

ORIGINAL ARTICLE

Cooling methods used in the treatment of exertional heat illness

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Objective: To review the different methods of reducing body core temperature in patients with exertional heatstroke.

Methods: The search strategy included articles from 1966 to July 2003 using the databases Medline and Premedline, Embase, Evidence Based Medicine (EBM) reviews, SPORTDiscus, and cross referencing the bibliographies of relevant papers. Studies were included if they contained original data on cooling times or cooling rates in patients with heat illness or normal subjects who were subjected to heat stress.

Results: In total, 17 papers were included in the analysis. From the evidence currently available, the most effective method of reducing body core temperature appears to be immersion in iced water, although the practicalities of this treatment may limit its use. Other methods include both evaporative and invasive techniques, and the use of chemical agents such as dantrolene.

Conclusions: The main predictor of outcome in exertional heatstroke is the duration and degree of hyperthermia. Where possible, patients should be cooled using iced water immersion, but, if this is not possible, a combination of other techniques may be used to facilitate rapid cooling. There is no evidence to support the use of dantrolene in these patients. Further work should include a randomised trial comparing immersion and evaporative therapy in heatstroke patients.

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Heat illness is an unchecked increase in body core temperature that occurs when intrinsic or extrinsic heat generation overwhelms homeostatic thermoregulation. Consequential dysfunction at cellular and organ level results in a spectrum of disease from minor heat cramps through symptoms of heat exhaustion to life threatening heatstroke.¹ Heatstroke is characterised by neurological disturbance associated with haematological abnormalities, and may result in multiorgan failure and death.²

Classical or environmental heat illness occurs in those whose thermoregulatory control mechanisms are inefficient, such as the very young or elderly, and those subjected to extreme temperatures. The main factor in the development of this condition is a high environmental temperature, with clusters of cases occurring after heat waves (700 heat related deaths were reported after the Chicago heat wave of 1995)³ and the annual pilgrimages in the Middle East.

In contrast, exertional heat illness typically affects young athletes or military personnel, who are pushed to their physical limits and suffer a clinical and pathological syndrome caused by an inability to dissipate heat produced by muscular exercise. This can occur at any time of year, and is a reflection of intrinsic heat production rather than external heat. There are usually identifiable risk factors such as dehydration, concurrent illness, lack of sleep, obesity, alcohol ingestion, wearing too much clothing, or poor cardiovascular fitness.^{1–4} However, sometimes no precipitating factors are evident, and the reason why one individual is affected by heatstroke while others remain unaffected is not clearly understood.

Despite differences in their pathophysiology, the recommended treatment of these conditions is similar. An assessment of airway, breathing, and circulation should be the priority, and basic life support instituted if appropriate. High flow oxygen should be administered, intravenous access achieved, and initial observations should include a rectal temperature. Subsequently the emphasis is placed on reduction of core temperature as quickly as possible, as it

has been suggested that the major determinant of outcome in heatstroke is the duration of hyperthermia. One case series found a trend towards improved survival in patients cooled to a core temperature below 38.9°C within 60 minutes,⁶ and another report found improved survival when patients were cooled to the same level within 30 minutes, although the methods of cooling are not explored in detail in this paper.³ The evidence is limited, but what little there is would suggest that outcome may be improved when core temperature is reduced as quickly as possible. This remains the cornerstone of treatment of heatstroke patients, and is emphasised in the Inter-Association Task Force on Exertional Heat Illness consensus statement.⁷

Several methods of body cooling have been described, as outlined in box 1. The evidence to support one method over the other is limited and appears contradictory, and authors have proposed there is no evidence one way or the other.¹ The aim of this review is therefore to examine and appraise this evidence, and give a summary and recommendations based on its findings.

METHODS

A comprehensive search of the literature was carried out, using Medline and Premedline 1966 to July 2003, Embase, Evidence Based Medicine (EBM) reviews (including the Cochrane database of systematic reviews and the Cochrane central register of controlled trials), and the SPORTDiscus database. Search terms included heat stress disorders, heat stroke, heatstroke, heat exhaustion, heat illness, and heat injury. Papers were included if they contained original data on cooling times or cooling rates in patients with heat illness, or normal subjects who were subjected to heat stress. Owing to the lack of evidence on the treatment of patients with exertional heat illness in particular, papers describing the treatment of patients with classical or environmental heat illness were also examined. The bibliographies of relevant papers were examined and cross referenced. Papers were critically appraised for the quality of evidence presented. The

Box 1: Methods of body cooling

- Body immersion in iced water
- Evaporative cooling: spraying water over the patient and facilitating evaporation and convection with the use of fans
- Immersing the hands and forearms in cold water
- Use of ice or cold packs in the neck, groins, and axillae
- Invasive methods: iced gastric, bladder, or peritoneal lavage
- Chemically assisted cooling with dantrolene

criteria used were relevance to the question asked and study design. Studies were preferred in accordance with the usual hierarchy of evidence, namely controlled clinical trials, prospective studies (including case control studies), and case reports.⁸ Review articles were examined for their reference lists.

SEARCH RESULTS

Two controlled trials comparing cooling methods (one randomised⁹ and one non-randomised comparison¹⁰), and two randomised controlled trials^{11, 12} investigating the use of dantrolene in the treatment of heat illness were found, and these are examined in detail in table 1. Several case series^{6, 13-19} and experimental models using healthy volunteers²⁰⁻²⁴ were also found, and these are summarised in table 2. In total 17 papers were used in the analysis.

Immersion

In some centres immersion in iced water is the preferred method of cooling, including the US Marine Corps training base at Parris Island,²⁵ although this may not be optimal treatment for patients with a reduced level of consciousness, and, for those who are alert, it is uncomfortable and often intolerable. However, the best cooling times and rates for treatment of heat illness patients were achieved using this technique.

In a non-randomised study, a comparison was made of iced water immersion and placing wet towels over the torso,¹⁰ showing that iced water immersion cooled patients faster than the wet towels, with a cooling rate of 0.20°C/min for iced water and 0.11°C/min for wet towels. However, the study design allowed clinicians to choose which patients received which treatment, a source of considerable selection bias. It also compared two similar forms of cooling, rather than comparing immersion with evaporative techniques.

In a case series of 28 classical heatstroke patients, immersion in iced water enabled cooling to less than 102°F (38.9°C) in less than 45 minutes in all patients.¹⁴ Of note, some of the patients in this study could not tolerate being immersed and were massaged with ice instead. These patients were not analysed separately, and the relative importance of the ice massage cannot therefore be elucidated. In another case series of 27 patients with exertional heatstroke or heat exhaustion, all were cooled by iced water immersion, achieving a mean cooling time (to T_{re}<39°C) of 19.2 minutes, with a cooling rate of 0.15°C/min.¹⁸

Supporters of other cooling methods suggest that iced water immersion may cause peripheral vasoconstriction and therefore slow cooling, although this has never been proven experimentally. Indeed, a recent study using normal volunteers has shown that cooling rates were fastest when the coldest water was used.^{25a}

Table 1 Summary of controlled trials comparing different methods of cooling in heatstroke patients

Reference, date, and country	Patient group and interventions	Study type	Outcomes	Key results	Comments
Al-Harhi <i>et al.</i> ⁹ 1986, Saudi Arabia	16 heatstroke patients (T _{re} >40°C, dry skin, CNS symptoms). Randomised to BCU or CM (see text)	Prospective randomised controlled trial	Cooling time to T _{re} <38.5°C, mortality	Mean cooling time 62 min (35-120) (BCU) and 64 min (35-120) (CM); no difference between groups. No deaths in patients followed up	Randomisation technique not defined. Small numbers. Not blinded. No exclusion criteria given. Outcomes not clearly defined. 2 patients lost to follow up. Comparison between 2 types of evaporative cooling
Channa <i>et al.</i> ¹¹ 1990, Saudi Arabia	20 classical heatstroke patients, T _{re} >41.9°C. Either given dantrolene 2-4 mg/kg or not	Prospective randomised controlled trial	Cooling time to T _{re} <39.0°C, neurological outcome, mortality	Mean (SD) cooling time significantly lower in treatment group: 49.7 (4.4) v 69.2 (4.8) min (p<0.01). No difference in outcome or mortality (all patients survived)	Small numbers not justified by power calculation. Randomisation not defined. Not blinded. Inclusion and exclusion criteria not clear. Possible bias from different cooling methods and different doses of dantrolene. The conclusion does not reflect the results
Bouchama <i>et al.</i> ¹² 1991, Saudi Arabia	52 classical heatstroke patients with T _{re} >40.1°C. Given dantrolene 2 mg/kg or placebo	Prospective randomised controlled trial	Cooling time to T _{re} <39.4°C, organ dysfunction, length of hospital stay, mortality	No significant difference between study group and control group in cooling time (67.9 (12.4) v 69.0 (10.5) min), organ dysfunction, length of hospital stay or mortality	Better study design. Powered to detect difference in cooling time of 30 min. Computer randomisation in blocks of 10. Treatment blinded to patients and clinicians. No mention of outcomes being blinded. Classical heatstroke patients
Armstrong <i>et al.</i> ¹⁰ 1996, USA	21 exertional heatstroke patients, cooled either by iced water immersion or wet towels	Non-randomised comparative trial	Cooling rates to unspecified target	Cooling rate 0.20°C/min for iced water, 0.11°C/min for wet towels	Non-randomised, large potential for bias. No outcome target given. Flawed comparison

CNS, Central nervous system; BCU, body cooling unit; CM, conventional methods; T_{re}, rectal temperature.

Table 2 Summary of papers describing case series and experimental cooling models

Author, date, and country	Patient group and interventions	Study type	Outcomes	Key results	Comments
Wyndham <i>et al.</i> ²⁰ 1959, South Africa	6 healthy volunteers exercised until T_{re} 40°C, cooled by immersion or evaporation	Within subject crossover trial	Cooling time to T_{re} 38.3°C, cooling rate (fall in T_{re}) over 60 min	Fastest mean cooling time 50 min, rate 0.07°C/min, with evaporative cooling	Small numbers. Applicable to heat stroke patients?
Weiner & Khogali, ²¹ 1980, UK	6 healthy volunteers exercised until T_{ty} 39.5°C, then cooled by immersion in 15°C water, cold air spray or warm air spray (BCU)	Within subject crossover trial	Reduction in T_{ty} of 2.0°C (to 37.5°C)	Cooling time 6.5 min (rate 0.31°C/min) with BCU, 18.4 min (rate 0.11°C/min) with immersion	Small numbers. Methodology not explained in detail. Tympanic measurement used. Applicable to heat stroke patients?
Kielblock <i>et al.</i> ²² 1986, South Africa	5 healthy volunteers exercised until T_{re} reached 2°C above baseline, then subjected to different methods of cooling (see results)	Within subject crossover trial	Reduction in T_{re} of 2.0°C (to baseline)	Mean cooling time 73.6 min (cold packs), 59.8 min (evaporative cooling); $p < 0.01$. Combined: 53.6 min or 0.04°C/min (no difference)	Small numbers. Methodology not explained in detail. Applicable to heat stroke patients?
Clapp <i>et al.</i> ²³ 2001, USA	5 healthy volunteers exercised until T_{re} 38.8°C, then subjected to different methods of cooling (see results)	Within subject crossover trial	Cooling rate (fall in T_{re}) over 30 min	Mean cooling rates 0.25°C/min (torso immersion), 0.16°C/min (hand and feet immersion) and 0.11°C/min (fan)	Small numbers. Not compared with standard of care. Low target temperature. Applicable to heat stroke patients?
Mitchell <i>et al.</i> ²⁴ 2001, USA	10 healthy volunteers exercised to preset limits, then cooled using 4 methods (see results)	Within subject crossover trial	Cooling rate (fall in T_{re}) during two 12 min cooling periods	Mean cooling rates 0.02–0.05°C/min, no difference between passive cooling and fan or spray assisted cooling	Study not designed to look at heatstroke model. Inadequate temperature rise and cooling times to assess treatments
Khogali & Weiner, ¹³ 1980, Kuwait	18 heatstroke patients cooled in a BCU	Case series	Cooling time to $T_{re} < 38^\circ\text{C}$. Mortality	Cooling times ranged from 30 to 300 min. 2 patients died. Calculated mean cooling rate 0.05°C/min	Data on cooling rates not given
Hart <i>et al.</i> ¹⁴ 1982, USA	28 classical heatstroke patients. All cooled by iced water immersion or ice massage if immersion not possible	Case series	Cooling time to $T_{re} < 102^\circ\text{F}$ (38.89°C)	26 out of 28 cooled within 30 min, all within 45 min	Different intervention (immersion v massage) not defined in study group. No numerical data given. Study designed to primarily look at other parameters
Vicario <i>et al.</i> ⁶ 1986, USA	39 heatstroke patients, cooled by various means depending on physician preference	Case series	Temperature reduction over first hour, mortality	69% cooled to $T < 38.9^\circ\text{C}$ within 60 min. Mortality 21%, lower when cooled faster	Case series looking at prognosis depending on cooling times, rather than comparing methods
Graham <i>et al.</i> ¹⁵ 1986, USA	14 classical heatstroke patients, cooled by evaporative methods. Ice also used around torso	Case series	Cooling time to $T_{re} < 39.4^\circ\text{C}$, mortality	Cooling times ranged from 34 to 89 min, median 60 min. 1 patient died	Cooling methods not well defined: mixed methods. Cooling rates not calculable
Al-Aska <i>et al.</i> ¹⁶ 1987, Saudi Arabia	25 classical heatstroke patients cooled with simplified cooling bed	Case series	Cooling time to $T_{re} < 39^\circ\text{C}$	Mean cooling time 40 min (rate 0.09°C/min) with simplified cooling bed	Methods not well described: brief letter
Poulton & Walker, ¹⁷ 1987, USA	3 heatstroke patients (2 exertional, 1 classical), cooled by helicopter downdraft	Case series	Cooling time to $T < 38.5^\circ\text{C}$	Mean cooling time 24 min, rate 0.10°C/min	Methods not adequately described. Only mean data given
Costrini, ¹⁸ 1990, USA	27 patients with exertional heat illness, all cooled by iced water immersion	Case series	Cooling time to $T_{re} < 39^\circ\text{C}$, mortality	Mean cooling time 19.2 min or rate 0.15°C/min. No deaths	Methods not adequately described. Only mean data given
Horowitz, ¹⁹ 1989, USA	Heatstroke patient cooled by iced peritoneal lavage	Case report	Cooling rate. No end point given	Cooling rate 0.11°C/min during lavage cycle. Patient survived	Case report. Evaporative cooling also used

BCU, Body cooling unit; T_{re} , rectal temperature; T_{ty} , tympanic temperature; T_{co} , core temperature.

Evaporative methods

Evaporative cooling involves the removal of clothing, spraying tepid water over the patient, and facilitating evaporation and convection with the use of a fan. This was shown in the first published study of its kind to be better than other methods of cooling in normal volunteers.²⁰ The basic idea was modified into a more sophisticated model termed a body cooling unit, involving water sprayed at 15°C being mixed with warm air flow to maintain skin temperature at 32–33°C.^{13–21} Theoretical advantages of this include reducing peripheral vasoconstriction and thereby allowing heat to be lost more effectively. In a randomised controlled trial of classical heatstroke patients, the body cooling unit was compared with conventional methods of cooling (covering the patient in a wet sheet, spraying tap water on to the sheet, and using fans to blow air over the patient), but no difference in cooling time was found.⁹ This comparison was also flawed, in that it compared two very similar methods of cooling with no reference made to iced water immersion therapy.

In another study, the body cooling unit was shown to be better than other methods of cooling in normal volunteers,²¹ achieving rapid cooling with a mean rate of 0.31°C/min, but in a case series of 18 heatstroke patients achieved a mean cooling rate of only 0.05°C/min, with cooling times (to $T_{re}<39^{\circ}\text{C}$) ranging from 30 to 300 minutes.¹³ In another case series, a simplified cooling bed achieved slightly better results, with a mean cooling time of 40 minutes (rate 0.09°C/min).¹⁶

Other cooling methods

Immersing the hands and forearms in cold water results in reduction of heat stress in normal subjects,^{26–28} but has not been evaluated in the treatment of heatstroke patients. The placement of ice packs in the axillae, groin, and neck has been recommended as an easy method to use in the field,^{29–30} but when compared with evaporative cooling in five healthy subjects, cooling times were longest when the ice packs were used alone and shortest when both methods were used simultaneously.²² Another method of evaporative cooling has been described using the downdraft of a helicopter, which was reported to have better results than using the body cooling unit, although this case series only involved three patients (mean cooling time to $T_{re}<38.5^{\circ}\text{C}$ 24 minutes, rate 0.10°C/min), and the method is clearly not generally available.¹⁷ Invasive methods of cooling include gastric, peritoneal, and bladder lavage with cold water. These have been investigated in animal models,^{31–33} but the only data in human subjects come from a case series where gastric lavage is described,⁶ and a single case report, when cooling was achieved in a patient resistant to evaporative techniques.¹⁹ The role of invasive cooling methods has therefore not been fully established.

Dantrolene

Dantrolene is an agent that impairs calcium release from the sarcoplasmic reticulum and by doing so reduces muscle excitation and contraction. It is used in the treatment of malignant hyperthermia and neuroleptic malignant syndrome, reducing heat production that occurs as a result of muscle rigidity or hypertonicity typical of these conditions.³⁴ It has been suggested that similar pathophysiological mechanisms underlie heat illness, and dantrolene has been proposed as a possible means to reduce core temperature in this condition.^{35–40} The search strategy for this review yielded two randomised trials^{11–12} as shown in table 1.

In the first trial, 20 heatstroke patients were randomised either to receive dantrolene 2–4 mg/kg (study group) or not (control group).¹¹ Patients were externally cooled using either a body cooling unit or conventional evaporative methods, although which patients received which method is not

defined. The results showed a significantly shorter cooling time ($T_{re}<39.0^{\circ}\text{C}$) in the study group (49.7 (4.4) *v* 69.2 (4.8) minutes, $p<0.01$), but no difference in outcome between the two groups. Table 1 outlines the methodological flaws in this study, which should induce caution in the interpretation of its results. In the second trial, 52 classical heatstroke patients were randomised to receive either dantrolene 2 mg/kg or placebo (normal saline).¹² All patients were externally cooled using a body cooling unit, and rectal temperature was continuously recorded to determine cooling time (time to reach $T_{re}<39.0^{\circ}\text{C}$). The results showed no difference in cooling times between groups (treatment group 67.9 (12.4) minutes *v* control group 69.0 (10.5) minutes), and no difference in complications, length of stay, or mortality (one patient died in the control group). From this well designed trial, the authors conclude that, at the dose given, dantrolene has no additional benefit over traditional external cooling methods.

DISCUSSION

As is evident from this collection of the available data, there is conflicting evidence as to the best form of cooling in heatstroke patients. Treatment should start with an assessment of airway, breathing, and circulation, and measurement of rectal temperature. According to the best evidence currently available, it would appear that immersion in iced water is the most effective method of whole body cooling, and should be used where possible. However, it may not be practical from a logistic or clinical perspective, and treatment may have to be tailored to the clinical situation. For patients with a reduced level of consciousness, it may prove hazardous and is not recommended unless specific facilities allowing continued intensive medical care are available.

If immersion is unavailable or inappropriate, cooling may necessarily involve a combination of evaporative cooling techniques and other methods such as immersion of the extremities in cold water. At the roadside of an endurance event, this may be the most appropriate method of cooling. Future work should include a prospective randomised trial comparing iced water immersion with evaporative techniques in exertional heat illness patients to clarify the optimal method.

There is no clear evidence to support the use of dantrolene in the treatment of exertional heatstroke, and the priority, after an assessment of airway, breathing, and circulation, should be to institute external cooling methods to reduce core temperature as quickly as possible. Other suggested treatments such as the use of antipyretics and immunomodulatory agents have not yet been evaluated in human subjects.

This review was essentially limited to human studies, and data from animal studies have not been included. It may be subject to publication bias, and has included papers from predominantly English Language journals. The distinction has been drawn between those papers describing cooling in heatstroke patients and those involving normal volunteers exposed to experimental conditions. It should be stressed that experiments in which cooling rates are measured in normal subjects who have been exercising have limited applicability to treating heatstroke patients whose thermoregulation mechanisms have failed. The treatment of classical heat illness patients has also been included, although whether this can be extrapolated to patients with exertional heat illness is not clear.

Comparison of papers was made more difficult by the different outcome measures used by different groups, but where possible cooling times and rates have been extracted and compared. The lack of robust evidence highlights the requirement for a large, well designed, randomised controlled trial comparing iced water immersion with evaporative techniques for the treatment of heatstroke.

What is already known on this topic

- Classical or environmental heat illness results from inefficient thermoregulatory control mechanisms in those subjected to extreme temperatures.
- Exertional heat illness results from an inability to dissipate heat produced by muscular exercise.
- The recommended treatment of these conditions is similar: assessment of airway, breathing, and circulation and basic life support, followed by reduction of core temperature as quickly as possible.
- Several methods of body cooling have been recommended.

What this study adds

- The main predictor of outcome in exertional heatstroke is the duration and degree of hyperthermia.
- Patients should be cooled using iced water immersion, but, if this is not possible, a combination of other techniques may be used.
- There is no evidence to support the use of dantrolene in these patients.
- Further work should include a randomised trial comparing immersion and evaporative therapy in heatstroke patients.

CONCLUSIONS

The treatment of exertional heatstroke should begin with an assessment of airway, breathing, and circulation, and initiation of resuscitation if necessary. Subsequently whole body cooling should be the priority. Where possible, patients should be cooled using iced water immersion, although this may not always be practical and a combination of other techniques may be needed to facilitate rapid cooling. There is no evidence to support the use of dantrolene in these patients.

Competing interests: none declared

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COMMENTARY

The author's review of the management of exertional heat illness clearly highlights the problem in deciding the best treatment for this group of patients, who are typically young and healthy but who have a high mortality and morbidity, related directly to the duration of the temperature rise.

With regard to the best form of treatment, there are two camps, equally split between immersion and evaporative therapy. The evidence presented here appears to support the use of immersion in ice water, while acknowledging the limitations both in terms of the quality of evidence available and the practicalities of using this technique.

This is yet another area of sports medicine in which the answer to a seemingly simple question is still unknown, and presents an area in need of a well conducted randomised trial.

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