Hospital Rewarming of Hypothermic Victims

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Hypothermia is associated with substantial morbidity and mortality, which most likely depends on the initial temperature. In one study, victims with a temperature above 32.2 °C had a mortality of 7 %, while those with a temperature below 32.2 °C had a mortality of 22.7 %. The inverse relation between high mortality and low admission temperature was also observed in a study of 61 ICU-admitted hypothermic patients. All these patients had a temperature below 32 °C. The patients with a temperature between 30 and 32 °C all survived. In contrast, patients with a temperature between 28 and 30 °C had 10 % mortality, patients with a temperature between 26 and 28 °C had 12 % mortality and below 26 °C the mortality was 29 %. In another study, the trend was the same, but mortality rates were higher: patients with a temperature of 32–35 °C had a mortality of 16 %, and with a temperature between 28 and 32 °C, mortality was 42 %. Below 28 °C, this was 60 %. Two other studies however did not find an association between initial temperature and outcome [1–5]. The overall mortality of hypothermic ICU-admitted patients has also been predicted by the Simplified Acute Physiology Score (SAPS II) mortality prediction model [5].

There are limited epidemiological data on hypothermia in relation to drowning. In one study, drowning was present in 56 % of patients who were admitted to hospital with accidental hypothermia. In another study, 27 % of the hypothermic immersion victims died [1, 2]. The National Intensive Care Evaluation (NICE), the database that includes the admissions of 90 % of all ICUs in the Netherlands, also registers drowning victims (www.stichting-nice.nl). Drowning-related ICU admissions varied between 30 and 50 per year: 1 per 2,000 ICU admissions. The mean

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J. Bierens (ed.), *Drowning*,
DOI 10.1007/978-3-642-04253-9_136,

Table 136.1 Relevant topics during the ICU treatment of accidental hypothermia

Restoration of caloric deficit
Optimisation of circulation to prevent and treat shock
Optimisation of gas exchange to prevent and treat acute respiratory distress syndrome (ARDS) and aspiration pneumonia
Correction of acid–base balance
Correction of electrolyte disorders
Correction of fluid balance
Post-resuscitation therapy for brain protection, including mild therapeutic hypothermia
Anticipation of complications such as systemic inflammatory response syndrome (SIRS), infections such as aspiration and ventilator associated pneumonia, renal failure and diffuse intravascular coagulation
Co-morbidity: trauma, sepsis, intoxication, alcoholism, underlying disease

initial temperature of the drowning victims was 33.7 °C. The initial core temperature was between 35 and 37 °C in 44 % of the drowning victims and below 28 °C in 4 % (unpublished data). The incidence of hypothermia is probably underestimated because of incomplete registration [2].

In hypothermic drowning patients, submersion time appears to be the only independent predictor of survival. A cut-off temperature cannot be indicated, and also age, water temperature and rectal temperature in the emergency room were not significant predictors of survival [5].

136.1 Hypothermia Management in the Hospital

Hypothermic patients need a multisystem approach as they usually suffer from comorbid factors like trauma, intoxication and post-anoxic neurological disease. Management of hypothermia in the emergency department and ICU focuses on the restoration of the caloric deficit, the treatment of vital functions and the prevention of organ failure and complication. Several studies show that mortality usually occurs after and not during the rewarming phase because many patients develop complications [1]. In many patients, this implies admission to the ICU. Flow charts are helpful to decide who needs ICU admission [6, 7] (Table 136.1).

136.2 Caloric Deficit in Hypothermia

At room temperature, a thermally unprotected adult needs to produce heat through thermogenesis at 70–80 kcal/h to prevent the body to cool down, which equals 81–93 W. The healthy body can easily produce this heat. When the person cools down due to environmental circumstances, thermogenesis should be higher to allow the body temperature to remain normal. In addition, the basic caloric deficit must be restored. The calories that need to be supplied can be roughly calculated. One kilocalorie is needed to warm 1 litre of water with 1 °C. A drop in body temperature from 37 to 30 °C results in a caloric deficit of 490 kcal in a patient of 70 kg. A patient with a core

Table 136.2 Theoretical rewarming rates with a variety of rewarming methods in a patient with a temperature of 27 °C. Derived from [9] but modified by the authors

Rewarming method	Rewarming rate (kcal/h)	Rewarming duration (h)
Hot water bath 45 °C	1,000	1
Haemodialysis 30 l/h at 45 °C	500	1, 5
Cardiopulmonary bypass	400	1–2
Veno-venous extracorporeal	240	3–4
Intravascular thermal probe	200–400	3–4
Shivering (above 33 °C)	250	3–4
Forced air rewarming	40–80	4–10
Oesophageal probe	30–60	6–12
Thermal ceiling/radiant heater	100	7
Peritoneal dialysis 4 l/h at 45 °C	60	8
Blanket roll/warm water mattress	80	9
Heated aerosol	30	12
Endogenous production	30–250	24
Mechanical ventilation with warmed air 10 l/min	23	24

temperature of 27 °C needs 700 kcal and a patient with 23 °C central body temperature 980 kcal. In this calculation, the caloric value of tissue is not taken into account.

Endogenous thermogenesis may be substantially lower than 80 kcal/h in patients with trauma, intoxication, hypothyroidism or at ages over 60 years. Also thermogenesis is lower at lower temperature. On the other hand, shivering produces around 250 kcal/h.

Most healthy patients with mild hypothermia (35–32 °C) are usually able to generate sufficient calories by means of endogenous heat production and shivering when completely isolated. This becomes a problem, or impossible, when the patient is not healthy or the temperature is below 28–32 °C.

In such situations, exogenous caloric supply is needed to regain normal central body temperature. When the intention is to achieve a rewarming rate of 2 °C/h in a 70 kg patient, the caloric supply has to be 140 kcal/h to increase the temperature and an additional 80 kcal to compensate for the insufficient endogenous thermogenesis. A caloric supply of 220 kcal/h will be sufficient to raise the central temperature to normal values.

In Table 136.2, a number of rewarming methods and their caloric support are summarised. For patients with a temperature above 32 °C, one single strategy can be selected if passive rewarming by endogenous thermogenesis and prevention of heat loss by complete insulation are ineffective. In all other patients, a combination of rewarming methods will provide a higher caloric supply. The calorie supply that is needed can be calculated as well as the expected rewarming rates by the several combinations of methods. Close monitoring is needed for timely intervention when treatment goals are not achieved.

Rewarming may have detrimental effects as well, and the best rate of rewarming still needs to be defined. A preliminary report shows an association of a fast rewarming rate with Nuclear Factor kappa B (NFkB) stimulation resulting in enhanced inflammatory response and brain injury [8].

Table 136.3 Criteria to be fulfilled for rewarming strategies

Safe
Efficacious
Quickly and easily applicable
Minimally invasive or non-invasive
Low-grade technology with no specialised personnel required
Patient access for instrumentation during rewarming
Apparatus should be familiar to attending staff. For instance, a specific rewarming equipment which is used in daily practice for post-surgical patients
Cost-effective

136.3 Rewarming Methods

Several rewarming methods are available (Table 136.2) [1]. The criteria that a rewarming method should fulfil are summarised in Table 136.3. The three major rewarming methods are passive rewarming (PR), active external rewarming (AER) and active internal rewarming (AIR) [6, 7, 10]. The information on efficacy of rewarming methods is mostly derived from uncontrolled case series. Controlled clinical studies that report comparison between rewarming methods are rare. Which method to choose depends on the clinical situation of the patient. The awake patient with stable circulation can be warmed by PR. The core temperature in these patients is between 32 and 35 °C, which is usually in agreement with stage I of the Swiss hypothermia staging system [11, 12]. AER or AIR should be initiated in patients with impaired consciousness or patients in shock. This usually applies to patients with a core temperature between 28 and 32 °C or stage II/III of the Swiss staging system. In more unstable circulatory situations or in a resuscitation setting, extracorporeal rewarming by ECMO or CPB should be initiated as soon as possible (stage III/IV) [11, 12].

136.3.1 Passive Rewarming

Passive external rewarming (PR) relies on the minimisation of caloric loss by insulation. Rewarming is achieved by endogenous production of heat by the thermogenesis of the patient. A metallic blanket around the head and neck in combination with multiple blankets around the rest of the body may be sufficient. To be effective, it is important that heat loss should be avoided during instrumentation and clinical investigations. If the heat loss of the patient is minimised by good isolation, active thermogenesis of over 80 kcal/h, eventually in combination with shivering, increases central temperature within the first hours of observation. When patients are paralysed by muscle relaxants to facilitate mechanical ventilation, this will considerably reduce endogenous thermogenesis, while shivering becomes impossible. This will prolong the rewarming phase. In most cases of hypothermia, between 35 and 32 °C PR is the method of choice. However, when in doubt of the indication or effectiveness, therapy should be changed to active rewarming.

In two studies, PR has been used in moderate and severe hypothermia patients with a body temperature that ranges between 22 and 32 °C. The mean ICU admission temperature was 28.8 ± 2.5 °C. Seven patients were colder than 26 °C. The rewarming rate was 11.5 h ± 7.5 in the survivors. In the non-survivors, rewarming rates were 17.2 ± 6.2 h [4, 13].

In the first hour with PR, the rewarming rate may be as high as 1.5 °C [10]. This rate is similar to the rewarming rates of other methods in the first hour. If PR fails to achieve a temperature gain of 0.5 °C in the first hour, active methods should be employed. Especially patients of over 60 years of age rewarm slowly and may need active rewarming interventions for the correction of the mild hypothermia.

A recent review observed a diminishing interest for the use of metallic blankets due to questionable efficacy [14].

136.3.2 Active External Rewarming

Active external rewarming (AER) is indicated in patients with a central body temperature between 28 and 32 °C, in patients with instable hemodynamics and when the central temperature fails to increase at least 0.5 °C in the first hour with PR. Also hypothermic patients that need treatment in the ICU for other reasons will require active rewarming [15].

A variety of methods are available to conduct heat directly from the skin. The fear of rewarming shock withholds many clinicians from AER. This complication is virtually absent with substantial intravenous infusions of 0.5–1 litre crystalloids per °C. This amount may be necessary to maintain adequate circulation and to prevent rewarming shock. The possible explanations for the need of this substantial infusion therapy are that cardiac insufficiency develops due to changes in preload, afterload, rheological changes and alterations in the peripheral vascular beds [16]. Capillary leakage of plasma proteins and changes in autonomous vascular control also contribute to rewarming shock. Moreover, hypothermia leads to a systemic inflammatory response syndrome, which amplifies loss of circulating volume and increases fluid demands [17, 18]. The circulatory instability is preferably counteracted by the infusion of large intravenous volumes than by vasoactive drugs.

Vasodilating Therapy

A significant faster rewarming occurs when active external rewarming is combined with vasodilatory therapy using infusion of vasoactive medication as nitroglycerin or ketanserin. Vasodilation facilitates the absorption of calories. In one study, the rewarming rate was 0.25 °C/h without vasodilation versus 0.75 °C/h with vasodilation in the first 2 h after operations [19]. The delivery of external calories should be high enough to prevent afterdrop.

Forced Air Rewarming

A forced air warming system is an efficient, and increasingly popular, non-invasive method to transfer heat [1, 20]. This method has been compared with cotton blankets in a study that includes 16 patients with a temperature below 32 °C. The forced air rewarming, at 43 °C, induced a rewarming rate of 2.5 °C/h, 1 °C more than the cotton blanket group. Afterdrop was not observed [21]. Another study, in a patient group that needed to be rewarmed during resuscitation, found a rewarming rate of 1 °C/h without afterdrop [22]. When forced air rewarming was used in nine patients with stable circulation, the rewarming rate was 1.9 ± 0.8 °C/h, while in six patients that received cardiopulmonary resuscitation (CPR), the rewarming rate was 1.5 ± 0.3 °C/h [23].

Various commercial forced air rewarming systems are available and their heat transfer capacity varies greatly. The airflow should be at least 19 l/min [24, 25]. Forced air rewarming systems are rapidly set up but disposables are needed. Patient instrumentation is somewhat hampered by the system, and heat transfer is impaired when instrumentation of the patient takes place.

Radiant Heating

Several commercial systems for torso radiant heating, also called thermal ceiling, are available [26, 27]. The caloric gain is estimated between 50 and 80 kcal/h. Usually these systems are operated in combination with other rewarming methods in moderate and severe hypothermia [3]. Radiant heating is often immediately operational because they are commonly used in daily practice in many ICUs for post-operative rewarming. No disposables are needed, the access to the patient is optimal and there is no heat loss during instrumentation of the patient.

Circulating Warm Water Mattress and Resistive Heating

These systems provide substantial heat transfer, approximately 80 kcal/h, depending on the temperature of the water in the mattress. This is usually 40 °C, but it can be adjusted. There is evidence that water mattresses perform better than forced air warming systems and radiant heating [28]. In post-cardiac surgery patients, the rewarming by a circulating water mattress produced normothermia more rapidly than a forced air rewarming blanket [29]. The combination of a radiant heating with a warm water mattress underneath the patient provides rewarming rates of 2.5 °C/h [3]. Water mattresses, with cold water, can also be used for induced hypothermia after cardiac arrest and CPR.

Heating with an electric blanket is called resistive heating [30]. The air between the blanket and the body however reduces the transfer of calories. Compared to other systems, resistive heating is less efficient [31, 32].

Immersion in Warm Water Bath

In a comparative study, a warm bath of 40 °C provides faster rewarming compared to shivering or hot air and with less afterdrop [33]. Trunk-only or whole-body bath rewarming is equally effective [34]. Rewarming by immersion is most of all a cumbersome and complicated technique, notably when monitoring and eventual resuscitation is warranted.

Heated Aerosol

The lungs have a huge surface area and it is attractive to use this surface as a heat exchanger. Simultaneously, heat loss via the lungs is reduced. In practice, efficacy is limited because less than 10 % of the metabolic heat is lost due to respiration, even if dry, cool gas is used for ventilation [35].

The use of heated gases as a primary rewarming strategy is challenged. Heated gases should, in the hospital setting, be considered as a supplemental tool and not as a primary rewarming strategy [36–38].

Arteriovenous Anastomosal Rewarming

Arteriovenous Anastomosal Rewarming (AVA) rewarming is a non-invasive technique. Heat is applied via immersion of parts of the upper or lower extremities in water with a temperature of 44–45 °C. This results in the opening of arteriovenous anastomoses, allowing large quantities of blood to pass that can absorb the calories. Most authors find disappointing results when hands and feet are immersed in hot water [39, 40]. It has been suggested that also the lower arms and legs have to be immersed to obtain an effective heat transfer [41]. AVAs can also be opened by vasodilators and the application of a negative pressure [42, 43]. The latter method has been challenged recently. Core temperature increased more rapidly with forced air warming (2.6 ± 0.6 °C) than with negative pressure rewarming [44]. This study shows that heat from a negative pressure rewarming device is largely constrained to the forearm and that heat does not flow to the core thermal compartment.

136.3.3 Active Internal Rewarming Strategies

Peritoneal Irrigation

Peritoneal irrigation is widely used. Lavage is performed with one or two large peritoneal catheters which are surgically placed. Irrigation of 4–12 l/h of a dialysis solution with a temperature that may vary between 37 and 43.5 °C produces a rise in central temperature of about 1.5 °C/h [45]. A report describes this technique in five patients with accidental hypothermia between 24 and 31.7 °C, two of them had been resuscitated. Rewarming with fluid at 37 °C was smooth and free of complications [46].

Oesophageal Thermal Probes

Oesophageal thermal probes have been developed from the Sengstaken–Blakemore tube [26]. This consists of an oesophageal probe in which water is circulating in a closed warm water system of 42 °C. Preliminary results showed a rewarming rate of 1.5 °C/h [47]. In another study, it was however not possible to maintain stable perioperative core temperatures in orthopaedic patients [48].

Fluid Warmers

The infusion of 1 litre cold fluid of 4 °C causes a fall in the core temperature of 0.5–1.0 °C, and infusion of 8–10 litres Ringer's lactate at room temperature reduces core temperature of about 2 °C. During rewarming, usually substantial amounts of intravenous fluids are needed. To avoid that this reduces the body temperature, intravenous fluids should be heated before infusion [49]. Safety and efficacy of fluids of 65 °C were compared with fluids of 38 °C in an experimental study in 18–20 kg beagles. The vascular injury at the site of infusion appeared to be insignificant. The rate of rewarming was 2.9 °C/h in the 65 °C group and 1.25 °C/h in the 38 °C group [50]. In a controlled clinical study in cardiac surgery patients, a commercial available system prevented induced hypothermia [51].

Intravascular Warming

Central rewarming can be achieved by a catheter placed in the femoral vein with the tip in the lower vena cava, which can be internally heated with warm water [52–55]. The catheter has an inflow and an outflow lumen with a flow depending on the rate of rewarming. The system can cool and rewarm at the precise rate that is preferred between 1 and 3 °C/h [52, 56]. The main disadvantages are the delay in the start of rewarming until the catheter is inserted and the costs of the disposable catheter.

Veno-venous Systems

Extracorporeal rewarming of venous blood is another invasive option [57, 58]. Blood is removed via a large-bore venous or arterial catheter, heated to 40 °C and consequently returned via another venous catheter with flow rates between 150 and 400 ml/min [59–61]. Rewarming rates of 1–3 °C/h can be achieved depending on flow rates. Problems with patency of the circuit due to clotting have been solved by heparin-coated systems [62]. Haemodialysis can be used as an alternative [63].

Conclusion

The practical feasibility and efficacy of rewarming methods clearly differ. There are no randomised controlled trials that definitively have established the most optimal rewarming strategy. Nevertheless, the in-hospital treatment of accidental hypothermia, with or without immersion or submersion, should be guided by a hospital protocol. A hospital protocol should clearly describe a strategy that is feasible for the local situation. Active rewarming is indicated when thermogenesis fails to increase central temperature more than 0.5 °C/h and in patients with a core temperature below 32 °C. A combination of several methods should be applied for effective rewarming.

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