HIGH ALTITUDE MEDICINE & BIOLOGY
Volume 15, Number 2, 2014

DOI: 10.1089/ham.2014.1008

Pre-Hospital Core Temperature Measurement in Accidental and Therapeutic Hypothermia

Giacomo Strapazzon, MD,[1] Emily Procter, MSc,[1] Peter Paal, MD,[2] and Hermann Brugger, MD[1]

Abstract

Strapazzon, Giacomo, Emily Procter, Peter Paal, and Hermann Brugger. Pre-hospital core temperature measurement in accidental and therapeutic hypothermia. *High Alt Med Biol.* 15:104–111, 2014.—Core temperature (T_{core}) measurement is the only diagnostic tool to accurately assess the severity of hypothermia. International recommendations for management of accidental hypothermia encourage T_{core} measurement for triage, treatment, and transport decisions, but they also recognize that lack of equipment may be a limiting factor, particularly in the field. The aim of this nonsystematic review is to highlight the importance of field measurement of T_{core} and to provide practical guidance for clinicians on pre-hospital temperature measurement in accidental and therapeutic hypothermia. Clinicians should recognize the difference between alternative measurement locations and available thermometers, tailoring their decision to the purpose of the measurement (i.e., intermittent vs. continual measurement), and the impact on management decisions. The importance of T_{core} measurement in therapeutic hypothermia protocols during early cooling and monitoring of target temperature is discussed.

Key Words: accidental hypothermia; core temperature measurement; pre-hospital triage, treatment and transport decisions; thermometer; therapeutic hypothermia

Introduction

Accidental hypothermia should be assessed in any patient with a history of cold exposure (including during outdoor recreation or expeditions) or a disease that predisposes them to hypothermia or a cold trunk (i.e., skin feels cold to touch). Hypothermia is defined as core body temperature (T_{core}) $< 35°C$. Accurate measurement of T_{core} is important in many patient care settings in order to make the most appropriate treatment and transport decision (e.g., a hypothermic unstable patient with systolic blood pressure < 90 mmHg or ventricular arrhythmia and $T_{core} < 28°C$ should be transferred to a tertiary care center with extracorporeal circulation), or for example to obtain the targeted T_{core} during therapeutic hypothermia (32°–34°C). For pre-hospital management of hypothermic victims, T_{core} is one of the fundamental guiding parameters for in-field treatment and triage decisions (Brown et al., 2012). Despite this, current practice uses a system of staging that is based primarily on clinical signs and symptoms, which, while being practical and applicable also by nonmedical providers, does not include direct measurement of T_{core}.

In an international registry of alpine trauma cases in the European Alps (http://traumaregistry.eurac.edu/), pre-hospital

[1]EURAC Institute of Mountain Emergency Medicine, Bozen/Bolzano, Italy.
[2]Department of Anesthesiology and Critical Care Medicine, Innsbruck Medical University, Innsbruck, Austria.

T_{core} was reported in only 9% of cases (unpublished data). Though these data are only indicative, pre-hospital measurement of T_{core} is likely not commonplace in many regions. International recommendations for management of accidental hypothermia encourage T_{core} measurement, but they also recognize that lack of equipment may be a limiting factor (Vanden Hoek et al., 2010; Brugger et al., 2013). The aim of this nonsystematic review is to highlight the importance of field measurement of T_{core} and, despite the absence of reliable evidence-based data, to provide practical guidance for clinicians on pre-hospital temperature measurement in accidental and therapeutic hypothermia.

History of Body Temperature Measurement

The first thermometer designed for clinical use was a very basic mouth thermometer introduced in 1612 by the Italian Sanctorius (Haller, 1985). Fahrenheit invented a more practical device, the mercury-in-glass thermometer, in 1714, and after further improvements in the following century, a small, faster-reading thermometer increased the clinical practice of temperature measurement (Haller, 1985; Guly, 2011). The problems associated with low T_{core} were recognized later when thermometers could record lower temperatures (to 24°C) (Wunderlich and Seguin, 1871; Guly, 2011). Since 1967, when cardiopulmonary bypass revolutionized the treatment of hypothermic arrested victims (Davies et al., 1967; Kugelberg et al., 1967), pulmonary artery temperature became the gold standard for T_{core} measurement in patients with severe accidental hypothermia (Walpoth et al., 1997). Concurrently, interest in alternative, less invasive sites for temperature measurement led to the auditory canal and tympanic temperature (Benzinger, 1959; Brinnel and Cabanac, 1989), and others investigated the effect of environmental factors (i.e., cold) on tympanic, esophageal, and rectal measurement (Marcus, 1973; Keatinge and Sloan, 1975).

Underlying Pathophysiological Considerations

Normally the temperature of blood in the human heart is 37.3°C–37.6°C; the lowest reported temperature compatible with human life is 9°C in hypothermia during cardiovascular surgery (Niazi and Lewis, 1958) and 13.7°C in accidental hypothermia (Gilbert et al., 2000). Under normal conditions, temperature in the heart remains fairly constant due to thermoregulation, even in a person without clothing or exposed to low ambient temperatures. In contrast, skin temperature rises and falls with changes in ambient temperature. Skin loses heat to the surroundings if it is warm and insulates the body if it is cold. Heat is produced in the internal organs, especially in the liver, brain, heart, and in skeletal muscles during exercise. Heat loss depends on the rate of energy transfer from the core to the skin, and this can be regulated through dilation or constriction of the subcutaneous vessels.

With fever or at high ambient temperatures, two mechanisms reduce T_{core}: (i) intensive dilation of skin vessels in almost all areas of the body by inhibition of the sympathetic centers in the hypothalamus, and (ii) heat evaporation by sweating. In contrast, when the body is too cold, hypothalamic sympathetic stimulation causes constriction of skin vessels, which has an insulating effect that protects the deep organs from sudden heat loss; in this case, skin temperature drops faster than T_{core} and an increasing gradient exists between skin and core temperature (Guyton, 1991). Thus, in hypothermia skin temperature does not reflect T_{core}, and T_{core} should be measured close to the inner organs, especially the heart or brain.

In practical terms, if the skin of a patient feels warm, the difference between external temperature and T_{core} are expected to be minimal and temperature can be reliably taken externally (axilla, oral cavity, ear canal); however, the clinician should consider possible bias from environmental (e.g., cold air) or other factors. If the skin is cold or skin temperature is lower than normal, one should not rely on external readings but measure T_{core} as close as possible to the heart or brain.

Thermometer Use in the Field

Measurement location

The ideal measurement site is dependent on environmental, logistical and clinical (e.g., perfusion) factors (Table 1). Sites for temperature measurement, in order of increasing invasiveness, include the skin/axilla, oral cavity, tympanic membrane, rectum, bladder, esophagus, and pulmonary artery. Measurement in the pulmonary artery is the gold standard and reflects temperature in the heart. However, the invasiveness is limiting for pre-hospital and most in-hospital applications. Esophageal temperature correlates well with pulmonary artery temperature if the probe is placed in the lower third of the esophagus, and is considered the standard for pre-hospital measurement of T_{core} in intubated hypothermic victims (Hayward et al., 1984; Robinson et al., 1998; Durrer et al., 2003; Brugger et al., 2013). Measurement in the bladder, despite widespread use and reliability for in-hospital monitoring (Fallis et al., 2002; Shin et al., 2013), is impractical for field measurement and can be falsely low with cold diuresis. Rectal probes should be inserted to a depth of 15 cm, but the patient has to be partially undressed and readings may lag behind esophageal temperature during rapid changes in temperatures (Vanggaard et al., 1999; Giesbrecht, 2000). Epitympanic temperature may be used in non-intubated patients if the ear canal is not obstructed (e.g., cerumen, snow) and if the canal is insulated from ambient air (Walpoth et al., 1994), but currently there is a need for modified epitympanic probes more suitable for field use. Case reports of deep hypothermic patients have shown that in-field epitympanic temperature was comparable to T_{core} measured invasively at hospital admission (Oberhammer et al., 2008; Koppenberg et al., 2012; Strapazzon et al., 2012), but there is still no clear evidence for the reliability of epitympanic T_{core} measurements at low ambient temperature. Skin/axilla and oral measurements with standard thermometers are not accurate in hypothermic patients.

In practical terms, if a hypothermic patient is intubated, T_{core} should be regularly recorded in the lower third of the esophagus. If the patient is responsive, the use of a contact-based epitympanic thermometer may be an acceptable alternative. If T_{core} measurement is not possible (e.g., clinical, environmental, or logistical reasons), out-of-hospital triage and treatment decisions can be based on clinical evaluation (Brugger et al., 2013; Lundgren et al., 2013), but the clinician should be aware of the pitfalls of using clinical signs to infer about T_{core}.

Types of thermometers

For in-field T_{core} measurement, the optimal thermometer would be as minimally invasive as possible, easy to handle, hygienic, and independent of environmental conditions, while

Table 1. Suitability of Temperature Measurement Sites for In-field Use in Hypothermic Patients in Order of Invasiveness

Measurement site	*Advantages*	*Disadvantages*	*In-field validation studies*[a]	*In-hospital validation studies*	*Suitability*[b]
Esophagus	• Reflects temperature of deep organs	• Only suitable if intubated or supraglottic airway device that allows passage down a gastric tube	Locher et al., 1997 (case series); Strapazzon et al., 2013 (experimental): healthy volunteers in cold environment (max. −20°C)	Robinson et al., 1998 (observational): in-hospital induced deep hypothermia	++ to +++ ground, air
Bladder	• Combined temperature and urine monitoring • Commonly used in-hospital thus no need to change probe after hospital admission	• False (low) measurement with cold diuresis • Response to changes in T_{CORE} may be delayed (less than rectal temperature) • Impractical for on-site use (may be possible during patient transport to hospital) • Not compatible with all monitors		Robinson et al., 1998; Camboni et al., 2008; Knapik et al., 2012; Shin et al., 2013 (all observational): in-hospital induced deep hypothermia	-
Rectum	• Reliable in steady-state conditions	• Slow response to changes in T_{CORE}, especially with presence of faeces or if lower extremities are frozen	Doyle et al., 1992 (experimental): healthy volunteers in cold environment (max. −5°C)	Robinson et al., 1998 (experimental); Camboni et al., 2008 (observational); Shin et al., 2013 (observational): in-hospital induced deep hypothermia	− to + ground
Epitympanic	• Minimally invasive • Correlates well with brain temperature	• Not accurate if cardiac arrest, obstructed canal • Influenced by ambient temperature if canal not insulated • Requires placement near tympanic membrane (thermistor/thermocouple) • Infrared method not accurate for hypothermic patients • Measurement may require initial stabilization period of a few minutes	Doyle et al., 1992 (experimental); Walpoth et al., 1994 (experimental); Locher et al., 1997 (case series); Strapazzon et al., 2013 (experimental): healthy volunteers in cold environment (max. −20°C)	Walpoth et al., 1994 (experimental); Camboni et al., 2008 (observational); Shin et al., 2013 (observational): in-hospital induced deep hypothermia	++ to +++[c] ground, air, exp
Skin: (zero) heat flux methods	• Noninvasive	• Measurement requires stabilization period of a few minutes • May not reflect temperature of deep organs	Werner et al., 2010 (experimental): animal model of accidental hypothermia	Zeiner et al., 2010 (observational); Opatz et al., 2013 (observational): in-hospital induced mild and deep hypothermia	− to +[c]

[a]These studies were performed on normothermic persons.
[b]Suitability is classified as highly suitable (+++), suitable (++), possibly suitable (+), and not suitable (−) for potential application during terrestrial-based mountain rescue (ground), air-based mountain rescue (air), or expeditions (exp).
[c]Devices modified for in-field use should be considered.

Table 2. Technical Information for Selected Thermometers by Measurement Site and Order of Invasiveness

Measurement site	*Producer*	*Device model*	*Probe type*	*Accuracy (for specified range)*	*Operating ambient temperature*	*Data display*
Esophageal/Rectal	Covidien	Mon-a-therm™ General Purpose Temperature Probe 400TM	not reported	not reported	not reported	monitor
	DeRoyal	General-purpose temperature probe 400 or 700 series	thermistor	not reported	not reported	monitor
	Geratherm	DataTherm® II	thermistor	not reported	not reported	hand-held unit
	Philips	Esophageal/Rectal Temperature Probe	thermistor	±0.1°C (25–45°C), ±0.2°C (0–60°C)	not reported	monitor
	Physio-Control	Esophageal-Rectal Temperature Sensor	thermistor	±0.2°C (24.8–45.2°C)	not reported	monitor
	Smiths Medical	Level 1® Thermistor General Purpose Probe 400, 700 or 700 substitute series; Thermocouple General Purpose Probe	thermistor, thermocouple	400 series: ±0.2°C 700 series: ±0.1°C 705 series: ±0.3°C Thermocouple: ±0.3°C (range not reported)	not reported	monitor
Bladder	Covidien	Mon-a-therm™ Foley with Temperature Sensor 400TM	thermistor	not reported	not reported	monitor
	DeRoyal	Foley catheter temperature probe 400 or 700 series	thermistor	not reported	not reported	monitor
	Philips	Foley catheter probe	thermistor	±0.1°C (25–45°C), ±0.2°C (0–60°C)	not reported	monitor
	Physio-Control	Foley Catheter Temperature Sensor	thermistor	±0.2°C (24.8–45.2°C)	not reported	monitor
	Smiths Medical	Level 1® Foley Catheter Temperature Sensor 400 series	thermistor	±0.2°C (range not reported)	not reported	monitor
Epitympanic	DeRoyal	Tympanic temperature probe 400 series	thermistor	not reported	not reported	monitor
	Smiths Medical	Level 1® Thermistor Tympanic Sensor 400 or 700 substitute series; Thermocouple Tympanic Sensor	thermistor, thermocouple	400 series: ±0.2°C 705 series: ±0.3°C Thermocouple: ±0.3°C	not reported	monitor
	Starboard Medical	Adult Tympanic Temperature Sensor 400 series	thermistor	±0.1°C (37°C), ±0.2°C (25–45°C)	not reported	monitor
Skin	3M™	SpotOn™	zero heat flux method	not reported	upper limit 45°C	monitor

Information is based on the product descriptions available on manufacturers' websites and is shown as ''not reported'' if not found on the website:
Covidien: http://www.covidien.com/rms/products/temperature-management/mon-a-therm
DeRoyal: http://www.deroyal.com/MedicalProducts/surgicalandacutecare/catalog.aspx?id=ac-tempmonitoring
Geratherm: http://geratherm.de/temperature-management/datatherm-ii/
Philips: http://www.healthcare.philips.com/ca_en/products/resuscitation/products/MRx/supplies_temp.wpd
Physio-Control: http://www.physio-control.com/uploadedFiles/Physio85/Contents/Healthcare_Professionals/Accessories_and_Disposals/Accessories_Catalog_3300304_J.pdf
Smiths Medical: http://www.smiths-medical.com/catalog/temperature-probes/
Starboard Medical: http://www.starboardmedical.com/products.html
3M™: http://solutions.3m.com/wps/portal/3M/en_US/IPD-NA/3M-Infection-Prevention/products/catalog/~/Infection-Prevention-Products/Temperature-Monitoring?N=7580173&rt=c3&WT.mc_id=spotontemperature.com

still able to reflect small temperature changes and have a short response time (Gunga et al., 2008). Unfortunately, most commercially available thermometers are designed for in-hospital procedures and require connection to patient monitors (Table 2). Many newer V monitors are compatible with standard probes, but the measurement range of these probes may be suitable to detect only mildly hypothermic (e.g., ≥32°C) patients. There are several hand-held, infrared-based tympanic devices commonly used for in-hospital applications; they are not reliable for use in a cold environment. There are no lightweight, hand-held devices tailored to T_{core} measurement in deep hypothermic victims and designed to withstand exposure to cold ambient temperatures. Pre-hospital use of most available thermometers falls outside the tested operating conditions, since standard sensors have either been validated in-hospital in relatively stable conditions, or during cold exposure but in normothermic, conscious, and healthy volunteers (Table 2). The user is responsible for understanding the technical limits of the device and the sources of error associated with the device and the measurement site.

In practical terms, choose an autonomous device if connection to a patient monitor is not possible (e.g., terrestrial-based rescue) and monitor-compatible probes if a monitor is available (e.g., air- or ambulance-based rescue). Consider that esophageal and epitympanic probes react more promptly to changes of T_{core} than measurements in the bladder and rectum and are more suitable for out-of-hospital emergency situations. The optimal probe will be a compromise between invasiveness and ease of use.

Implications of T_{core} Measurement for Accidental Hypothermia

On-site hypothermia staging

Though direct measurement of T_{core} is optimal to assess the severity of hypothermia accurately, common classifications schemes use descriptive stages based on clinical signs and symptoms to infer actual T_{core} (Table 3). These systems differ slightly in the cut-off temperature between stages. The Swiss system is based on evaluation of consciousness, shivering, and vital signs (stages HT I to HT IV) and can be used also by nonmedical providers (Durrer et al., 2003). The clinical manifestation of accidental hypothermia is typically a progressive deterioration from mild neurologic impairment to cardiac instability to loss of vital signs. However, the disadvantage of descriptive staging is that the level of consciousness varies widely among patients at a given T_{core} and therefore it is difficult to recognize the temperature thresholds for risk of cardiac arrhythmias or cardiac arrest (Vanden Hoek, 2010; Brown et al., 2012). Also, vital signs can be present in hypothermic patients despite T_{core} <24°C (Pasquier et al., 2014). Moreover, hypothermia is often complicated by associated injuries or illnesses such as traumatic brain injury or intoxication (Danzl and Pozos, 1994).

In practical terms, T_{core} does not always correspond to a patient's clinical presentation or level of consciousness. Clinicians should consider other underlying reasons for signs and symptoms and preferably rely on direct T_{core} measurement.

Early assessment of afterdop

Afterdrop is defined as continued core cooling after removal of a hypothermic patient from the cold environment. It is possible that both general circulatory changes (i.e., convection of heat by blood from the cooler peripheral tissue to the warmer central organs) as well as temperature equilibration (i.e., conduction of heat from the warmer core to the cooler peripheral tissue) contribute to this temperature drop (Giesbrecht and Bristow, 1992). The occurrence of afterdrop has been inferred from studies on regional temperature variations in the body (rectal vs. pulmonary/esophageal) and its pathophysiological mechanisms were clarified by discrepancies in temperature change during cooling and rewarming (Romet, 1988; Giesbrecht and Bristow, 1992; Opatz et al., 2013). Rescue personnel should be aware of this phenomenon, in particular when rescuing victims of cold-water immersion or when using infusion of cold fluids for volume resuscitation.

In practical terms, avoid T_{core} measurement with a rectal probe because of the delay in response to changes in body temperature. Epitympanic temperature may be a valid alternative. Esophageal temperature will provide the fastest and most reliable measurement both for diagnostic and monitoring purposes. Meanwhile, rescuers should keep the victims horizontal and move them gently.

Triage and transport decisions

Although all cardiac arrhythmias may occur already with T_{core} <32°C, cardiac arrest is likely with T_{core} <28°C (Duguid et al., 1961; Grueskin et al., 2007; Paal et al., 2013). Below 28°C, a patient with circulation should be considered at risk of imminent cardiac arrest and should be, similar to all

Table 3. Staging of Hypothermia

American Heart Association[a]		*Danzl*[b]		*Swiss*[c]	
>34°C	Mild hypothermia	37.6 to >32°C	Mild hypothermia	35–32°C	Hypothermia I (clearly conscious, and shivering)
34–30°C	Moderate hypothermia	32 to >28°C	Moderate hypothermia	<32–28°C	Hypothermia II (impaired consciousness, without shivering)
<30°C	Severe hypothermia	28 to >20°C	Severe hypothermia	<28–24°C	Hypothermia III (unconscious)
		≤20°C	Severe and profound hypothermia	<24°C	Hypothermia IV (minimal vital signs or apparent death)

[a]Vanden Hoek et al., 2010; [b]Danzl, 2012; [c]Durrer et al., 2003; Gordon et al., 2014.

hypothermic arrested patients deemed eligible for extracorporeal rewarming, primarily transported to an CPB/ECMO center (Brown et al., 2012; Brugger et al., 2013). Despite occasional cases of successful defibrillation, defibrillations may be unsuccessful if T_{core} <30°C (Vanden Hoek et al., 2010). For completely buried avalanche victims in asystolic cardiac arrest, T_{core} should be measured if burial time is unknown: with T_{core} <32°C and an obstructed airway, asphyxia should be presumed and resuscitation withheld (Brugger et al., 2013). In a mass avalanche accident, priority for transport and treatment should be given to those victims with higher T_{core} (Brugger et al., 2013).

In practical terms, T_{core} and ECG monitoring are equally important and required to make on-site triage and treatment decisions based on recommendations. A pre-hospital monitor that allows connection to standard temperature probes (not standard skin sensors) should be used.

Implications of T_{core} Measurement for Therapeutic Hypothermia

Therapeutic hypothermia was first described in the early 1950s (Belluci, 1953) and has since become the keystone in the treatment of cardiac arrest patients with return of spontaneous resuscitation (ROSC) (Pederby et al., 2010; Nolan et al., 2012; Scirica, 2013). In the last years, research on therapeutic hypothermia has been extended to other fields of emergency medicine such as cerebral ischemia, myocardial infarction, aneurysmal subarachnoid hemorrhage, and traumatic spinal cord injury (Karibe et al., 2000; Abou-Chebl et al., 2011; Testori et al., 2013; Wilson et al., 2013). Guidelines suggest cooling as soon as possible after ROSC (Pederby et al., 2010) and only recently, the potential additional benefit of pre-hospital cooling has been investigated (Diao et al., 2013; Kim et al., 2014). Heterogeneity in T_{core} measurement location has been highlighted (Diao et al., 2013); measurement and monitoring have been performed pre-hospitally with epitympanic and esophageal probes (Kim et al., 2014) and intra-hospitally with esophageal, rectal, bladder, brain, or pulmonary artery probes (Karibe et al., 2000; Abou-Chebl et al., 2011). During therapeutic hypothermia protocols, it is mandatory not only to assess the target T_{core}, but also to maintain the target temperature within a narrow range. Temperature <32°C increases the risk of further cardiac instability (Vanden Hoek et al., 2010) and experimental animal studies have shown that high temperature, even a minimal rise, can have detrimental effects on neuron functioning (Lei et al., 1994; Wass et al., 1995).

In practical terms, in the field T_{core} monitoring with epitympanic or esophageal probes is recommendable for early application and monitoring results of therapeutic hypothermia protocols. Harmful effects can arise with cooling to <32°C (e.g., if external and endovenous cooling procedures are combined), and untreated increase in T_{core}.

Future Perspectives

Apart from invasive T_{core} measurement sites, a reliable T_{core} measurement device for conscious patients in the field is currently not available. Though epitympanic temperature may have advantages over other noninvasive sites, suitability remains a problem—a previous epitympanic thermometer is no longer produced (Walpoth et al., 1994) and newer commercially-available probes may be used in-hospital but are not reliable in cold ambient temperatures (Strapazzon et al., 2013). Further developments in technology and/or design of epitympanic probes may be of interest. A new hand-held device for measurement on the skin has recently been developed and is able to monitor regional temperature differences of the two main target organs (i.e., brain and heart; Gunga et al., 2008; Kimberger et al., 2009). Studies with this device in cold patients and in nonstandardized conditions are ongoing (Werner et al., 2010; Zeiner et al., 2010; Opatz et al., 2013).

Reliable and continuous pre-hospital T_{core} measurement could increase use in the field and compliance to guidelines and consequently lead to improvements in pre-hospital management of accidental and therapeutic hypothermia.

Author Disclosure Statement

The authors have no conflicts of interest to disclose.

References

Abou-Chebl A, Sung G, Barbut D, and Torbey M. (2011). Local brain temperature reduction through intranasal cooling with the RhinoChill device: Preliminary safety data in brain-injured patients. Stroke 42:2164–2169.

Bellucci G. (1953). [Controlled hypothermia in resuscitation]. Atti Accad Fisiocrit Siena Med Fis 21:78–83.

Benzinger TH. (1959). On physical heat regulation and the sense of temperature in man. Proc Natl Acad Sci USA 45: 645–659.

Brinnel H, and Cabanac M. (1989). Tympanic temperature is a core temperature in humans. J Therm Biol 14:47–53.

Brown D, Brugger H, Boyd J, and Paal P. (2012). Accidental hypothermia. New Engl J Med 367:1930–1938.

Brugger H, Durrer B, Elsensohn F, Paal P, Strapazzon G, Winterberger E, Zafren K, and Boyd J. (2013). Resuscitation of avalanche victims: Evidence-based guidelines of the international commission for mountain emergency medicine (ICAR MEDCOM) intended for physicians and other advanced life support personnel. Resuscitation 84:539–543.

Camboni D, Philipp A, Schebesch KM, and Schmid C. (2008). Accuracy of core temperature measurement in deep hypothermic circulatory arrest. Interact Cardiovasc Thorac Surg 7:922–924.

Danzl DF. (2012). Accidental hypothermia. In: Wilderness Medicine, 6th ed. P.S. Auerbach, ed. Mosby, Philadelphia; pp. 116–142.

Danzl DF, and Pozos RS. (1994). Accidental hypothermia. N Engl J Med 331:1756–1760.

Davies DM, Millar EJ, and Miller IA. (1967). Accidental hypothermia treated by extracorporeal blood-warming. Lancet 1:1036–1037.

Diao M, Huang F, Guan J, Zhang Z, Xiao Y, Shan Y, Lin Z, and Ding L. (2013). Prehospital therapeutic hypothermia after cardiac arrest: A systematic review and meta-analysis of randomized controlled trials. Resuscitation 84:1021–1028.

Doyle F, Zehner WJ, and Terndrup TE. (1992). The effect of ambient temperature extremes on tympanic and oral temperatures. Am J Emerg Med 10:285–289.

Durrer B, Brugger H, Syme D, and International Commission for Mountain Emergency Medicine (2003). The medical on-site treatment of hypothermia: ICAR-MEDCOM recommendation. High Alt Med Biol 4:99–103.

Duguid H, Simpson RG, and Stowers JM. (1961). Accidental hypothermia. Lancet 2:1213–1219.

Fallis WM. (2002). Monitoring urinary bladder temperature in the intensive care unit: State of the science. Am J Crit Care 11:38–45.

Giesbrecht GG. (2000). Cold stress, near drowning and accidental hypothermia: A review. Aviat Space Environ Med 71:733–752.

Giesbrecht GG, and Bristow GK. (1992) A second postcooling afterdrop: More evidence for a convective mechanism. J Appl Physiol 73:1253–1258.

Gilbert M, Busund R, Skagseth A, Nilsen PA, and Solbø JP. (2000). Resuscitation from accidental hypothermia of 13.7 degrees C with circulatory arrest. Lancet 355:375–376.

Grueskin J, Tanen DA, Harvey P, Santos FD, Richardson WH, and Riffenburgh RH. (2007). A pilot study of mechanical stimulation and cardiac dysrhythmias in a porcine model of induced hypothermia. Wilderness Environ Med 18:133–137.

Gordon L, Ellerton JA, Paal P, Peek GJ, and Barker J. (2014). Severe accidental hypothermia. BMJ 348:g1675.

Guly H. (2011). History of accidental hypothermia. Resuscitation 82:122–125.

Gunga HC, Sandsun M, Reinersten RE, Sattler F, and Koch J. (2008). A non-invasive device to continuously determine heat strain in humans. J Therm Biol 33:297–307.

Guyton AC. (1991). Body temperature, temperature regulation, and fever. In: Textbook of Medical Physiology, 8th ed. A.C. Guyton, ed. Saunders, Philadelphia; pp. 797–808.

Haller JS. (1985). Medical thermometry—A short history. West J Med 142:108–116.

Hayward JS, Eckerson JD, and Kemna D. (1984). Thermal and cardiovascular changes during three methods of resuscitation from mild hypothermia. Resuscitation 11:21–33.

Karibe H, Sato K, Shimizu H, Tominaga T, Koshu K, and Yoshimoto T. (2000). Intraoperative mild hypothermia ameliorates postoperative cerebral blood flow impairment in patients with aneurysmal subarachnoid hemorrhage. Neurosurgery 47:594–599.

Keatinge WR, and Sloan RE. (1975). Deep body temperature from aural canal with servo-controlled heating to outer ear. J Appl Physiol 38:919–921.

Kim F, Nichol G, Maynard C, et al. (2014). Effect of prehospital induction of mild hypothermia on survival and neurological status among adults with cardiac arrest: A randomized clinical trial. JAMA 311:45–52.

Kimberger O, Thell R, Schuh M, Koch J, Sessler DI, and Kurz A. (2009). Accuracy and precision of a novel non-invasive core thermometer. Br J Anaesth 103:226–231.

Koppenberg J, Brugger H, Esslinger A, and Albrecht R. (2012). [Life-saving air supported avalanche mission at night in high alpine terrain]. Anaesthesist 61:892–900.

Knapik P, Rychlik W, Duda D, Gołyszny R, Borowik D, and Cieśla D. (2012). Relationship between blood, nasopharyngeal and urinary bladder temperature during intravascular cooling for therapeutic hypothermia after cardiac arrest. Resuscitation 83:208–212.

Kugelberg J, Schüller H, Berg B, and Kallum B. (1967). Treatment of accidental hypothermia. Scand J Thor Cardiovasc Surg 1:142–146.

Lei B, Tan X, Cai H, Xu Q, and Guo Q. (1994). Effect of moderate hypothermia on lipid peroxidation in canine brain tissue after cardiac arrest and resuscitation. Stroke 25:147–152.

Locher T, Merki B, Eggenberger P, Walpoth B, and Hilfiker O. (1997). Measurement of core temperature in the field: Comparison of two tympanic measuring methods with oesophageal temperature. In: Proceedings International Congress of Mountain Medicine Francois-Xavier Bagnoud, pp.56.

Lundgren P, Henriksson O, Kuklane K, Holmér I, Naredi P, and Björnstig U. (2013). Validity and reliability of the Cold Discomfort Scale: A subjective judgement scale for the assessment of patient thermal state in a cold environment. J Clin Monit Comput Dec 6. [Epub ahead of print]

Marcus P. (1973). Some effects of cooling and heating areas of the head and neck on body temperature measurement at the ear. Aerosp Med 44:397–402.

Niazi SA, and Lewis FJ. (1958). Profound hypothermia in man; Report of a case. Ann Surg 147:264–266.

Nolan JP, Soar J, Wenzel V, and Paal P. (2012). Cardiopulmonary resuscitation and management of cardiac arrest. Nat Rev Cardiol 9:499–511.

Oberhammer R, Beikircher W, Hormann C, Lorenz I, Pycha R, Adler-Kastner L, and Brugger H. (2008). Full recovery of an avalanche victim with profound hypothermia and prolonged cardiac arrest treated by extracorporeal re-warming. Resuscitation 76:474–480.

Opatz O, Trippel T, Lochner A, et al. (2013). Temporal and spatial dispersion of human body temperature during deep hypothermia. Br J Anaesth 111:768–775.

Paal P, Strapazzon G, Braun P, et al. (2013). Factors affecting survival from avalanche burial—A randomised prospective porcine pilot study. Resuscitation 84:239–243.

Pasquier M, Zurron N, Weith B, Turini P, Dami F, Carron PN, and Paal P. (2014). Deep accidental hypothermia with core temperature below 24°C presenting with vital signs. High Alt Med Biol 15:58–63.

Peberdy MA, Callaway CW, et al. and American Heart Association. (2010). Part 9: Post-cardiac arrest care: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 122:S768–786.

Robinson J, Charlton J, Seal R, Spady D, and Joffres MR. (1998). Oesophageal, rectal, axillary, tympanic and pulmonary artery temperatures during cardiac surgery. Can J Anaesth 45:317.

Romet TT. (1988). Mechanism of afterdrop after cold water immersion. J Appl Physiol (1985). 65:1535–1538.

Scirica BM. (2013). Therapeutic hypothermia after cardiac arrest. Circulation 127:244–250.

Shin J, Kim J, Song K, and Kwak Y. (2013). Core temperature measurement in therapeutic hypothermia according to different phases: Comparison of bladder, rectal, and tympanic versus pulmonary artery methods. Resuscitation 84:810–817.

Strapazzon G, Procter E, Avancini G, et al. (2013). Thermistor probe for measurement of tympanic temperature: Influence of ambient temperature. Resuscitation 84S:S93.

Strapazzon G, Nardin M, Zanon P, Kaufmann M, Kritzinger M, and Brugger H. (2012). Respiratory failure and spontaneous hypoglycemia during noninvasive rewarming from 24.7°C (76.5°F) core body temperature after prolonged avalanche burial. Ann Emerg Med 60:193–196.

Testori C, Sterz F, Delle-Karth G, et al. (2013). Strategic target temperature management in myocardial infarction—A feasibility trial. Heart 99:1663–1667.

Vanden Hoek TL, Morrison LJ, Shuster M, et al. (2010). Part 12: Cardiac arrest in special situations: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 122:S829–861.

Vanggaard L, Eyolfson D, Xu X, Weseen G, and Giesbrecht GG. (1999). Immersion of distal arms and legs in warm water (AVA rewarming) effectively rewarms mildly hypothermic humans. Aviat Space Environ Med 70:1081–1088.

Walpoth BH, Galdikas J, Leupi F, Muehlemann W, Schlaepfer P, and Althaus U. (1994). Assessment of hypothermia with a new ''tympanic'' thermometer. J Clin Monit 10:91–96.

Walpoth BH, Walpoth-Aslan BN, Mattle HP, et al. (1997). Outcome of survivors of accidental deep hypothermia and circulatory arrest treated with extracorporeal blood warming. N Engl J Med 337:1500–1505.

Wass CT, Lanier WL, Hofer RE, Scheithauer BW, and Andrews AG. (1995). Temperature changes of ≥1 degree C alter functional neurologic outcome and histopathology in a canine model of complete cerebral ischemia. Anesthesiology 83: 325–335.

Werner A, Tiedemann J, Gunga HC, Falk M, Brugger H, and Paal P. (2010). Measurement of body core temperature by heat flux double sensor in hypothermic pigs during artificial avalanche burial. Resuscitation 81S:S78.

Wilson JR, Forgione N, and Fehlings MG. (2013). Emerging therapies for acute traumatic spinal cord injury. CMAJ 185: 485–492.

Wunderlich CA, and Seguin E. (1871). On the Temperature in Diseases: A Manual of Medical Thermometry. William Wood & Co., New York.

Zeiner A, Klewer J, Sterz F, et al. (2010). Non-invasive continuous cerebral temperature monitoring in patients treated with mild therapeutic hypothermia: An observational pilot study. Resuscitation 81:861–866.

Address correspondence to:
Hermann Brugger, MD
EURAC Institute of Mountain Emergency Medicine
Viale Druso 1
I-39100 Bolzano
Italy

E-mail: hermann.brugger@eurac.edu

Received February 3, 2014;
accepted in final form March 11, 2014.