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Thoracic lavage in accidental hypothermia with cardiac arrest — report of a case and review of the literature☆

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Abstract

Background: Accidental hypothermia resulting in cardiac arrest poses numerous therapeutic challenges. Cardiopulmonary bypass (CPB) should be used if feasible since it optimally provides both central rewarming and circulatory support. However, this modality may not be available or is contraindicated in certain cases. Thoracic lavage (TL) provides satisfactory heat transfer and may be performed by a variety of physicians. This paper presents the physiological rationale, technique, and role for TL in accidental hypothermia with cardiac arrest.
Methods: A patient with hypothermic cardiac arrest, treated by the author using TL, serves as the basis for this report. A search of the English language literature using PubMed® (National Library of Medicine, Bethesda, Maryland) was conducted from 1966 to 2003 and 13 additional patients were identified. Demographic information, lavage method, rewarming rate, complications, and neurological outcome were analysed.
Results: There were numerous causes for hypothermia, with drug and alcohol intoxication being the most common ($n = 4$; 28.6%). Patient age ranged from 8 to 72 years (median = 36 years). Mean core temperature was 24.5 ± 0.60 °C. Most patients were without blood pressure or pulse upon presentation to the Emergency Department and the predominant cardiac rhythm was ventricular fibrillation (VF) ($n = 9$; 64.3%). Thoracic lavage was accomplished by thoracotomy in seven patients and tube thoracotomy in the remaining seven. Median rewarming rate was 2.95 °C/h. Median time until sinus rhythm was restored was 120 min. Median length of hospital stay was 2 weeks. Four (28.6%) patients died. Complications were seen in 12 (85.7%) patients. Among survivors, neurological outcome was normal in 8 (80%) while two were left with residual impairments.
Conclusions: Patients presenting in cardiac arrest from accidental hypothermia may be rewarmed effectively using TL. Among survivors, normal neurological recovery is seen. Thoracic lavage should be strongly considered for these patients if CPB is not available or contraindicated.

Keywords: Cardiac arrest; Hypothermia; Outcome; Resuscitation; Temperature; Thoracotomy

1. Introduction

Accidental hypothermia is an unintentional decrease in body temperature below 35 °C (95 °F). The most severe manifestation of accidental hypothermia is cardiac arrest and aggressive efforts must be undertaken for any chance of survival [1–3]. Active core rewarming is preferred for these patients, but the method of choice has yet to receive universal agreement for every clinical situation [1,3,4]. Cardiopulmonary bypass has been shown to be both highly efficient and efficacious and is the preferred method for rewarming patients in cardiac arrest [2–7]. However, this modality is not available at all hospitals or may be contraindicated. In these circumstances, TL has been found to be an effective modality for rewarming [8–18]. The objective of this article is to examine clinical data from patients undergoing TL, review the technical aspects of this procedure, and define the place of TL in the treatment of patients with severe hypothermia and cardiac arrest.

2. Materials and methods

The series presented consists of a patient treated by the author and a literature review. A search of the English lan-

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guage literature of human studies using PubMed® (National Library of Medicine, Bethesda, Maryland) was conducted from 1966 to 2003 using the following search terms for all PubMed® fields: hypothermia, thoracic, pleural, mediastinal, lavage, and cardiac arrest. Demographic information, lavage method, rewarming rate, complications, and neurological outcome were analysed. Descriptive statistics were generated when appropriate. Unless otherwise stated, values are expressed as means (±standard deviation) and ranges.

3. Patient report

A 35-year-old male was brought to hospital after being found lying in the driver's compartment of a car. The door was open and the engine was not running. Ambient temperature was 28 °F (−2.2 °C). Paramedics found the patient unconscious with agonal respirations. The pulse rate was 42 beats/min and blood pressure unobtainable. An intravenous catheter was inserted and one ampoule of 50% dextrose and 0.4 mg of naloxone hydrochloride were administered. The pulse rate increased to 62 beats/min and he began to make moaning sounds. As the patient was being taken out of the ambulance, the pulse was lost. Initial rhythm in the Emergency Department was VF and external chest compressions were begun. Pupils were 4 mm and unreactive. No evidence of trauma was noted. Urine toxicology revealed cocaine metabolites.

Cardiopulmonary resuscitation continued as a tracheal tube was placed. Initial temperature was 27.0 °C (80.6 °F) by rectal probe. The operating room was alerted that CPB would be required. However, the cardiac surgery team was already performing an emergency coronary artery bypass procedure. Faced with this situation, TL was selected for rewarming. Two 36 French chest tubes were placed in each hemithorax. One tube was placed in the fourth intercostal space in the midclavicular line. Another tube was placed into the sixth intercostal space in the mid-axillary line. Sterile saline at 39.0 °C (102 °F) was infused by gravity into each superior chest tube and allowed to drain passively through each inferior tube.

When the core temperature reached 32.8 °C (91 °F), a single countershock of 200 J was sufficient to restore normal sinus rhythm 86 min after arrival. His hospital course was complicated by pneumonia with *Staphylococcus aureus*, *Streptococcus pneumoniae*, and *Haemophilus influenzae*. Mechanical ventilation was carried out until hospital day eleven. He was discharged from the hospital against medical advice 21 days after admission neurologically normal.

4. Results

The literature review identified 13 other patients who underwent TL. Clinical data are presented in Table 1. There were numerous causes of hypothermia, with drug and alcohol intoxication being the most common ($n = 4$; 28.6%). Concurrent medical problems were responsible in three patients (21.4%), environmental exposure alone in three, trauma in two (14.3%), immersion in one (7.1%) and fresh-water submersion in one. Patient age ranged from 8 to 72 years (median = 36 years). Mean presenting core temperature was 24.5 ± 0.60 °C (range = 21.1–29.4 °C). Nine (64.3%) patients presented in VF or deteriorated into VF soon after arrival in the Emergency Department. The remaining five patients (35.7%) presented in or developed asystole soon after arrival.

Thoracic lavage was accomplished by thoracotomy in 7 patients (50%) and tube thoracotomy in the remaining 7. Sterile saline was used in 10 (71.4%) patients while tap water was used in 4. Of the saline patients, 4 (40%) developed infectious complications, while one (25%) of the tap water patients developed an infection.

Where calculable (12 patients), the median rewarming rate was 2.95 °C/h (mean = 6.0 ± 15.7 °C/h). Median time until sinus rhythm was restored was 120 min (mean = 130 ± 23 min; range = 14–240 min) in 11 patients. Two patients could not be converted from asystole and the time interval was not stated in one patient.

Complications were seen in 12 (85.7%) patients (Table 2). Where stated (12 patients), median length of hospital stay was 14.5 days (mean = 16.1 ± 15.7 days; range = 1–60). After excluding three patients who died within 24 h, the median length of stay increased to 17 days (mean = 21.1 ± 15.0 days).

Four (28.6%) patients died. One patient died in the operating room after sustaining gunshot wounds to the aorta and superior mesenteric artery. The second patient died in the Emergency Department and autopsy revealed deep venous thrombosis with massive pulmonary embolism. The third developed intractable asystole after drug overdose and died in the Emergency Department. The fourth suffered upper gastrointestinal hemorrhage due to esophageal varices and died of multisystem organ failure on the 15th hospital day.

Among the 10 survivors, neurological outcome was normal at discharge in 8 (80%) while 2 were left with residual impairments. An 8-year-old boy developed a cerebral infarction after a 40 min fresh-water submersion. This resulted in serious language dysfunction requiring special education due to learning difficulty. A 19-year-old man developed minor sensory changes after immersion in a creek.

5. Discussion

Cardiac arrest is the most profound manifestation of accidental hypothermia. Ventricular fibrillation and asystole are seen as core temperature falls below 28 °C [1]. These patients may appear clinically dead with no easily discernable pulse or blood pressure, but it is important to remember that clinical death is not necessarily biological death. Because life is difficult to detect at such low temperatures, resuscitation should

Table 1
Cases of thoracic lavage

Investigator	Age (years)	Mechanism	Temperature (°C)	Rhythm	Lavage method	Rate of rewarming	Time to sinus rhythm	Length of stay	Complications	Neurological
Linton and Ledingham [8]	27	Ethanol and barbiturate intoxication	23 (rectal)	VF	Thoracotomy (40 °C saline)	4 °C in 35 min (esophageal)	2.5 h	3 weeks	Pneumonia	Normal
Coughlin [9]	35	Exposure	21.1 (not stated)	VF	Thoracotomy (76 l warm tap water)	Not stated	3.5 h	Not stated	Wound infection	Normal
Althaus et al. [10]	41	Avalanche (trapped 2.5 h)	22 (rectal)	VF	Thoracotomy (40 l saline)	4 °C in 90 min (rectal)	4 h	2 weeks	Pulmonary edema	Normal
Best et al. [11]	23	Gunshot wound (Aorta and SMA lacerations)	25 (rectal)	VF	Thoracotomy (60 l saline/tap water)	Not stated	30 min	5.5 h	Coagulopathy	Death
Iversen et al. [12]	63	Exposure	23.7 (bladder)	VF	Tube thoracotomy (27 l of 39.5 °C saline)	3 °C in 90 min, 4.3 °C in 150 min (bladder)	120 min (junctional)	13 days	None	Normal
Hall and Syverud [13]	72	Drug overdose	23.9 (rectal)	SB to asystole	Tube thoracotomy (40 l of 41 °C tap water)	61 °C in 20 min (esophageal)	NA	<1 day	Pulmonary embolism	Death
Hall and Syverud [13]	36	Drug overdose	25 (rectal)	Asystole	Tube thoracotomy (41 °C tap water)	7 °C in 20 min (esophageal)	NA	<1 day	Asystole	Death
Walters [14]	49	DKA/Sepsis	25.5 (rectal)	VF	Tube thoracotomy (20 l of 35 °C saline)	5.6 °C in 90 min (rectal)	14 min	17 days	Pneumonia, rhabdomyolysis, acute renal failure	Normal
Brunette et al. [15]	60	Bleeding esophageal varices	26.8 (rectal)	SB to asystole	Thoracotomy (39 °C saline)	3.2 °C in 30 min (rectal)	90 min	15 days	ARDS, sepsis, DIC, recurrent bleeding	Death
Brunette et al. [15]	63	Lung carcinoma	29.4 (rectal)	ST to asystole	Thoracotomy (39 °C saline)	2.4 °C in 90 min (rectal)	120 min	Not stated	None	Normal
Kangas et al. [16]	8	Fresh-water submersion (40 min)	25 (rectal)	Asystole	Thoracotomy (50 l of 37 °C saline)	4 °C in 90 min (esophageal)	135 min after discovery	60 days	Rhabdomyolysis, cerebral infarct	Verbal/motor impairment
Knottenbelt [17]	36	Stab wounds to lungs	24 ("core")	SB to VF	Tube thoracotomy (4 l of 40 °C saline)	"1 °C/h" ("core")	Not stated	19 days	Bleeding, abscess, renal failure	Normal
Weingard [18]	19	Fresh-water immersion to chin (14 h)	22 (rectal)	VF	Tube thoracotomy (40 °C saline)	7.5 °C in 145 min (rectal)	4 h after discovery	10 days	Rhabdomyolysis	"Minor sequelae"
Current study	35	Cocaine intoxication	27 (rectal)	VF	Tube thoracotomy (20 l of 39 °C saline)	6.4 °C in 136 min (rectal)	84 min	21 days	Pneumonia, ARDS	Normal

VF: ventricular fibrillation; SMA: superior mesenteric artery; SB: sinus bradycardia; NA: not applicable; DKA: diabetic ketoacidosis; ARDS: acute respiratory distress syndrome; DIC: disseminated intravascular coagulation; ST: sinus tachycardia.

Table 2
Complications in TL patients

Complication type	Number of patients
Pulmonary (total)	6 (42.8%)
Pneumonia	3 (21.4%)
Acute respiratory distress syndrome	2 (14.3%)
Pulmonary edema	1 (7.1%)
Pulmonary embolism	1 (7.1%)
Infection (total)	
Pneumonia	3 (21.4%)
Wound	1 (7.1%)
Abscess	1 (7.1%)
Sepsis	1 (7.1%)
Renal[a] (total)	4 (28.6%)
Rhabdomyolysis	3 (21.4%)
Acute renal failure	2 (14.3%)
Hemorrhage/coagulopathy (total)	3 (21.4%)

[a] One patient displayed both rhabdomyolysis and acute renal failure.

be thoughtful, vigorous, and prolonged, since normal neurological outcome may be achieved [6–10,12,14,15,17,18]. If an arrest rhythm (VF or asystole) is identified, and resuscitation is indicated, external chest compressions should be performed.

Aggressive efforts, including active core rewarming, must be undertaken if these patients have any chance of survival [1,2,10]. In hypothermic patients it is important to note that rapid rewarming does not necessarily improve the chance of survival, except when cardiac arrest is present [4]. The process of rewarming begins at the time of rescue and all available and appropriate means should be utilized, so as to deliver maximal exogenous heat. The goal of any rewarming method is to place the heart into a favorable environment for either defibrillation or spontaneous conversion to normal sinus rhythm.

The technique that affords the most rapid and efficient means of energy transfer is CPB and, when available, is the preferred treatment in arrested patients since it provides simultaneous rewarming and circulatory support [2–7,10]. Rewarming rates as high as 1–2 °C every 3–5 min have been reported [2,7]. Portable equipment may even be used to initiate CPB in the Emergency Department to conserve time [19].

Patients who have sustained trauma or have concurrent bleeding problems are not appropriate for CPB because of the need for anticoagulation. While CPB without heparin has been used successfully both in an animal model [20] and in a 13-year-old patient with exposure and cerebral contusions [21], widespread experience using CPB without heparin is very limited. Since CPB may be contraindicated or not available, physicians must be able to use other active core rewarming methods.

While airway rewarming may prevent further heat loss, it does relatively little to raise core temperature [2,5]. Gastric, colonic, and bladder lavage offer very minimal heat transfer due to limitations in surface area [2,5]. Peritoneal lavage is used effectively in cardiac arrest and provides rewarming rates = 2–4 °C/h, but does not warm the myocardium directly [2]. Thoracic lavage offers strategically directed heat transfer by warming the heart in order to facilitate defibrillation and rewarming rates of 3–6 °C/h have been reported [22].

Thoracic lavage is particularly advantageous for the heart in an arrested rhythm since it does not depend upon intact circulation to warm the myocardium [5,17]. Because the pleural space is well perfused, the rate of rewarming for TL is higher than that for other methods of cavity lavage where the surface area or vascularity are limited [5]. For these reasons, investigators consider TL a logical choice for the arrested patient when CPB is not available or not indicated [9–11,13,14,16–18]. Thoracic lavage has been used extensively for rewarming in animal models of hypothermia, pediatric cardiac surgery, and aortic surgery, as well as for induction of hypothermia in an animal model [23–29].

Thoracic lavage may be accomplished either by thoracotomy (“open”) or tube thoracotomy (“closed”). Two large bore chest tubes are inserted into one or both hemithoraces. The first is placed anteriorly and superiorly (i.e. second to fourth intercostal space in the mid-clavicular line) and the second tube in a more posterior and inferior location (i.e. fifth to sixth intercostal space in the mid-posterior axillary line) [13,22]. Sterile saline at 40–42 °C (104–107.6 °F) is infused (using three-liter bags) into the anterior tube and allowed to passively exit via the posterior tube into a thoracotomy drainage reservoir.

Although I prefer to heat normal saline bags in a commercial warmer, countercurrent fluid warmers/infusers such as the Level 1® are successfully employed [12,22]. Sterile saline is recommended for the procedure, but use of tap water has also been reported [9,11,13]. Effluent is collected in a standard thoracotomy drainage container, monitoring input and output closely. Care must be taken to ensure adequate drainage from the chest so intrathoracic hypertension does not occur [22]. Upon completion of rewarming, the superior chest tube should be removed and the inferior tube left in place to allow for complete thoracic drainage. Alternatively, either a single chest tube set-up or infusion into the inferior tube with anterior suction may be used to potentially increase energy transfer by increasing saline dwell time [12,14,18].

One potential advantage of “closed” TL is that external chest compressions may be performed throughout the resuscitation. Data indicate that antegrade flow during cardiopulmonary resuscitation is largely the result of alterations in intrathoracic pressure with the heart serving as a passive conduit [30]. This “thoracic pump” model may explain the large number of neurologically intact survivors after hours of external chest compressions in cases of severe hypothermia where cold-induced myocardial contracture renders the heart “hard as stone” [10,22]. By causing a break in chest wall continuity, thoracotomy would negate the advantage of the “thoracic pump” model.

While a logical choice for arrested patients, “closed” TL should probably be considered hazardous in perfusing patients, since VF may be induced with left-sided chest tube insertion [22]. It is unknown whether right-sided tube thoracotomy, coupled with other active core rewarming methods, in perfusing severely hypothermic patients might be beneficial.

The "open" technique involves a left thoracotomy followed by instillation of warmed saline directly onto the heart. The pericardium need not be opened unless tamponade is present. Saline is allowed to "dwell" in the hemithorax and then may be aspirated and replaced with new fluid. On completion of resuscitation, a chest tube should be left in the thorax to ensure adequate drainage. The operator should be skilled in the technique of thoracotomy so that iatrogenic complications may be minimized.

Defibrillation may be attempted after myocardial or "core" temperature reaches 26–29 °C (78.8–84.2 °F) [8,10,16,22]. Lavage should be continued until spontaneous conversion to normal sinus rhythm or until the myocardial temperature exceeds 32–33 °C (89.6–91.4 °F) [22].

Potential problems with either method of TL include bleeding and the introduction of infection. Because coagulation is impaired in hypothermia, great care should be taken when placing chest tubes or performing thoracotomy. Electrocautery, topical hemostatic agents, and sutures should be available during these procedures. Sterile technique should be carefully observed during TL. While these patients often develop infections, there is no clear evidence supporting routine prophylactic antibiotics [22]. This review revealed no increase in infections when tap water was used for lavage. Relative contraindications to TL include thoracic trauma or previous surgery [3,17]. If "closed" TL is used, pleural adhesions from infection or previous surgery may render the procedure technically impossible. Although roller pumps are used in animal models, they are not recommended for clinical use due to the possibility of tension hydrothorax [29].

Complications are common in these patients. In a series of 68 patients resuscitated by CPB, 42% developed acute respiratory distress syndrome, pneumonia was seen in 22%, and 20% developed acute renal failure [7]. Among 15 patients resuscitated by CPB, Walpoth found pulmonary complications in 11 (73%), neurological in 9 (60%), cardiac in 4 (27%), and renal in 5 (33%) [6]. Patients in Walpoth's series had a mean acute hospital stay over 17 days. This review of TL patients compares similarly to these series with respect to both complication frequency and length of stay.

Despite critical illness, hypothermic patients with cardiac arrest may experience good long-term neurological function. Resuscitation can only be successful if cardiac arrest is due to hypothermia and not anoxia or acidosis [10]. Vretenar et al. found survival lowest (32%) in avalanche victims and highest (70%) in patients with hypothermia due to ethanol or drug intoxication [7]. Markers that indicate irreversibility include a serum potassium concentration greater than 10 mequiv./l and serum fibrinogen concentration less than 50 mg/dl [31,32]. Data indicate that resuscitation in these patients is futile. Eighty percent of survivors in Vretenar's literature review returned to work or previous activities. In Walpoth's series, all resumed their previous lifestyle [6]. Similarly, this review found that 80% of survivors were neurologically normal.

6. Conclusions

For patients presenting in cardiac arrest from accidental hypothermia, TL is a logical option for rewarming. The procedure may be accomplished via techniques and equipment at the disposal of any emergency medicine physician, surgeon, or intensivist. Rewarming rates compare favorably with other methods of active core rewarming. Survivors often have normal neurological outcome. In patients with arrested rhythms where CPB is not available or contraindicated, TL should receive strong consideration.

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