Heat Stroke
A Review of Cooling Methods

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The prognosis of heat stroke in patients is directly related to the degree of hyperthermia and its duration. Therefore, the most important feature in the treatment of heat stroke is rapid cooling. Several cooling methods have been presented in the literature including immersion in water at different temperatures, evaporative cooling, ice pack application, pharmacological treatment and invasive techniques. This article describes the various cooling techniques in terms of efficacy, availability, adverse effects and mortality rate. Data suggest that cooling should be initiated immediately at time of collapse and should be based on feasible field measures including ice or tepid water (1–16°C), which are readily available. In the emergency department, management should be matched to the patient’s age and medical background and include immersion in ice water (1–5°C) or evaporative cooling.

Heat stroke is one of the most serious of conditions characterised by a core body temperature that rises above 40°C and central nervous system dysfunction.[1] It occurs when the metabolic and/or environmental accumulated heat exceeds the body’s ability to dissipate it. The individual with heat stroke usually experiences a characteristic multi-organ clinical and pathological syndrome caused by a constellation of events including acute physiological alternations associated with hyperthermia, the direct cytotoxicity of heat and the inflammatory and coagulation responses of the host.[2,6] Complications of heat stroke may include renal and hepatic failure, disseminated intravascular coagulation, rhabdomyolysis and adult respiratory distress syndrome. Morbidity and mortality are directly related to the duration and intensity of elevated core temperature, and are a function of the temperature-duration area.
above a critical core body temperature. Thus, early diagnosis and proper treatment are crucial for the patient’s survival. Treatment includes administration of basic resuscitative measures combined with simultaneous initiation of aggressive cooling efforts aimed at reducing body temperature. Core temperature should be monitored constantly with a rectal or oesophageal probe in order to assess cooling efficiency. Active cooling should be ceased when core body temperature falls to 38–38.5°C to avoid hypothermic overshoot.

1. General Aspects of Thermoregulation

From a thermodynamic perspective, it is convenient to distinguish the core of the body from its shell. The core consists of the deeper body tissues and is the predominant area of heat generation. The shell encompasses superficial tissues, namely, skin and subcutaneous tissues from which heat is dissipated to the outside environment. Effective heat dissipation depends on the rapid transfer of heat from the core to the skin and from the skin to the external environment. The former is controlled by peripheral vascular tone. When vasoconstricted, the shell acts as an insulator, while when vasodilated it acts as a heat exchanger. Skin blood flow can increase from approximately 0.2–0.5 L/min in normothermia to values exceeding 7–8 L/min in hyperthermia.

Heat dissipation from the skin to the external environment is achieved by physical cooling of the skin via radiation, conduction and/or evaporation (convection in this context is essentially conduction of heat to gas or liquid). A nude person who is exposed to normal room temperature loses heat primarily by radiation and to a lesser extent by evaporation and conduction. Conduction and radiation of heat from the skin depend upon a temperature gradient between the skin and the environment. When skin to ambient temperature gradient is low, heat dissipation by radiation and conduction is minimal.

In this case, sweating occurs to permit heat dissipation by vaporisation of water. The environment’s capacity to vaporise sweat is determined by the water-vapour gradient, which varies according to ambient temperature, relative humidity and wind velocity. As ambient temperature and wind velocity increase, and the relative humidity decreases, the water-vapour gradient is greater.

When heat dissipation is overwhelmed by heat accumulation and body core temperature rises, hyperthermia occurs and active cooling should be initiated. Since cutaneous vasodilation is usually present, active cooling is aimed at accelerating the transfer of heat from the skin to the environment while causing minimal peripheral vasoconstriction.

A study of the literature reveals various methods for cooling hyperthermic patients (table I). These methods are classified into physical methods, which include conductive or evaporative cooling, and pharmacologically induced cooling. Conductive-based methods may be further categorised into non-invasive methods that are applied to the surface of the body, and invasive methods that are aimed at cooling the core of the body.

2. Water Immersion

Cooling of patients with heat stroke by water immersion has been strongly advocated by some

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**Table I. Cooling methods for patients with heat stroke**

<table>
<thead>
<tr>
<th>Evaporation techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>wetting of the body surface during continuous tanning (Israeli Defence Force routine)</td>
</tr>
<tr>
<td>use of alcohol sponge</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conduction techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>external/non-invasive</td>
</tr>
<tr>
<td>water immersion</td>
</tr>
<tr>
<td>ice-water immersion</td>
</tr>
<tr>
<td>application of ice packs over part or the whole body</td>
</tr>
<tr>
<td>cooling blankets</td>
</tr>
<tr>
<td>internal/invasive</td>
</tr>
<tr>
<td>iced gastric lavage</td>
</tr>
<tr>
<td>iced peritoneal lavage</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Pharmacological techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>dantrolene</td>
</tr>
</tbody>
</table>

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Sports Med 2004; 34 (8)
investigators. This cooling technique exploits the high conductance properties of water, which are about 25 times that of air. Since heat conduction is dependent upon a temperature gradient, there are many who support using ice-cold water, thereby establishing even a steeper thermal gradient between the skin and the environment. However, aggressive skin cooling may induce heat producing shivering and peripheral vasoconstriction, impeding the cooling efficacy. In an attempt to overcome these limitations, skin massage has been suggested by many as an integral part of this cooling technique.

The first studies on immersion cooling were conducted in the 1930s by Daily and Harrison and by Ferris et al. Based on these studies, ice-water immersion became an accepted treatment for cooling heat-stroke patients. A cooling rate of 0.15 °C/min, without any cases of death or other complications, was reported by Costrini in the treatment of 25 US marine corps soldiers with heat stroke and heat exhaustion (mean rectal temperature: 41.8 °C; range: 41.1–43.1 °C). Patients were immersed in ice water and their skin was concomitantly massaged vigorously until core temperature was decreased to 39 °C or less. O’Donnell and Clowes reported similar results.

A question has been raised regarding the optimal water temperature when using the immersion approach. This issue was evaluated by three different controlled trials, one of which was conducted on dogs and the other two were human studies (table II). Using a heat-stroke dog model, Magazanik et al. evaluated the relative cooling efficiency of immersion in varying water temperatures. They found comparable cooling rates when using tap water at 15–16 °C (0.23 °C/min), cold water at 10–11 °C (0.23 °C/min) or ice water at 1–3 °C (0.21 °C/min). The equal effectiveness of different water temperatures, despite the higher thermal gradient of ice water, was explained by the vigorous shivering noted during immersion in ice water, which caused additional heat production and a slower rate of cooling. It was also argued by these investigators that water immersion causes rapid peripheral vasoconstriction, producing a ‘rind’ of relatively bloodless tissue over the entire body surface that results in tissue resistance to heat flow from the core to the body’s surface. In addition, tap-water immersion is preferable to ice water as it is usually readily available and does not require any complicated logistic arrangements. It is also less uncomfortable to the patients than ice water. However, a canine model may not be a reliable representative for human thermoregulation. Dogs do not lose heat by sweat evaporation, but rather by panting. They also have fur and a different skin surface to body mass ratio compared with humans, both of which alter heat loss via conduction.

In a recent study, the cooling rate during immersion in various water temperatures was also investigated in human volunteers. A significantly greater cooling rate during 2 °C water immersion (0.35 °C/min) was achieved compared with water immersion at 8, 14 and 20 °C (0.19, 0.15 and 0.19 °C/min, respectively). Moreover, shivering was seldom observed during the 2 °C water immersion.

In another study, the cooling capacity of ice-water immersion (5.2 °C), tepid water immersion (14 °C) and passive cooling were compared in 17 highly trained distance runners who raised their temperature to 39.3–39.6 °C. Results showed a comparable cooling rate by using ice-water or cold water immersion, while both were more effective than passive cooling after 12 minutes of cooling.

Table II. Summary of studies evaluating optimal water immersion

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Model</th>
<th>Maximal rectal temperature (°C)</th>
<th>Optimal water temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magazanik et al. (1980)</td>
<td>Dogs</td>
<td>44–44.5</td>
<td>Comparable cooling rate with 1–3 °C, 10–11 °C and 15–16 °C</td>
</tr>
<tr>
<td>Clements et al. (2002)</td>
<td>Highly trained runners</td>
<td>39.3–39.6</td>
<td>Comparable cooling rate with 5.2 °C and 14 °C</td>
</tr>
<tr>
<td>Proulx et al. (2003)</td>
<td>Healthy active subjects</td>
<td>40</td>
<td>2 °C</td>
</tr>
</tbody>
</table>
According to the two previously mentioned studies, a clear recommendation regarding the optimal water temperature cannot be given. The different results in these studies may be attributed to the water temperature evaluated. Clements et al. [27] who found similar cooling rates by using water at temperatures of 5°C and 14°C, did not use ice water (2°C), which was found to yield the greatest cooling rate in the Proulx et al. study [26]. A 3°C difference in water temperature for altering cooling rate to this extent is questionable. Furthermore, Proulx et al. [26] used circulatory water, a fact that was not reported in the Clements et al. [27] study. Circulating water may help in maintaining water temperature adjacent to the skin and thereby keep the skin-water thermal gradient at a constant value. [26]

3. Evaporative Cooling

Evaporation cooling is based on a significantly more efficient physical cooling principle than conduction cooling, given an appropriate water-vapour gradient. Evaporation of 1mL of water has been shown to dissipate seven times as much heat as melting 1g of ice. [34] Evaporation-based cooling can be achieved by the continuous spraying of water over the skin combined with forced-air equipment (ventilator/fan), which creates a warm, dry microclimate around the skin and promotes water evaporation. The warm forced air is crucial not only for the evaporation process but also for warming the skin, thus maintaining a good peripheral perfusion and preventing shivering. [15] For that reason, it is customary to spray lukewarm water, which, although it might seem to be counter-intuitive, is important for maintaining the warmth of the skin. [16]

In a clinically controlled prospective study conducted on six healthy volunteers whose rectal temperature was 40°C, Wyndham and colleagues exhibited cooling rates with evaporative cooling that were significantly higher (0.07 °C/min) compared with immersion in water at 14.4°C (0.04 °C/min). [15] Following this study, Weiner and Khogali developed the Body Cooling Unit (BCU), which was reported to be used successfully in the management of heat-stroke patients during the annual pilgrimage to Mecca. [16,35,36] The BCU consisted of spraying finely atomised water under pressure, at 15°C, over the entire nude body on a supine patient. This spray was combined with warm air (45–48°C) fanning over the skin at a linear flow of about 0.5 m/sec. [16] In one study that included six healthy subjects with body temperature of 39.5°C, cooling rates were reported to be 0.31 °C/min. [16] In comparison, immersion in water at 15°C, or the combination of spraying atomised water with air blowing at room temperature, yielded almost 3-fold lower cooling rates (0.11 °C/min and 0.12 °C/min, respectively). [16] However, when applying the BCU on patients with heat stroke from the Mecca pilgrimage, cooling rates were much lower than those reported in the controlled study (0.05 °C/min). [36,37]

The BCU technique has been criticised because of its high price, dependency on trained personnel, and the need for its installation in a special treatment centre. [38] For these reasons, a simpler, cheaper, portable device, which could be used in any health centre, was developed at King Saud University. [38] Patients were covered with a gauze sheet soaked in water at 20°C, while two fans directed the air in the room over the patients. The cooling rate achieved with this device when treating patients with heat stroke (0.087 °C/min) was almost twice that reported by Khogali and Weiner. [36] Nevertheless, this system is still not fully portable and relies on expensive logistics.

Successful evaporative cooling in the field was illustrated by Poulton and Walker, who treated three patients with heat stroke by using a light helicopter as a large powerful fan in order to provide surface cooling and enhance evaporation of water sprayed over the patient. [39] Estimated environmental temperatures on the helipad ranged from 31.1–40.5°C. An average cooling rate of 0.1 °C/min was reported, which is much faster than that reported for the BCU. [36,39] These investigators concluded that the combination of a large and powerful fan with a warm environment provide an efficient cooling method. However, using the helicopter rotary blade downdraft carries potential risks both for the patient, who inhales noxious jet exhaust and dust, as well as...
Heat Stroke Cooling Methods

Table III. Summary of studies comparing evaporative cooling to water immersion

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Model</th>
<th>Evaporative cooling technique</th>
<th>Temperature of water for immersion (°C)</th>
<th>Superior cooling method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wyndham et al.</td>
<td>Healthy volunteers</td>
<td>Spraying water at 30.5°C over the patient while exposure to 30.6–32.2°C air temperature with air movement of 0.6 m/sec</td>
<td>14.4</td>
<td>Evaporative cooling</td>
</tr>
<tr>
<td>Weiner &amp; Khogali</td>
<td>Healthy volunteers</td>
<td>Spraying atomised water at 15°C over the patient combined with warm air (45–48°C) fanning. Air movement is ~0.5 m/sec</td>
<td>15</td>
<td>Evaporative cooling</td>
</tr>
<tr>
<td>Armstrong et al.</td>
<td>Heat-stroke patients</td>
<td>Covering the patient’s torso and limbs with wet towels while exposure to 24.4°C air temperature without fans</td>
<td>1–3</td>
<td>Ice-water immersion</td>
</tr>
</tbody>
</table>

5. Invasive Cooling Techniques

Iced peritoneal lavage (PL) and gastric lavage (GL) are the two principle invasive treatment modalities that have been suggested and investigated.\(^{45-49}\) The rationale of invasive therapies is to bypass the shell and achieve direct cooling of the internal body organs encompassing the core. Initial interest in the possible benefits from central body cooling arose after Bynum et al.’s observation of the fastest cooling rate yet reported (0.56 °C/min) than total coverage with ice packs (0.034 °C/min) or evaporative cooling (0.034 °C/min). The combination of local ice-packs with evaporative cooling yielded a somewhat higher cooling rate than the latter (0.036 °C/min).\(^{44}\)

PL can be difficult to perform. Personnel must be technically trained and large volumes of cold sterile...
Table IV. Summary of controlled studies evaluating dantrolene treatment in heat stroke

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Study type</th>
<th>Model</th>
<th>Improved parameters</th>
<th>Non-improved parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moran et al. (1999)</td>
<td>Randomised controlled</td>
<td>Exercising rats</td>
<td>Non-exercising rats</td>
<td>Cooling rate</td>
</tr>
<tr>
<td>Zuckerman et al. (1997)</td>
<td>Randomised controlled</td>
<td>Non-exercising piglets</td>
<td>Cooling rate</td>
<td>Cooling rate</td>
</tr>
<tr>
<td>Bouchama et al. (1991)</td>
<td>Randomised, double-blind, controlled</td>
<td>Patients with non-exertional heat stroke</td>
<td></td>
<td>Cardiovascular parameters</td>
</tr>
<tr>
<td>Channa et al. (1990)</td>
<td>Randomised controlled</td>
<td>Heat-stroke patients</td>
<td>Cooling rate</td>
<td>Survival</td>
</tr>
<tr>
<td>Amsterdam et al. (1986)</td>
<td>Randomised controlled</td>
<td>Non-exercising dogs</td>
<td></td>
<td>Neurological sequelae</td>
</tr>
</tbody>
</table>

a Improvement was reported with or without mannitol.

Lately there have been a few reports that have assessed the efficacy of a new emerging cooling device, an intravascular cooling catheter. This system circulates temperature-controlled sterile saline through balloons that are inserted into the inferior vena cava or into the urinary bladder, resulting in the cooling of the adjacent tissue or blood. The system was found to be highly effective in human and animal models with intracranial diseases. However, it has not been applied to patients with heat stroke and therefore, still cannot be recommended at this time.

6. Pharmacologically Induced Cooling

Dantrolene, a hydantoin derivative, is a muscle relaxant that attenuates the amount of calcium released from the sarcoplasmic reticulum of skeletal muscles to the cytosol. The resultant decrease in intracellular calcium concentrations reduces muscle metabolic activity and, in turn, body heat production is decreased. Dantrolene has been successfully used in the treatment of various hyperthermic syndromes such as malignant hyperthermia and neuroleptic malignant syndrome, but its efficacy in the treatment of heat stroke is controversial. Lydiatt and Hill in 1981 and Denborough in 1982 were the first to report positive results with dantrolene as a cooling therapy of last resort in two cases of severe heat stroke.

A review of the literature revealed five controlled trials that dealt with the efficacy of dantrolene in the treatment of heat stroke. Among these studies, three are animal studies and two are human studies (Table IV). Dantrolene administration in non-exercising dogs with heat stroke did not significantly affect cooling rates, haemodynamic parameters, pathological changes or clinical outcome. Channa et al., who evaluated whether dantrolene provides an additional cooling effect to evaporative cooling in the treatment of patients with heat stroke, found that although cooling rate was increased, it did not affect survival. In another placebo-controlled trial, dantrolene was given as an additive treatment to 53 patients with non-exertional heat stroke who were treated by the BCU. Dantrolene did not demonstrate any enhancement of the cooling rate and there was no significant difference in the number of hospital stays. Moran et al. demonstrated an improvement in the cooling rate when using dantrolene on exercising rats. This effect was not achieved in sedentary rats.
Using a non-exercising piglet model with heat stroke, Zuckerman et al. evaluated whether dantrolene had an additive effect on 'conventional cooling' (intravenous fluid resuscitation, sponging with tap water, mechanical fanning and ice GL) with or without mannitol.[60] While some improvement in cooling rates was demonstrated, dantrolene did not significantly shorten cooling time compared with mannitol, and thus it was concluded that conventional methods were equally effective.

Among the various parameters evaluated, the only one that improved with dantrolene treatment was the cooling rate. This was achieved in two of the four animal studies and one of the two human studies.[57,59,60] Dantrolene showed some efficacy in an exercising model.[59] This may be explained by the fact that dantrolene inhibits muscle contraction, which might play a role in the pathophysiology of exertional heat stroke. The limited literature does not support the routine use of dantrolene as an adjuvant cooling technique in the setting of heat stroke. Wider studies, focusing on exercising humans, are still needed to evaluate the effects of dantrolene on the cooling rate and survival of heat stroke.

Several studies support the possibility that cytokines have a pathogenic role in heat stroke.[6,61-63] Patients with heat stroke were found to have elevated levels of inflammatory cytokines including tumour necrosis factor-α (TNFα), interleukin (IL)-1β, and interferon-γ and anti-inflammatory cytokines such as IL-6 and IL-10 and soluble TNF receptors p55 and p75. Moreover, cooling of the body to normal temperature does not result in the suppression of these factors.[6,61-63] Therefore, the various antipyretic agents, which affects cytokine metabolism, may be valuable in lowering body temperature of patients with heat stroke. However, treatment of patients with heat stroke by antipyretic agents cannot currently be recommended since their effect has not been systematically studied in this population. Moreover, these substances lower body temperature by normalising the elevated hypothalamic set-point.[64] In heat stroke, the body temperature set-point is not affected and temperature elevation reflects failure of normal cooling mechanisms. Noteworthy, certain antipyretics can cause additional damage; i.e. temperature-induced hepatic dysfunction may worsen from the use of paracetamol (acetaminophen), administration of nonsteroidal anti-inflammatory drugs may reduce potassium excretion, and aspirin (acetylsalicylic acid) may aggravate bleeding diathesis.

7. Other Cooling Methods

A review of the literature reveals other alternative cooling approaches. Several investigators used alcohol sponge baths, exploiting the high evaporative properties of alcohol.[65] Others used cooling blankets for lowering core body temperatures.[66] Although widely in use, the effectiveness of these approaches was evaluated only in patients with fever, and no data are provided concerning heat stroke. Noteworthy, the application of alcohol sponge baths should be avoided since this method may lead to alcohol poisoning and coma if absorbed through the skin.[67]

8. Discussion

A review of the literature with regard to cooling techniques revealed a large diversity in connection with the model investigated, the preliminary clinical state and the method applied. The most extensively investigated cooling methods were water immersion and evaporative cooling. Three controlled trials, all conducted on human subjects, compared both methods (table III).[15,16,20] In two studies, evaporative cooling was found to be superior.[15,16] These studies were carried out in young, healthy volunteers, where normal function of the cardiovascular and thermoregulatory mechanisms was maintained despite extreme elevated body temperature. In contrast, in the only study where evaporative cooling was compared with ice-water immersion in patients with heat stroke, the latter was found to be advantageous.[20] Moreover, Khogali and Weiner,[36] who used evaporative cooling for the treatment of patients with heat stroke, demonstrated considerably slower cooling rates compared with cooling rates of patients with heat stroke achieved in another study, where ice
water immersion was utilised.\textsuperscript{[21]} The controversy between the results can be attributed to the fact that when a heat-stroke model was used, evaporative cooling included air exposure without active fans, which might have reduced evaporation efficiency. Notably, when evaporative cooling was superior, the water temperatures used for immersion were 14.4 and 15°C, while immersion in water at temperatures of 1–3°C were more effective than evaporative cooling.

Therefore, a clear recommendation regarding the cooling methods that provide higher cooling rates cannot be given. Moreover, recommendations of several sports organisations,\textsuperscript{[21,68,69]} which suggest using ice-water or cold water immersion for the treatment of patients with heat stroke, cannot be supported by available data, and evaporative cooling may be equally effective.

The only available controlled studies regarding invasive cooling techniques were tested on animals. In these studies, PL and GL were proven to be less effective than evaporative methods.\textsuperscript{[47,49]} Invasive techniques are also less attractive than non-invasive methods since they are time consuming, are applicable only in the emergency room and have inherent risks. Therefore, the use of invasive techniques should be avoided in the treatment of heat stroke. Similarly, accumulated data do not support the use of dantrolene for cooling patients with heat stroke.

The cooling rate should not be the only parameter evaluated when choosing the method of choice; other parameters such as mortality rate, availability and adverse effects should also be considered. Khogali et al.\textsuperscript{[70]} reported a mean mortality rate of 12.1% with BCU treatment in 1119 patients with heat stroke from a Mecca pilgrimage. Mortality rates using ice-water immersion have not been conclusive. Tucker et al.\textsuperscript{[71]} reported an 18% mortality rate when treating Kansas city heat-wave victims with ice-water immersion, while Costrini\textsuperscript{[21]} witnessed no mortalities when treating soldiers. These results highlight the basic characteristic differences between the study groups investigated. Khogali et al.\textsuperscript{[70]} and Tucker et al.\textsuperscript{[71]} treated an elderly population with a variety of underlying medical illnesses, while Costrini’s patients were young soldiers with exertional heat stroke. Furthermore, the soldiers were given immediate treatment, while in the other cases, although not reported, treatment was probably delayed. It follows that mortality rate is most reasonably attributed to the basic physiological state of the study population and the time elapsed from collapse to cooling initiation, rather than any intrinsic cooling technique efficiency. Nevertheless, differences in mortality rates should not be overlooked as proven by Costrini’s regime as the most efficacious in preventing death.

The major objection for using ice-cold water immersion comes from its related adverse effects, namely, shivering and peripheral vasoconstriction, which compromise its efficacy. The heat-producing effect of shivering is inconclusive. Jacobson claimed that shivering is temporary, inconsequential and has a minor heat-generating effect compared with the high cooling capacity of cold water.\textsuperscript{[31]} Interestingly, shivering was seldom observed in humans who were immersed in ice water (1–3°C), while it was much more evident in subjects who were immersed in water at higher temperatures.\textsuperscript{[20,26]}

The lower shivering incidence in ice water can be attributed to a shorter immersion epoch or higher initial core temperature, resulting in a greater central nervous system damage with impaired shivering.

The idea that peripheral vasoconstriction has a negative effect on body cooling has been rejected by some authors. Peripheral blood flow is controlled by both central and cutaneous receptors, with the effect of the latter being dominant.\textsuperscript{[18]} Thus, when core temperature is elevated, as in the case of hyperthermia, the peripheral vasoconstriction will not be as intense as would have been anticipated under normal circumstances.\textsuperscript{[72]} Costrini further postulated that shivering and vasoconstriction increase peripheral vascular resistance and therefore assist in restoring cardiovascular stability.\textsuperscript{[21]}

Jacobson reported on an association between cold water immersion and generalised seizures.\textsuperscript{[31]} The latter often results in aspiration, which may be fatal. The incidence of aspiration during cold water immersion is not reported in the literature, but it
obviously should be considered as an additive risk factor. Another concern related to water immersion is the risk of a core temperature drop after exiting the water. This phenomenon was found to be inversely correlated with water temperature and can result in impairment of cardiovascular functions, especially in elderly patients with atherosclerotic vessels who may experience coronary vasospasm.\textsuperscript{[26,73]}

Ice-cold water immersion causes considerable patient discomfort. Medical attendants also experience difficulties in performing cardiopulmonary resuscitation, in maintaining sanitary conditions and in accessing the patient for continuous monitoring. These difficulties can be prevented when using evaporative-based cooling techniques.

All authors agree that treatment of patients with heat stroke at the site of collapse should begin immediately and be based on available measures. British military sources strongly advocate field-available evaporative techniques, such as using helicopter down-draft.\textsuperscript{[39]} On the other hand, Roberts and his colleagues indicated that on-site immersion is the only practical option since electricity to drive fans is absent.\textsuperscript{[74]} In our opinion, at site of collapse, the need for the previously mentioned sophisticated logistics is not crucial. Alternatively, the IDF routine, which is based on field-feasible measures and has been effectively administered on patients with heat stroke, should be applied instead.\textsuperscript{[40]} Since the optimal water temperature for cooling patients with heat stroke is not conclusive, using water at any temperature from 1–16°C may be acceptable. This approach is also supported by other authors.\textsuperscript{[21,69,75]}

9. Conclusions

Comprehensive research has been done concerning the efficiency of various cooling techniques in patients with heat stroke (Table V). The majority of data, which was based on experimental models or healthy subjects, suggest evaporative cooling as the method of choice. However, when the various cooling approaches were practiced on patients with heat stroke, cold water immersion was also found to be advantageous. Both of these methods, however, depend on cumbersome logistics (electricity to drive fans or ice water) that are not always readily available at the point of collapse.

In the field, where the administration of immediate cooling measures is imperative, splashing copious amounts of water (1–16°C) over the patient, together with air fanning, is strongly recommended. When the patient arrives at a clinical facility, other treatment modalities may also be considered. The cumulative data suggest that in this case, treatment should be matched to the patient’s age and clinical background. Young patients may tolerate aggressive treatment with ice water (1–5°C), while the more vulnerable older population and patients with prior cardiovascular illnesses should not be exposed to unnecessary risks. Therefore, the more conservative technique of tepid water (12–16°C) and fans should be used instead.

In summary, current knowledge does not reveal the superiority of evaporative cooling with water

<table>
<thead>
<tr>
<th>Table V. Range of cooling rates in different cooling modalities</th>
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<tr>
<td>Healthy subjects</td>
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<tr>
<td>Passive</td>
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<tr>
<td>Evaporation</td>
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<tr>
<td>Tap-water immersion (12–16°C)</td>
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<tr>
<td>Ice-water immersion (1–5°C)</td>
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<tr>
<td>Gastric lavage</td>
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<td>Peritoneal lavage</td>
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<tr>
<td>Ice packs</td>
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<td>References</td>
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immersion. Wider randomised controlled studies, conducted on humans with heat stroke, should be designed to compare the various cooling techniques in order to find the cooling method of choice.

**Acknowledgements**

No sources of funding were used to assist in the preparation of this review. The authors have no conflicts of interest that are directly relevant to the content of this review.

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