6).

Hypothermia affecting infants can be a substantial public health problem in areas with severe winter weather. In

December and January of the winters 1961-1962 and 1962-1963, 110 babies with severe hypothermia (temperature < 90 F or 32.2 C) were admitted to hospitals in Glasgow, Scotland. Mortality in this group was 46% (41). Hypothermia affecting babies and young children can also be a winter problem in tropical climates, where it is associated with protein-calorie malnutrition (42).

For older children and young adults, lethal hypothermia is relatively infrequent (Figure 2). However, persons in these age groups are still susceptible to an overwhelming cold stress.

Death due to cold is relatively more frequent among males than females of virtually all age groups (Table 2). The reasons for this are unknown, but differences in the occurrence of risk factors and in patterns of cold exposure between the sexes may play a role.

Hypothermia is common among persons with hypothyroidism. Persons with myxedema (severe hypothyroidism) may be hypothermic without having any unusual cold stress. Lack of thyroid hormone results in a low rate of metabolic heat production, leading to hypothermia (43).

TABLE 2. Death rates* associated with cold (ICD E901), by sex and age and rate ratios, † United States, 1968-1980

COLD (*International Classification of Diseases* E901)

Age (in years)	Male	Female	Rate ratio
<1	16.1	9.9	1.6
1	0.9	1.8	0.5
2-4	2.4	2.0	1.2
5-9	0.9	0.3	2.6
10-14	3.4	0.4	8.6
15-24	13.1	3.4	3.8
25-34	17.3	3.3	5.2
35-44	33.1	6.2	5.3
45-54	58.1	14.8	3.9
55-64	86.3	17.6	4.9
65-74	116.8	24.1	4.8
≥75	230.8	73.0	3.2

* Per 10 million population per year.
† Rate ratio = male/female.

Prevention of Illness Resulting from Cold

Since severe illness and death from hypothermia are not only seen in association with cold snaps, efforts to prevent hypothermia must be taken all winter long. Since elderly persons are particularly vulnerable to hypothermia, they form a prime target group toward which preventive efforts should be directed. All dwellings, particularly those in which elderly persons reside, should be properly heated. Local governments can assist in this effort by adopting housing maintenance and occupancy ordinances that require each dwelling to have heating equipment that can safely maintain a reasonable room temperature under expected winter conditions (44). Maintenance of thermal standards is particularly important in nursing homes, hospitals, and other institutions that frequently house the elderly. Economically disadvantaged elderly persons may not make sufficient use of heating equipment because they are unable to pay the resulting fuel bills. In recent years financial assistance has been made available by Federal and certain state authorities to help needy elderly persons pay these bills. Publicity regarding the existence of such programs may enable them to better accomplish their purpose. Health education programs may be useful in informing elderly persons of their susceptibility to the cold.

New parents, pediatricians, and other health professionals involved in the care of babies in their first year of life should be aware that this age group is vulnerable to cold stress. Prevention of hypothermia among infants requires an adequate ambient air temperature and sufficient insulation by blankets or clothing.

Prevention of hypothermia, frostbite, and local nonfreezing cold injury among recreationists participating in winter sports also requires clothing with adequate insulating capacity. Recreationists should make themselves aware of the magnitude of the cold stress likely to be encountered and should dress accordingly. Care should be taken to keep clothing dry and to avoid immersion in cold water (45).

Alcohol and sedative drugs should not be used during periods of cold stress. Persons being maintained on neuroleptic drugs (phenothiazines, butyrophenones, and thioxanthenes) should be advised by their physicians of their increased susceptibility to the cold.

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