Effectiveness of Resistive Heating Compared With Passive Warming in Treating Hypothermia Associated With Minor Trauma: A Randomized Trial

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- **Objectives:** To determine the occurrence of hypothermia in patients with minor trauma, to test the hypotheses that resistive heating during transport is effective treatment for hypothermia and that this treatment reduces patients’ thermal discomfort, pain, and fear, and to evaluate the accuracy of oral temperatures obtained at the scene of injury.
- **Patients and Methods:** In December 1999 and January 2000, 100 patients with minor trauma were randomly assigned to passive warming or resistive heating. All patients were covered with a carbon-fiber resistive warming blanket and a wool blanket, but the warming blanket was activated only in those assigned to resistive heating. Core (tympanic membrane) and oral temperatures, heart rate, pain, fear, and overall satisfaction of patients were compared between the 2 groups on arrival at a hospital.
- **Results:** Hypothermia was noted in 80 patients at the time of rescue. Mean initial core temperatures were 35.4°C (95% confidence interval [CI], 35.2°C-35.6°C) in the patients who received passive warming and 35.3°C (95% CI, 35.1°C-35.5°C) in those who received resistive heating. From the time of rescue until arrival at the hospital, mean core temperature decreased 0.4°C/h (95% CI, 0.3°C/h-0.5°C/h) with passive warming, whereas it increased 0.8°C/h (95% CI, 0.7°C/h-0.9°C/h) with resistive heating. Oral and tympanic membrane temperatures were similar. Mean heart rate decreased 23 beats/min in those assigned to resistive heating but remained unchanged in those assigned to passive warming. Patients in the resistive heating group felt warmer, had less pain and anxiety, and overall were more satisfied with their care.
- **Conclusions:** Oral temperatures are sufficiently accurate for field use. Hypothermia is common even in persons with minor trauma. Resistive heating during transport augments thermal comfort, increases core temperature, reduces pain and anxiety, and improves overall patient satisfaction.


Body temperature is normally highly regulated. None-theless, hypothermia can result after extreme or pro-longed environmental exposure2,3 or when thermoregu-latory defenses are impaired by drugs, including alcohol.4,6 Minor trauma may pose a risk for hypothermia, the mag-nitude of which is unknown.

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Mild hypothermia is associated with numerous complications, including coagulopathy,7,8 reduced resistance to wound infection,9 inhibition of drug metabolism,10-12 impaired cognitive function,13 and thermal discomfort.14 Hypothermia may also contribute to pain either directly or via shivering, which might further disturb injured tissues. In patients with hypothermia, aggravated thermal discomfort and pain likely contribute to fear and an overall sense of dissatisfaction.

Numerous options exist for treating hypothermia once the patient is at a hospital.15-19 However, suitable methods for treating hypothermia that occurs during transport have been limited. A resistive heating system offers a method of treating hypothermia at the scene of injury and during transport.20

The core thermal compartment represents roughly half the body mass and comprises the head and highly perfused abdominal and thoracic organs.21-22 About 80% of the thermal input to the regulatory system is derived from the core,24,25 and most complications associated with hypothermia are best related to core temperature.2,9,26-28 Thus, core temperature is the single best indicator of a patient’s thermal status. Core temperatures are easy to measure with
invasive techniques, such as tympanic membrane, distal esophageal, or pulmonary artery probes. Core temperature can also be estimated noninvasively from the mouth, axilla, external aural canal, and even skin surface. However, these peripheral sites are highly susceptible to artifactual cooling in a cold environment.

We performed this randomized study to determine the occurrence of hypothermia in patients with minor trauma, to test the hypotheses that resistive heating during transport is effective treatment for hypothermia and that this treatment improves patient satisfaction and reduces thermal discomfort, pain, and fear, and to compare the accuracy of oral temperatures with tympanic membrane temperatures.

PATIENTS AND METHODS
This study was conducted with approval from the Ethics Committee of the Research Institute of the Vienna Red Cross. It was conducted in December 1999 and January 2000 in Vienna, Austria. Written consent was waived, but a verbal consent was obtained from the participants. Based on a preliminary study of 55 patients, we calculated that a sample size of 100 would provide more than a 99% chance of identifying a statistically significant difference in core temperature at an \( \alpha \) level of 0.01. Thus, we enrolled 100 patients older than 19 years.

The Austrian Red Cross is divided into 2 parallel systems. Minor trauma and illnesses are handled by paramedics who are not permitted to give drugs or fluids or to perform any invasive procedures. Patients with serious injuries or illnesses are transported to a hospital by ambulance with a physician in attendance. All our patients were transported by paramedics and thus had minor trauma, including limited bleeding, fractures, or contusions. Patients were excluded if they were not fully conscious or if they could not easily communicate with paramedics.

Protocol
At the scene of injury, 1 investigator (F.L.) determined whether patients were suitable for this study and obtained verbal consent for participation. Patients in both groups were covered with a carbon-fiber electric heating blanket, which itself was covered by a single wool blanket.

The carbon-fiber heating blanket (ThermaMed, GmbH, Hamm, Germany) is 80 × 200 cm, with the actively heated section being 40 × 148 cm. Resistive heating is provided by a 7- to 8-A current passing through the carbon fiber. The batteries weigh 0.5 kg, each lasting 30 to 40 minutes.

Patients were then randomly assigned to 2 groups: passive warming or resistive heating. Randomization was based on computer-generated codes that were sealed in sequentially numbered opaque envelopes. The blankets were set to 42°C for the patients assigned to resistive heating, but the blanket electrical system was not activated in patients assigned to passive warming. The electrical system was set by an unblinded investigator (W.V.) based on randomization, and the control unit was subsequently locked in a metal box. Once positioned, the blankets were left in place until the patients arrived at the hospital. The designated treatment began at the scene of the injury, before patients were transferred to the ambulance.

Routine care was administered, including bandaging injuries and splinting fractures. Because the injuries were minor and nonurgent, the paramedics often packed a small bag for the patients to take with them to the hospital. This entire process required 30 minutes or more. Patients were then transported to a hospital. The patient’s choice of hospital was considered since the injuries were nonurgent; consequently, patients were not necessarily transported to the nearest facility.

Measurements
We recorded morphometric and demographic characteristics, type of injury, whether injury occurred indoors or outdoors, and how much time had elapsed between injury and rescue. Intoxication was qualitatively rated as none, moderate, or severe.

Measurements were performed at the injury scene, on entering the ambulance, and on arrival at the hospital. The first set of measurements was obtained before the randomization envelope was opened. All measurements were recorded by 1 investigator (A.K.) who was blinded to randomization and whether the carbon-fiber blanket electrical system had been activated. He was not allowed to touch the patient or blanket but could talk to the patient during rescue and transport. The study was unblinded to the extent that many patients assigned to resistive heating said that the blanket felt warm.

Measurements included oscillometric blood pressure and heart rate and whether patients were shivering. Patients were asked to rate their anxiety level as none, mild, or severe. Patients also rated their pain on a scale of zero to 5, in which zero indicated no pain and 5 was the worst imaginable pain. Patients rated their thermal sensation as very cold, somewhat cold, comfortable, somewhat warm, or hot.

Air temperature was recorded from a thermocouple positioned at the level of the patient’s head. Oral temperatures were determined from an electronic sublingual thermometer that was kept in position for at least 3 minutes, during which patients breathed nasally. Core temperatures were recorded from the tympanic membrane, a site that correlates optimally with distal esophageal and pulmonary artery temperatures, even during extreme thermal perturbations of cardiopulmonary bypass.
As in previous studies, the aural probe was inserted until patients felt the thermocouple touch the tympanic membrane; appropriate placement was confirmed when patients easily detected a gentle rubbing of the attached wire. The aural canal was occluded with cotton, the probe securely taped in place, and a gauze bandage positioned over the external ear. The first reading was performed at least 5 minutes after the tympanic membrane probe was inserted. Temperatures were recorded with digital thermometers (Mon-a-Therm, Mallinckrodt Anesthesiology Products, Inc, St Louis, Mo) that have an accuracy near 0.1°C.

On arrival at the hospital, patients were asked to rate their overall satisfaction with their care as very good, good, satisfactory, barely acceptable, and unacceptable.

**Statistical Analyses**

Tympanic membrane temperatures lower than 36°C were considered hypothermic. Normally distributed, continuous data were compared with 2-tailed, unpaired t tests. Nonparametric, continuous data were compared with the Wilcoxon signed rank test, and nominal data were compared with a χ² test. Data are presented as mean (95% confidence interval [CI]) or mean ± SD; P<.01 was considered statistically significant. Intention-to-treat analyses were used throughout the study.

Tympanic membrane temperatures were considered core values. The correlation between oral and tympanic membrane temperatures was evaluated with linear regression and Bland-Altman statistics. All 3 sets of temperatures (injury scene, entry into ambulance, and arrival at hospital) were included in the analysis. As in previous studies, we considered oral temperatures within 0.5°C of the tympanic membrane values (ie, a 1°C range) sufficiently accurate for routine clinical use. Unless otherwise specified, all temperatures are reported as tympanic membrane values.

**RESULTS**

An audit confirmed that patients were properly assigned to passive warming or resistive heating. None of the enrolled patients dropped out of the study, and all patients completed the study in the group to which they were assigned. Thus, our analysis is based on 50 patients in each treatment group.

Although all injuries were minor, many of the patients were unable to telephone for help because they were intoxicated or because fractures restricted their movement. Time before rescue averaged 1 to 1 1/2 hours but was as long as 10 hours. Hypothermia (tympanic membrane temperature <36°C) was observed in 80 patients at the time of rescue; 27 had core temperatures lower than 35°C.

Morphometric and demographic characteristics of the patients in each treatment group were similar. None of the potential confounding factors differed significantly in the 2 groups. Duration of rescue and transport averaged about 1 hour in each group (Table 1). Initial reports of pain, thermal comfort, and anxiety did not differ significantly in the 2 groups.

Mean initial core temperatures were 35.4°C (95% CI, 35.2°C-35.6°C) in patients assigned to passive warming and 35.3°C (95% CI, 35.1°C-35.5°C) in those assigned to resistive heating. From the time of rescue until arrival at the hospital, mean core temperature decreased 0.4°C/h (95%
Table 2. Patients’ Temperature, Hemodynamic Responses, and Shivering on Arrival at Hospital*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Passive warming</th>
<th>Resistive heating</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core temperature (°C)</td>
<td>35.0 (34.8 to 35.2)</td>
<td>36.3 (36.2 to 36.4)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Rewarming rate (°C/h)</td>
<td>–0.4 (–0.35 to –0.45)</td>
<td>+0.8 (0.72 to 0.88)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Systolic arterial pressure (mm Hg)</td>
<td>111 (107 to 115)</td>
<td>119 (117 to 121)</td>
<td>.009</td>
</tr>
<tr>
<td>Change in systolic arterial pressure (mm Hg)</td>
<td>–2 (0.5 to –3.5)</td>
<td>+4 (2 to 6)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Diastolic arterial pressure (mm Hg)</td>
<td>71 (68 to 74)</td>
<td>80 (78 to 82)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Change in diastolic arterial pressure (mm Hg)</td>
<td>–3 (1 to –6)</td>
<td>+8 (5 to 11)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>96 (94 to 98)</td>
<td>74 (72 to 76)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Change in heart rate (beats/min)</td>
<td>+1 (–1 to +3)</td>
<td>–23 (–20 to –26)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Duration of rescue and transport (min)</td>
<td>64 (61 to 67)</td>
<td>69 (67 to 71)</td>
<td>.09</td>
</tr>
<tr>
<td>Shivering</td>
<td>44</td>
<td>1</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*Data are shown as number of patients or mean (95% confidence interval).
tion, and prolonged time between injury and rescue. These data suggest that minor injuries are often associated with hypothermia.

Detection of hypothermia before a patient arrives at the hospital requires a method of temperature measurement suitable for routine field use. Standard core-temperature monitoring sites (typanic membrane, nasopharynx, distal esophagus, or pulmonary artery) are not practical for field use.39,47 Many peripheral sites used to estimate core temperature in hospitals are also unsuitable for field use because of access difficulty (ie, rectum) or because they are subject to environmental artifact (ie, axilla).31,38,41 Our data indicate that carefully obtained oral temperatures remain reliable over a wide range of ambient temperatures.

The measurements must be taken carefully, with the probe properly positioned under the patient’s tongue and with the patient’s mouth closed.42 We used a thermocouple connected to a standard intraoperative electronic thermometer; however, handheld digital thermometers intended for oral use are inexpensive and readily available. Their utility is comparable to the type we used because the variation in clinical temperature measurements is largely related to the site rather than accuracy of the thermometers themselves.

Resistive heating transfers more heat than “space blankets” under laboratory conditions.20 Thus, it is hardly surprising that core temperature increased in our patients in the resistive heating group, whereas it continued to decrease in those in the passively warmed group. As a result, core temperature was 1.3°C greater in the resistive heating group when they arrived at a hospital. This difference is clinically important because temperature differences of this magnitude are associated with numerous complications.7-13

Shivering occurred in 44 patients (88%) in the passively warmed group but in only 1 patient (2%) in the resistive heating group. Shivering typically increases metabolic rate by roughly a factor of 2.47 although the increase can be considerably less46 or more.47 That core temperature in the resistive heating group increased more than that in the passively warmed group suggests that the resistive heating blanket was able to compensate for the presumed disparity in metabolic heat production in the 2 treatment groups. Thus, resistive heating likely transferred more heat than would be expected based on the difference in core temperature alone.

Postoperative patients with hypothermia appear to experience pronounced surgical pain. We had thought that hypothermia per se aggravated pain perception. However, hypothermia increases the potency of anesthetic drugs.48,49 Hypothermia also slows elimination and metabolism of analgesics, thus prolonging their duration of action.10,12 Consequentially, it would be difficult to control the confounding effects of temperature-dependent pharmacokinetic and pharmacodynamic variation in the immediate postoperative period. Our study participants differed from postoperative patients in that they were not given analgesics. Thus, they were an ideal group for evaluating effects of hypothermia on pain perception. The results are clear: warm patients experience less pain.

Cutaneous contribution to autonomic thermoregulatory cold defenses is about 20%.24,25 This means that each 4°C of skin warming compensates for 1°C of core hypothermia with respect to initiation of arteriovenous shunt vasoconstriction and shivering. In contrast, behavioral responses are 50% controlled by cutaneous thermal input.50 Our patients in the passively warmed group were centrally hypothermic but presumably also had cool skin and certainly felt cold. Therefore, we are unable to estimate the relative contributions of core and skin hypothermia to pain perception. Nonetheless, our data clearly show that the combination of core and cutaneous hypothermia markedly increases perception of pain from minor trauma. This suggests that cutaneous warming, which is easy to provide and essentially risk free, will reduce the need for analgesic medication.

Both pain and hypothermia activate the sympathetic nervous system.51-53 Thus, it is not surprising that resistive

Figure 2. Patient pain, thermal comfort, and anxiety on arrival at hospital differed significantly in the 2 groups (P<.001 in all 3 categories).

heating was also associated with a marked reduction in anxiety and improved patient satisfaction. Both are likely to result from improved thermal comfort, reduced pain, and less activation of the sympathetic nervous system. Our data suggest that resistive heating provides considerable benefit in addition to restoring core normothermia.

Our randomized study was blinded to the extent feasible, although the patients in the resistive heating group were obviously able to sense that they were being warmed and may have communicated this to one of the investigators. Nonetheless, our main results were obtained objectively, and basic physiological values, including core temperature and heart rate, are unlikely to be influenced by patient expectations or investigator bias.

CONCLUSION
Hypothermia is common, even in persons with minor trauma. Resistive heating during hospital transport augments thermal comfort, increases core temperature, reduces pain and anxiety, and improves overall patient satisfaction. Therefore, we recommend that persons with minor trauma be actively warmed during transport to the hospital.

REFERENCES


