COOLING METHODS IN HEAT STROKE

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INTRODUCTION

Heat stroke is a life-threatening illness characterized by an altered level of consciousness with an elevated core body temperature ≥40°C. It may develop in persons exerting themselves in a hot environment; or susceptible, sedentary persons during periods of high ambient temperatures. Victims of advanced heat stroke require transportation to a medical facility capable of critical care management of multiple organ failure, though treatment of heat stroke should begin as early as possible in the prehospital setting. The primary goals of treatment for heat stroke are lowering core body temperature and supporting organ system function. The pathophysiology and clinical manifestations of heat stroke have been described in detail elsewhere (1,2). The focus of this article is to review the available evidence on the principal cooling methods used in the treatment of heat stroke.

To this end, we conducted a PubMed search of journal articles applicable to the cooling of human subjects with heat stroke—using the key words “heat stroke” and “cooling.” References in these journal articles in turn were searched for additional relevant studies. Original studies and reviews commonly cited in the heat-stroke literature, as well as noteworthy recent additions to this literature, are summarized below (Tables 1–6) (3–21).

Historically, heat stroke has been divided into two broad categories. Exertional heat stroke may develop in able-bodied individuals such as athletes, soldiers, or laborers performing rigorous physical activity in a hot
environment. Nonexertional or classic heat stroke may arise in elderly or infirm persons confined indoors during protracted hot weather. Nonexertional heat stroke may also develop with low-level physical activity in older, ambulatory persons with associated medical or psychiatric illnesses, including obesity, diabetes, hypertension, heart disease, renal disease, dementia, and alcoholism. Advanced age and associated illnesses may impair the body’s ability to dissipate heat, which normally would require a rise in cardiac output to shunt blood to dilated blood vessels in the skin; as well as sufficient intravascular volume to allow for increased sweating. Medications such as beta-blockers, diuretics, and anticholinergics may also blunt the compensatory increase in cardiac output and sweating needed to dissipate heat.

In both exertional and nonexertional categories, the clinical diagnosis of heat stroke rests on findings of hyperthermia (core body temperature $\geq 40^\circ C$) together with a disturbance of consciousness in the setting of environmental heat stress. Acute central nervous system dysfunction may include delirium, obtundation, coma, or seizures. Injury to the pulmonary, cardiovascular, hepatic, renal, and coagulation systems also commonly accompanies heat stroke. Such widespread injury arises from heat-induced conformational changes to cellular proteins, enzymes, and membranes. These changes disrupt cellular function, metabolism, and barrier functions, leading to the capillary leakage, severe systemic inflammation, and multiple organ failure characteristic of advanced heat stroke.

In addition to aggressive cooling, treatment of heat stroke may require interventions to support airway, breathing, blood pressure, and end-organ function. Such interventions include supplemental oxygen and intubation, as well as intravenous volume resuscitation and vasopressors.

Even with treatment, the risk of mortality in heat stroke remains high, with an upward range near 30% (9,22). A zero fatality rate has been recorded in young heat-stroke patients treated with immediate cooling; yet, for elderly victims during the 2003 heat wave in France, mortality rates were catastrophic—reaching 2000 deaths on a single day; and 15,000 deaths over the month of August (6,23). In the United States, from 2006 to 2010, there were at least 3332 deaths attributed to heat stroke (24).

In marked contrast, heat exhaustion is a less severe form of heat-related illness. Its clinical features may include general weakness, fatigue, headache, nausea, muscle aches, or cramps; as well as brief syncope or minimal confusion. In general, heat exhaustion responds to the conservative treatments of resting in a cool area and replenishing the body’s fluid and nutritional needs. Heat stroke may progress from antecedent heat exhaustion, but may also develop without such progression or apparent warning.

## DISCUSSION

Cooling a victim of heat stroke requires creating a gradient for heat loss from the skin to the environment via conduction, convection, or evaporation (Table 7). Debate in the medical literature over the optimal cooling method has continued for nearly 100 years without a clear answer. Scientific studies on different methods of cooling

### Table 1. Case Series on Conductive Cooling in Exertional Heat Stroke

<table>
<thead>
<tr>
<th>Study (First Author)</th>
<th>Number of Subjects</th>
<th>Cooling Technique</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beller 1975 (3)</td>
<td>41 military recruits, mean age 21 y</td>
<td>Ice-water immersion; cooling times 10–60 min</td>
<td>No mortality or morbidity</td>
</tr>
<tr>
<td>Costrini 1979 (4)</td>
<td>41 military recruits, mean age 21 y</td>
<td>Ice-water immersion</td>
<td>No mortality</td>
</tr>
<tr>
<td>O’Donnell 1975 (5)</td>
<td>41 military recruits, mean age 21 y</td>
<td>Ice-water immersion</td>
<td>No mortality</td>
</tr>
<tr>
<td>Costrini 1990 (6)</td>
<td>252 Marine recruits</td>
<td>Ice-water immersion</td>
<td>No mortality</td>
</tr>
<tr>
<td>Demartini 2015 (7)</td>
<td>274 runners, mean age 32 y</td>
<td>Ice-water immersion (10°C); mean cooling rate 0.22°C/minute</td>
<td>No mortality</td>
</tr>
<tr>
<td>Shibolet 1967 (8)</td>
<td>36 Israeli soldiers, mean age 19 y</td>
<td>Numerous ice-filled rubber bottles over the body; cooling times 1–3 h</td>
<td>22% mortality; 11% neurological morbidity</td>
</tr>
</tbody>
</table>

**Table 2. Case Series on Conductive Cooling in Nonexertional Heat Stroke**

<table>
<thead>
<tr>
<th>Study (First Author)</th>
<th>Number of Subjects</th>
<th>Cooling Technique</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferris 1938 (9)</td>
<td>44 hospital patients, mean age 61 y</td>
<td>Ice-water immersion for 25 more critically ill patients, cooling times 9–40 min</td>
<td>32% mortality</td>
</tr>
<tr>
<td>Hart 1982 (10)</td>
<td>28 ED patients, mean age 71 y</td>
<td>Ice-water immersion or crushed ice to body; cooling times generally $&lt;30$ min</td>
<td>14% mortality; 14% neurological morbidity</td>
</tr>
</tbody>
</table>

ED = emergency department.
have used a heterogeneous range of subjects: healthy volunteers exercising in hot, humid conditions; military recruits or miners operating in the field; patients admitted to hospitals during heat waves; and pilgrims traveling in desert environments (3–5,9,13,14,17–20).

Of the studies comparing different cooling methods, those involving randomized trials generally have been performed on healthy volunteers and have enrolled relatively few subjects. The remaining studies on treating heat-stroke patients have, for the most part, been case-series reports or nonrandomized comparisons of treatment methods—with considerable variations in the baseline characteristics of subjects from one study to the next. Moreover, findings in case-series reports may have limited applicability based on the retrospective collection of incomplete data. For these reasons, the historical record has not settled upon one undisputed method for cooling heat-stroke patients. Still, despite such limitations, this record has promoted two methods of cooling overall: 1) in exertional heat stroke, conductive cooling via ice-water immersion of the patient; and 2) in nonexertional heat stroke, evaporative and convective cooling via the application of sprayed water and forced air currents over the body.

Ice-water Immersion in Exertional Heat Stroke (Tables 1 and 5)

Immersion cooling, in which subjects have been partly submerged to the upper torso or neck in baths of cold water (Figure 1), has resulted in variable cooling rates depending on the water temperature used. In a small study of young, healthy volunteers who exercised to a core temperature of 40°C, immersion in an ice-water slurry at 2°C produced cooling rates of 0.35°C/min (18). Immersion in water at higher temperatures of 14°C–20°C produced experimental cooling rates of 0.15°C–0.19°C/min. In comparison, simply allowing hyperthermic subjects to rest in air-conditioned or temperature-controlled rooms has resulted in cooling rates of only 0.03°C–0.06°C/min (17,19,20).

In studies involving actual heat-stroke patients instead of experimental volunteers, immersion in an ice-water slurry has resulted in slower, yet still effective cooling rates of 0.15°C–22°C/min (6,7). This slower cooling of heat-stroke patients may be explained by the preservation of endogenous cooling mechanisms in study volunteers who exercise to hyperthermia. In contrast, in actual heat-stroke patients, endogenous cooling mechanisms such as increased blood flow to the skin and sweating may be impaired, resulting in slower cooling.

In the United States, studies on ice-water immersion in actual patients with exertional heat stroke historically have involved military recruits. Several case series in military personnel treated with ice-water immersion to a target temperature between 38.3°C and 38.8°C reported cooling times ranging from 10–60 min (3–5). No fatalities or adverse outcomes were reported—despite initial mean core body temperatures of 42°C. Additional support for immersion cooling in exertional heat stroke has come from an internal United States Marine Corps case series involving 252 recruits over 20 years, which demonstrated a zero fatality rate (6).

Table 3. Case Series on Evaporative + Convective Cooling in Nonexertional Heat Stroke

<table>
<thead>
<tr>
<th>Study (First Author)</th>
<th>Number of Subjects</th>
<th>Cooling Technique</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Aska 1987 (11)</td>
<td>25 pilgrims, mean age 58 y</td>
<td>Water-soaked fine gauze sheets + fans; mean cooling time 40 min</td>
<td>No mortality or neurological morbidity</td>
</tr>
<tr>
<td>Bouchama 1991 (12)</td>
<td>52 pilgrims, mean age 59 y</td>
<td>Body-cooling unit (BCU); mean cooling time 88 min</td>
<td>Mortality 2%; neurological morbidity 8%</td>
</tr>
<tr>
<td>Khogali 1980 (13)</td>
<td>18 pilgrims, mean age 54 y</td>
<td>BCU; mean cooling time 96 min</td>
<td>Mortality 11%</td>
</tr>
<tr>
<td>Khogali 1981 (14)</td>
<td>174 pilgrims, mean age 57 y</td>
<td>BCU; mean cooling time 78 min</td>
<td>Mortality 15%</td>
</tr>
</tbody>
</table>

Table 4. Case Series on Combined Methods, Nonexertional Heat Stroke

<table>
<thead>
<tr>
<th>Study (First Author)</th>
<th>Number of Subjects</th>
<th>Cooling Technique</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graham 1986 (15)</td>
<td>14 ED patients, mean age 66 y</td>
<td>Water spray + fanned air; plus crushed ice to lateral aspects of trunk and chilled IV fluids; mean cooling time 60 min</td>
<td>7% mortality; 0% neurological morbidity</td>
</tr>
<tr>
<td>Vicario 1986 (16)</td>
<td>39 ED patients, mean age 63 y</td>
<td>Cold wet sheets + fanned air; plus ice packs to axilla and groin; ice-water gastric lavage or cooling blanket also used in 8 patients</td>
<td>Mortality 21% Majority of patients cooled &lt;1 h</td>
</tr>
</tbody>
</table>

ED = emergency department; IV = intravenous.
with an ice-water slurry. The excellent outcomes support the effectiveness of ice-water immersion; but attest also to the underlying good health of the study subjects and to the importance of immediate cooling.

Outside the military setting, immersion cooling has been effective as a field treatment for exertional heat stroke at large-scale athletic events. A recent study examined 274 cases of heat stroke that occurred over 18 years during an annual summer road race (7). Male and female runners were treated within 2 min of collapse by immersion in a tub of ice water at 10°C. Runners were cooled from an average initial core temperature of 41.4°C to a target temperature of 38.8°C at an average cooling rate of 0.22°C/min. Remarkably, there were no fatalities, and > 90% of the runners with heat stroke were discharged home from medical tents without a need for hospital transfer. Similar to the U.S. military research, this study has highlighted the efficacy of immediate immersion cooling in exertional heat stroke. Furthermore, definitive cooling at the onset of heat stroke seems to have halted the progression to multi-systems injury characteristic of later stages of this illness.

Indeed, such a large-scale “treat and release” approach to exertional heat stroke is unprecedented in the literature. However, given the limitations of this retrospective study, future clarification is needed on specific clinical criteria for the safe discharge of patients. For example, time to collapse of athletes, a potential marker for the severity of heat stroke, was not recorded. Similarly, a detailed medical history or clinical course was not provided for each patient, including whether point-of-care laboratory testing was performed. Finally, whether discharged athletes later presented to hospitals with delayed injuries was also not known. For these reasons, the concept of treating and releasing athletes with exertional heat stroke after immediate, on-site immersion cooling remains promising, but not yet fully defined or established.

Ice-water Immersion in Nonexertional Heat Stroke (Table 2)

Studies on ice-water immersion generally have involved fit individuals with exertional hyperthermia or heat stroke (8,25). There have been fewer studies on immersion cooling in older patients with nonexertional stroke (9,10). One classic study followed the hospital course of 44 patients with nonexertional heat stroke admitted during a heat wave in 1936. Overall mortality in this study was high, given the older age (mean: 61 years) and associated medical conditions of the patients—such as hypertension, heart disease, or alcoholism. In addition, the majority of patients presented with coma, critically abnormal vital signs, and core body temperature > 41.7°C.

Despite such presentations in extremis, in an era prior to modern intensive care units, nearly 70% of the patients who received ice-water immersion survived, suggesting a distinct benefit for this treatment. Patients were cooled to a target temperature < 39°C, and cooling times ranged between 9 and 40 min (9).

Concerns with Immersion Cooling

Notwithstanding the benefits to immersion cooling, shivering, agitation, or combativeness may occur during

Table 5. Comparative Trials on Cooling in Healthy Volunteers Who Exercise to Hyperthermia

<table>
<thead>
<tr>
<th>Study (First Author)</th>
<th>Number of Subjects</th>
<th>Cooling Technique</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kielblock 1986 (17)</td>
<td>25 experimental conditions among 5 subjects</td>
<td>Comparison of evaporative + convective cooling to ice packs</td>
<td>Evaporation + convection cooled at 0.035°C/min; whole-body ice packs cooled at 0.034°C/min; strategic ice packs added 0.001°C/min to cooling Water at 2°C cooled 0.35°C/min; water at 8°C–20°C cooled at 0.15–0.19°C/min</td>
</tr>
<tr>
<td>Proulx 2003 (18)</td>
<td>28 experimental conditions among 7 subjects</td>
<td>Immersion in water baths at 2°C, 8°C, 14°C, and 20°C</td>
<td>Body-cooling unit cooled at 0.31°C/min; 15°C water bath cooled at 0.11°C/min</td>
</tr>
<tr>
<td>Weiner 1980 (19)</td>
<td>38 experimental conditions among 6 subjects</td>
<td>Comparison of conductive vs. evaporative + convective cooling</td>
<td>Evaporation + convection cooled at 0.06°C/min; immersion cooled at 0.04°C/min</td>
</tr>
<tr>
<td>Wyndham 1959 (20)</td>
<td>42 experimental conditions among 6 subjects</td>
<td>Comparison of immersion in water at 14°C to water spray + compressed air</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Controlled Trial on Cooling in Normothermic Subjects

<table>
<thead>
<tr>
<th>Study (First Author)</th>
<th>Number of Subjects</th>
<th>Cooling Technique</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moore 2008 (21)</td>
<td>16 healthy volunteers</td>
<td>30 mL/kg IV bolus over 30 min of cold (4°C) vs. room temperature (23°C) saline</td>
<td>Reduction of core body temperature by 1°C in cold saline group and 0.5°C in room-temperature saline group</td>
</tr>
</tbody>
</table>
treatment. Pronounced shivering of study subjects has been observed in cold-water immersions lasting longer than 9–10 min (18–20). Theoretically, such shivering and the accompanying reflex peripheral vasoconstriction may hinder cooling; but immersed patients have been effectively cooled despite any shivering. Several reasons help explain this.

First, the total body heat generated by shivering remains small compared to the high thermal conductivity of a large ice-water bath. Second, several authors have observed shivering occurring with less frequency and severity in actual heat-stroke patients with depressed mental status than in conscious, experimental volunteers who have intact shivering mechanisms (9,18,20). Finally, in modern practice, shivering of heat-stroke patients has been pharmacologically controlled with benzodiazepines or narcotics.

Nonetheless, shivering or agitation may become problematic. In one study involving older patients with non-exertional heat stroke, several patients experienced such discomfort or agitation with ice-water immersion that they were switched to cooling by the application of crushed ice over the body (10).

Other authors have cited the additional theoretical concern of impaired access to an elderly, immersed patient who may require advanced cardiac monitoring or additional resuscitative procedures (3,9,10,26). Given the absence of large, controlled trials in heat stroke, concerns with the potential discomfort and impaired access of the immersed, elderly patient must be judged clinically on an individual, patient-by-patient basis; but weighed against a case-series record that has indicated a benefit to immersion cooling in several score of older patients.

Studies on Cooling by Ice Packs in Exertional Heat Stroke (Tables 1 and 5)

Conductive cooling by the application of crushed ice or ice packs to the body has been proposed as a reasonable alternative to cold-water immersion, though experience has been more limited with this method (27,28). In an experiment of healthy volunteers who exercised to hyperthermia, the diffuse application of ice packs over the body cooled as well as evaporative plus convective cooling (17). In this small study, an important distinction was between the diffuse application of ice packs, which cooled effectively, and the strategic application of ice packs to the axilla, neck, and groin—which only marginally contributed to cooling. Ice-filled packs may contain more cooling capacity and remain colder longer compared to instant, chemical cold packs (29).

On the other hand, cooling by the application of numerous ice-filled rubber bottles over the body led to suboptimal outcomes in an Israeli case series on exertional heat stroke in military personnel. This study had a 22% mortality rate and 11% neurological morbidity rate. However, delays in definitive cooling (from 30 min to 2 h), rather than simply the cooling method itself, may have contributed to such outcomes (8).

Summary on Conductive Cooling

In summary, the available evidence indicates that ice-water immersion is effective in younger or fit persons, such as athletes and military personnel, with exertional heat stroke. Immersion cooling has been studied to a lesser extent in older patients with nonexertional heat stroke, though case series reports have suggested a benefit. Certain patients may not tolerate immersion cooling and require an alternate method of treatment. Conductive cooling via the diffuse application of crushed ice or ice packs to the body has been reported as a reasonable alternative to ice-water immersion—though with less of a demonstrated track record. Strategic application of ice packs to the axilla, neck, and groin has been shown to contribute minimally to cooling under experimental

Table 7. Primary Methods of Heat Loss from the Body  
(See Also Figure 5)

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation</td>
<td>Simple loss of heat across the skin barrier to the ambient air</td>
</tr>
<tr>
<td>Conduction</td>
<td>Transfer of heat through contact with a cooler object or cold water</td>
</tr>
<tr>
<td>Evaporation</td>
<td>Transfer of heat to evaporating sweat or water on the skin</td>
</tr>
<tr>
<td>Convection</td>
<td>Evaporative heat loss enhanced by wind or air currents</td>
</tr>
</tbody>
</table>
conditions and would not be expected to be effective in treating heat stroke. This last point should be emphasized, as published articles continue to promote such treatment despite a lack of proven effectiveness as a primary cooling method (30).

Evaporative and Convective Cooling

Studies on nonexertional heat stroke (Table 3). The technique of evaporative and convective cooling involves directing air currents while simultaneously spraying water on study subjects (Figure 2). Experimental cooling rates ranging from 0.034°C to 0.31°C/min have been achieved (17,19,20). This wide variation in rates may be attributed to differences in the temperatures of the water and air currents used in each study; the quantity of water used; the velocity of air currents directed at subjects; and differences in baseline characteristics of study participants. In general, larger quantities of water and stronger air currents directed at younger, healthier subjects have produced faster cooling.

In a small study of young, healthy volunteers who exercised to a core body temperature of 40°C, a specially constructed device, termed a body-cooling unit (BCU), produced a superior cooling rate of 0.31°C/min (19). The BCU sprayed a standardized combination of cool water mist (15°C) and warm, compressed air (45°C—to help prevent shivering) at patients lying on mesh netting. In actual heatstroke patients, however, the BCU produced cooling rates ranging from 0.04°C to 0.11°C/min—at best, a third as effective as the experimental cooling rates (10).

Differences in health and fitness between experimental subjects vs. actual heat-stroke patients help explain this wide variation in cooling rates. The majority of studies on the BCU have been performed during the Muslim summer pilgrimages to Saudi Arabia. In this context, many patients have been older, obese, and with medical conditions such as diabetes, high blood pressure, and heart disease. In addition, the endogenous cooling mechanisms of healthy study subjects remain intact and contribute to cooling, whereas those of heat-stroke victims may lose effectiveness. For these reasons, the BCU has performed better in the laboratory than in actual clinical practice or field conditions.

Nonetheless, despite slower cooling rates in clinical practice, the BCU has demonstrated a useful role in treating patients with nonexertional heat stroke. In a report on heat stroke in 192 summer pilgrims, the BCU lowered body temperature to 38°C in a mean time of 78 min. The mortality rate was 14.6% and there was no neurological morbidity post-cooling among the survivors (13,14).

In another study involving 52 pilgrims, treatment with the BCU resulted in a mean cooling time of 68 min to reach a core temperature of 39.4°C, and only one death (12).

Other studies have used evaporative and convective cooling without the BCU. Two case series (n = 25, n = 14) used fans and water applied to patients with non-exertional heat stroke. Mortality was low in both studies: 0% and 7%, respectively; short-term morbidity was 24% and 0%, respectively (11,15).

Studies on exertional heat stroke. Large series or studies on the use of evaporative plus convective cooling in actual patients with exertional heat stroke are lacking. One historical reference may be found during the period 1956–1961 in the South African mines, where miners with exertional heat stroke were initially treated with sprayed water and fanned air (22). The mortality rate was 28%—considerably higher than the 0% rate in the U.S. military studies. However, fair comparison cannot be made between the two rates. Details regarding the ages and medical conditions of the miners; the specific treatment techniques used; and the delays inherent in evacuating victims from deep tunnels have not been published.

More recently, in a pilot study, a field-deployed BCU was used at a half-marathon to definitively cool three runners with exertional heat stroke prior to hospital transfer (31). The runners made a full recovery after 3–10 days of hospitalization. In a separate case report, two runners were cooled in a striking variation of the evaporative plus convective technique using sprayed water and the down-drafts of a light-utility helicopter. Both runners made a full recovery after several days of hospitalization (32).

Summary on evaporative plus convective cooling. Evaporative plus convective techniques have shown an effective role in the treatment of nonexertional heat stroke. The...
higher morbidity and mortality with such techniques compared with immersion cooling may be explained in part by the older study population in nonexertional heat stroke. The BCU has been used on several hundred patients with nonexertional heat stroke. Although results from these case-series studies have shown a beneficial effect of the BCU, they have not demonstrated that this device is superior to adequate wetting and fanning of the skin in general. Studies demonstrating the effectiveness of evaporative plus convective cooling in exertional heat stroke have involved only a handful of patients to date.

Combined or Adjunctive Cooling Treatments (Tables 4 and 6)

Several authors have described applying ice packs or crushed ice to patients cooled primarily by evaporation plus convection (Figure 3)(15,16). In one study on nonexertional heat stroke (n = 14), applying crushed ice along the sides of the body supplemented cooling by sprayed water and fanned air. There was only one death, and among the survivors, no neurological sequelae. It is plausible that adding a conductive heat-loss mechanism may speed cooling and improve outcomes, but there are no controlled, comparative trials in actual patients showing an incremental benefit. In an experimental model of heat stroke, placing ice packs over the whole body of hyperthermic subjects achieved higher cooling rates than evaporative plus convective cooling alone. On the other hand, in the same study, placing ice packs only to the axilla, neck, and groin increased cooling minimally (17).

In patients receiving hydration, cold intravenous fluids may supplement primary cooling. In a study of healthy volunteers (n = 16), infusion of cold (4°C) intravenous saline over 30 min cooled core body temperature by 1°C, compared to 0.5°C with room-temperature saline. Cold saline, therefore, may be beneficial when added to evaporative or conductive cooling; but would be insufficient as a primary treatment for heat stroke (21).

The U.S. military studies on ice-water immersion also reported massaging the extremities during cooling to limit cutaneous vasoconstriction and promote blood flow to the skin. Whether such treatment contributed meaningfully to cooling or outcomes has not been separately studied and remains unknown.

Invasive techniques of body cavity lavage with cold isotonic fluid have been reported, but have not been adequately studied (28,33). Both intravascular cooling devices and noninvasive external cooling systems (such as the Arctic Sun™; Medivance, Inc., Louisville, CO) have provided adjunctive treatment for heat stroke in individual case reports, but also require further study (34,35). The use of cooling blankets in heat stroke has not been well described or studied (16).

End Point of Cooling

Evidence is lacking for an optimal target temperature at which to end cooling. Concern for potential cardiac dysrhythmias with overcooling has led to proposed end points of cooling slightly above normal body temperature. The majority of studies on evaporative cooling have used an end point near 38°C; studies on immersion cooling instead have used an end point just below 39°C. Although mortality with either cooling method has generally been low, this could not be specifically attributed to the end-point temperature chosen. Similarly, the effect of end-point temperature on long-term morbidity or neurological outcome has not been established (27).

Pharmacologic Treatment of Heat Stroke

No pharmacologic agent has been shown to be helpful as a treatment for heat stroke. Dantrolene has been used for treatment of malignant hyperthermia and neuroleptic malignant syndrome. It acts by impairing calcium release from the sarcoplasmic reticulum, thereby reducing the muscular muscle rigidity and hypertonicity typical of these conditions. A well-designed, randomized clinical trial of dantrolene vs. placebo in 52 Muslim pilgrims with heat stroke showed no difference in cooling rates or outcome (12).

Commonly used antipyretic agents have not been studied for treatment of heat stroke. Theoretically, such agents would not be expected to have benefit, because...
fever and heat stroke raise core body temperature through different physiological pathways.

CONCLUSIONS

Current evidence supports both immersion and evaporative methods for cooling of heat-stroke victims. The historical record has shown that ice-water immersion until core body temperature falls below 39°C is safe and highly effective for young, athletic patients with exertional heat-stroke. In this population, the water temperature most often used has been 0°C–10°C. Among elderly study subjects with nonexertional heat stroke, the weight of experience has involved evaporative and convective cooling to a core body temperature near 38°C. Evaporative cooling in elderly patients may offer several theoretical advantages, such as greater patient comfort and less agitation, as well as easier access to patients who may need advanced monitoring or resuscitation. Considerable variation in cooling rates with evaporative cooling, however, has suggested that this method is more dependent on the specific technique used. At a minimum, such technique must ensure that a sufficient quantity of water and strength of air currents be applied to the heat-stroke patient.

Based on the evidence, we recommend that patients with heat stroke in a medical facility be treated as soon as possible with either conductive cooling by whole-body ice-water immersion (preferential method in exertional heat stroke); or evaporative and convective cooling by a combination of cool water spray with continual airflow over the body (acceptable alternative in elderly patients with nonexertional heatstroke). Cooling should continue until core body temperature is 38°C–39°C. Either cooling method may be augmented by the addition of cold intravenous saline if hydration is needed. Evaporative and convective cooling may be augmented with the addition of ice packs or crushed ice over the whole body to promote conductive cooling.

Regardless of the cooling method used, mortality and morbidity have been higher in older patients with heat stroke, due in part to the preexisting diseases and baseline characteristics of this population.

There is insufficient evidence to recommend utilization of an intravascular cooling device, noninvasive external cooling system, body cavity lavage, or antipyretic agents. Dantrolene is not recommended in the treatment of heat stroke. Evidence is lacking to support the use of cooling blankets or ice packs placed strategically to the neck, axilla, and groin as primary cooling methods.

Acknowledgments—Brief excerpts of this review article written by the authors have appeared also in the Wilderness Medical Society’s 2013 practice guidelines on the prevention and treatment of heat-related illness. The authors acknowledge the contributions of their colleagues on the practice guidelines working group toward a better understanding of this topic.

REFERENCES


ARTICLE SUMMARY

1. Why is this topic important?
   In the United States, from 2006 to 2010, there were at least 3332 deaths attributed to heat stroke. Rapid, effective cooling is fundamental to treatment.

2. What does this review attempt to show?
   Although large, controlled trials are lacking, both ice-water immersion and evaporative plus convective cooling have a demonstrated track record in the treatment of heat stroke.

3. What are the key findings?
   Ice-water immersion has been shown to be highly effective in exertional heat stroke, with a zero fatality rate in large case series of younger, fit patients. In older patients with nonexertional heat stroke, studies have more often promoted evaporative plus convective cooling.

4. How is patient care impacted?
   Heat-stroke patients should be cooled by the methods most supported by clinical experience—namely, ice-water immersion (preferential method in exertional heat stroke) or evaporative plus convective cooling. Evaporative plus convective cooling may be augmented by crushed ice or ice packs applied diffusely to the body. Chilled intravenous fluids may also supplement primary cooling. Ice packs applied strategically to the neck, axilla, and groin; cooling blankets; and intravascular or external cooling devices should not be considered primary cooling methods in heat stroke.