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Clinical paper

Clinical characteristics and outcomes of witnessed hypothermic cardiac arrest: A systematic review on rescue collapse

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Abstract

Aims: Cardiac arrest related to accidental hypothermia may occur at temperatures below 32 °C. Our goal was to describe the clinical characteristics and outcomes of patients who suffered from witnessed hypothermic cardiac arrest (CA) and assess the occurrence of hypothermic CA as a function of patient body temperature.

Methods: We conducted a systematic review of the literature on cases of hypothermic CA due to rescue collapse. Patient information data from hypothermic CA patients were collected and combined with additional unpublished data to assess the clinical characteristics and outcome of hypothermic CA patients.

Results: A total of 214 patients was included in this systematic review. Of the 206 witnessed hypothermic CA patients with a recorded body temperature, the average body temperature was 23.9 ± 2.7 °C with five patients (2.4%) having a core body temperature of >28 °C. The highest temperature of a patient surviving hypothermic witnessed cardiac arrest without other associated risk factors for cardiac arrest was 29.4 °C. The first recorded cardiac rhythm was asystole in 33 of the 112 patients (30%) for whom this information was available. The survival rate at hospital discharge of these hypothermic cardiac arrest patients was 73% (153 of 210 patients) and most survivors had favourable neurological outcome (89%; 102 of 105 patients).

Conclusions: CA that is solely caused by hypothermia did not occurs for patients with a body temperature >30 °C. Our findings provide valuable new information that can be incorporated into the international clinical management guidelines of accidental hypothermia.

Keywords: Cardiac arrest, ECMO, ECPR, Hypothermia, Accidental, Potassium, Resuscitation, Triage

Introduction

Accidental hypothermia is a potentially reversible cause of cardiac arrest.[1] Patients that suffer from cardiac arrest (CA) due to accidental hypothermia might have a more favourable outcome compared to patients with other CA aetiologies if they are treated appropriately. The risk of cardiac arrest is thought to occur at temperatures below 32 °C,[1–3] and it is believed that hypothermia is unlikely the sole cause of CA in patients with body temperature >28 °C.[2] However, evidence that support these figures is sparse.

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A notable proportion of hypothermic patients are already suffering from unwitnessed cardiac arrest when first discovered. However, other hypothermic patients may suffer from a witnessed cardiac arrest that occurs upon rescue, especially in the case of patients with deep hypothermia.[4,5] In a recent study on hypothermic CA patients who were rewarmed with Extracorporeal Life Support (ECLS), CA was witnessed in 85 out of 250 of the hypothermic patients (34%).[6] The notion of rescue collapse has been included in some international guidelines on managing patients suffering from hypothermia[3] and it has been defined as the occurrence of CA relating to the extrication or transfer of a patient suffering from profound hypothermia.[7] This type of witnessed CA has been associated with a favourable outcome, especially in the case of avalanches victims.[7–10] However, other reports do not confirm this association.[6] The pathophysiological process of rescue collapse is not well-understood. However, it might be related to the movement of a hypothermic patient that occurs during extrication, mobilisation or transfer.[2]

Currently, the epidemiological clinical characteristics of patients that suffer from witnessed hypothermic cardiac arrest are not well defined. Thus, a greater understanding of these patients might improve clinical management of hypothermic CA patients. The main objective of this study was to describe the clinical characteristics and outcomes of patients who suffered from witnessed cardiac arrest/ rescue collapse. In particular, we assessed the occurrence of CA in hypothermic patients as a function of their first recorded body temperature.

Methods

Potential hypothermic CA patients that could be included in this study were identified through a systematic literature review. It was conducted in accordance with current guidelines on systematic literature reviews and it complied with the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement. The following keywords were used: rescue collapse, cardiopulmonary resuscitation, hypothermia, and witness.

We searched the literature from January 1st 1987 to August 31st 2018. The precise research approach for identifying witnessed hypothermic CA patients is described in Supplementary file 1. One author (CF) conducted the literature search with the help of a professional librarian to produce a database of references. The abstracts of the retrieved references were screened and full texts of potentially eligible references were further examined for inclusion (CF). Additional patient cases were identified from the bibliography of retrieved articles and the personal list of references of the authors. We also included unpublished patients cases that were collected from a previously published study[6] and convenience samples from another ongoing study on HOPE score validation that were provided by co-authors of this study (GD and TD). We used age and gender to exclude overlapping cases and, if needed, other more specific data (e.g. temperature, potassium). Patients were subsequently selected based on specific inclusion and exclusion criteria. We included patients with accidental hypothermia (e.g. who had a first recorded body temperature <35 °C) and experienced a witnessed cardiac arrest that was thought to be due to hypothermia. Patients were excluded if cardiac arrest was unwitnessed or a result of another cause; cases of therapeutic, iatrogenic or neonatal hypothermia; or cases in which individual data were not available. Cases identified through the systematic literature review were independently and blindly assessed for eligibility by two authors and (CF, MP) disagreements on eligibility was resolved by a third independent author (PNC).

Original data used for this study have been published recently with permission by the institutional review board (N° 2016-01267).[6] Data from additional unpublished cases were treated anonymously and were exempted from formal ethical approval. The work in this study, "Clinical characteristics of witnessed hypothermic cardiac arrest: a systematic review on rescue collapse", is registered to the PROSPERO registry (CRD42018108616).

Data collection

The following variables of interests were collected for each patient when available: age; gender; mechanisms for hypothermia (i.e. outdoor or indoor exposure to cold, immersion, submersion, avalanche); first vital parameters on-site and upon hospital arrival (heart rate, respiratory rate, pulse); pre-CA neurological state (Glasgow Coma Scale - GCS); first recorded body temperature (°C); potential risk factor for triggering CA; detection of shivering; potassium; lactates; pH and pCO_2 at hospital admission; first documented cardiac rhythm after cardiac arrest (e.g. asystole, ventricular fibrillation, pulseless ventricular tachycardia and pulseless electrical activity (PEA)); presence of trauma, drugs, toxins, alcohol, and main comorbidities; treatment (e.g. defibrillation, reanimation drugs); no flow and low flow durations; automated versus manual CPR; and, if any, modality of hospital rewarming. In the case of ECLS rewarming, the following data were also collected: ECLS method, duration and delay before initiation. The mechanism for hypothermia were further classified as non-asphyxia related (i.e. immersion, outdoor or indoor exposure to cold) or asphyxia related (i.e. submersion, avalanche with head burial under the snow). Patient outcomes of witnessed hypothermic CA were assessed by survival and neurological status at hospital discharge. A cerebral performance category (CPC) of 1 or 2 at hospital discharge was considered a favourable neurological outcome.[11]

Data analysis

Descriptive statistics were determined for variables of interest that were collected from patients and they were expressed as frequencies, means and standard deviations, or median and interquartile range (IQR). Witnessed hypothermic CA patients were grouped based on various variables of interest and outcomes. Data was retrieved from the patient information database that was established for this study and exported into Stata version 14 (Stata Corporation, College Station, TX, USA) for analysis.

Results

Our literature search strategy yielded 135 cases of witnessed hypothermic cardiac arrest due to rescue collapse (Supplementary file 2). Although the two co-authors that assessed the inclusion eligibility of cases agreed on nearly all cases, eligibility of five cases had to be discussed and resolved by a third, independent author.[12–17] Furthermore, 79 additional unpublished cases derived from a previous study[6] and an ongoing study were added for a total of 214 patient cases of witnessed hypothermic cardiac arrest (Fig. 1).

The baseline characteristics of the 214 patients included in this study are presented in Table 1. Eight of the included patients had no

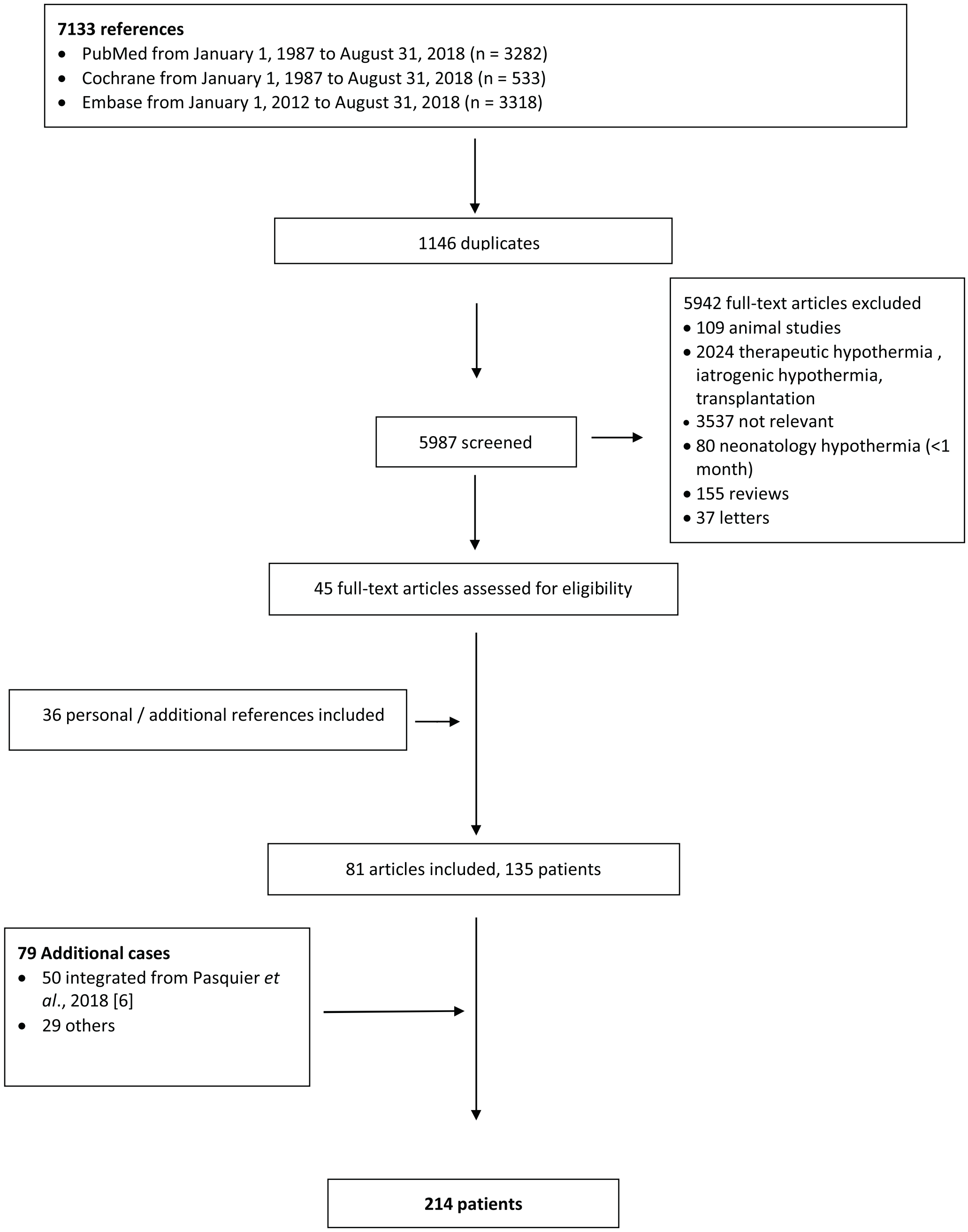

Fig. 1 – Flow-chart for patient selection in the systematic review of clinical characteristics and outcomes of witnessed hypothermic cardiac arrest patients.

precise temperature value but either a temperature range (e.g. <28 °C)[20] or were diagnosed as hypothermic.[21–24] For the 206 patients with a reported first recorded on site body temperature, the mean body temperature was 23.9 ± 2.7 °C. Moreover, 90 (44%) of the 206 patients had a temperature below 24 °C. We observed that 30% of witnessed hypothermic CA patients had asystole as their first recorded cardiac rhythm after CA. The temperatures were similar between patients with shockable and non-shockable rhythms (Fig. 2). CA occurred during endotracheal intubation in two patients.[25,26] The mean serum potassium levels of witnessed hypothermic CA patients at hospital admission was 4.3 ± 1.5 mEq/L (range = 1.4–14.1 mEq/L); it was of 4.9 ± 2.0 mEq/L and 4.0 ± 1.1 mEq/L in survivors and non-survivors, respectively. The mean serum lactate levels was 10.4 ± 5.4 mmol/L (range = 0.66–28 mmol/L), the mean pH 7.0 ± 0.2 (range = 6.41–7.86) and the median pCO_2 7.5 kPa (IQR 5.5–9.7 kPa; range = 1.6–50.1 kPa).

Information on the clinical characteristics and outcomes of the 214 witnessed hypothermic CA patients is summarised in Table 2. We observed that survival rate of hypothermic CA patients is 73% and 89% of these survivors had a favourable neurological outcome. Since it is thought that hypothermia is unlikely the sole cause of CA in patients with body temperature >28 °C we were interested in the characteristics and clinical outcome of patients with a first recorded body temperature > 28 °C. We found that five of the 206 patients

Table 1 – Pre-cardiac arrest characteristics of 214 witnessed hypothermic cardiac arrest patients. SD = standard deviation; IQR = interquartile range.

Demographic		
Age (n = 208; missing = 6)		
	Mean ± SD	46 ± 17
	Range	4–95
Male (missing = 6), n (%)		146/208 (70)
Circumstances		
Mechanism (missing = 9), n (%)		
	Exposure	156/205 (76)
	Immersion	34/205 (17)
	Avalanche	12/205 (5.8)
	Submersion	3/205 (1.5)
Asphyxia-related mechanism (missing = 9), n (%)[a]		15/205 (7.3)
Alcohol abuse (missing = 132), n (%)		43/82 (52)
Drug intoxication (missing = 113), n (%)		35/101 (35)
Trauma (missing = 150), n (%)		18/64 (28)
Vital signs		
Respiratory rate (n = 12; missing = 202)		
	Median (IQR)	7 (4–11)
	Range	2–40
Heart rate (n = 22; missing = 192)		
	Median (IQR)	40 (30–78)
	Range	6–179
Systolic blood pressure (n = 19; missing = 195)		
	Median (IQR)	80 (60–105)
	Range	35–170
Movements (missing = 201), n (%)		11/13 (85)
Glasgow Coma Scale (missing = 190), n (%)[b]		
	3–8	20/24 (83)
	9–10[c]	4/24 (17)
Glasgow Coma Scale (n = 24; missing = 190)		
	Median (IQR)	5 (3–7)
	Range	3–10[b]
Temperature		
Temperature (n = 206; missing = 8)		
	Mean ± SD	23.9 ± 2.7
	Range	15.2–32.2

[a] Asphyxia-related cases included avalanche with head burial and submersion cases.
[b] The mean body temperature of patients with GCS ≤ 8 was 24.2 °C (SD = 2.12 °C) versus 25.5 °C (SD = 2.3 °C) for patients with GCS ≥ 9.
[c] GCS score of 14 in patient data taken from Winkler et al. 2016[18] was defined as GCS score of 9–10 to match Maeder et al. 2018[19].

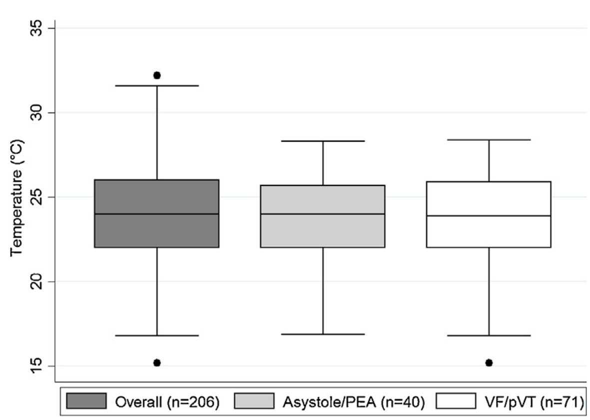

Fig. 2 – Boxplot analysis of the body temperature of 206 witnessed hypothermic cardiac arrest patients. Hypothermic cardiac arrest patients were grouped according to the first cardiac rhythm documented after their cardiac arrest. Data of these groups were expressed as boxplots. VF = ventricular fibrillation; pVT = pulseless ventricular tachycardia; PEA = pulseless electrical activity. Values for temperature (n = 8) and first documented cardiac rhythm after cardiac arrest (n = 102) were missing for witnessed hypothermic cardiac arrest patients.

Table 2 – Cardiac arrest characteristics and outcomes of 214 witnessed hypothermic cardiac arrest patients. ECLS = Extracorporeal Life Support; CPC = cerebral performance categories; IQR = interquartile range.

Cardiac arrest characteristics		
Cardiac arrest first recorded rhythm (missing = 103), n (%)		
	Ventricular fibrillation / pulseless ventricular tachycardia	71/111 (64)
	Asystole	33/111 (30)
	Pulseless electrical activity	7/111 (6)
Place where cardiac arrest occurred (missing = 141), n (%)		
	Out-of-hospital	54/73 (74)
	Hospital	19/73 (26)
Potential risk factor for triggering cardiac arrest (missing = 41), n (%)		62/173 (36)
Risk factors type (n = 62), n (%)		
	Out-of-hospital intubation	2 (3.2)
	Out-of-hospital patient mobilisation	15 (24)
	During transfer to hospital	29 (47)
	Hospital patient mobilisation	16 (26)
No flow duration (n = 52; missing = 162), min[a]		
	Median (IQR)	0 (0–0)
	Range	0–15
Low flow duration (n = 98; missing = 116), min		
	Median (IQR)	132 (71–180)
	Range	2–480
Treatments and outcomes		
Defibrillation (missing = 162), n (%)		44/52 (85)
Resuscitation drugs (missing = 186), n (%)		17/28 (61)
Mechanical cardiopulmonary resuscitation (missing = 195), n (%)		15/19 (79)
ECLS (missing = 83), n (%)		118/131 (90)
ECLS type (missing = 0), n (%)		
	Extracorporeal Membrane Oxygenation	80/118 (68)
	Cardiopulmonary Bypass	38/118 (32)
ECLS duration (n = 11; missing = 107), min		
	Median (IQR)	225 (139–1440)
	Range	64–1920
Return of spontaneous circulation (missing = 27), n (%)		158/187 (84)
Survival rate (missing = 4), n (%)		153/210 (73%)
Survival rate according to the rhythm (missing = 106), n (%)		
	Ventricular fibrillation / pulseless ventricular tachycardia	57/68 (84)
	Asystole	23/33 (70)
	Pulseless electrical activity	3/7 (43)
Neurological outcome of survivors (missing = 38), n (%)		
	Good (CPC = 1-2)[b]	102/115 (89)
	Bad (CPC = 3-5)[b]	13/115 (11)

[a] Defined from initiation of external CPR until ROSC or start of ECLS.
[b] CPC and their corresponding cerebral characteristics are as follows: 1 = normal or slightly diminished cerebral function, 2 = moderate cerebral disability, 3 = severe cerebral disability, 4 = coma or vegetative state, 5 = brain dead.

(2.4%) had a first recorded body temperature >28 °C. The characteristics and clinical outcomes of these patients are found in Table 3. Furthermore, nine patients who suffered from witnessed hypothermic cardiac arrest had a core temperature of 28 °C; four of which survived and had good neurological outcome (CPC = 1).

Discussion

To our knowledge, this work, which includes 214 patients, is the largest study to assess the clinical characteristics and outcomes of patients that suffer from CA due to rescue collapse (hypothermic witnessed cardiac arrest). We observed that CA occurred in hypothermic patients with a mean body temperature of 23.9 °C. Furthermore we did not observed cardiac arrest solely due to hypothermia with a temperature >30 °C. Although a notable proportion (30%) of patients had asystole as their first recorded cardiac rhythm after CA. Importantly, this study highlights the excellent prognosis of patients that suffer from CA due to rescue collapse as indicated by a survival rate of 73% and a favourable neurological outcome for 89% of the survivors.

Our study made several key contributions that could impact clinical care practises on patients with hypothermia. First, our results provide further evidence regarding the temperature at which CA would likely occur following accidental hypothermia. Back in 2006 Giesbrecht and Hayward wrote: “at low core temperatures (i.e. below about 28 °C) there can be a fine line between potential survival and death”.[5] Current clinical practice guidelines on hypothermia use a dichotomous triage based on temperature that claims a patient with a body temperature below 32 °C can experience CA and this risk increases substantially below 28 °C.[2,31] Knowledge about the estimated temperature at which

Table 3 – Characteristics of the five witnessed hypothermic cardiac arrest patients who had body temperatures >28 °C. CPC = cerebral performance categories.

Source	Age	Sex	Temperature (°C)	Mechanism	Survival	CPC[a]	Remarks
Nagamine et al.[27]	75	Female	32.2	Exposure	Yes	Unknown	Risperidone at daily treatment
Silfvast et al.[28]	63	Male	31.6	Immersion	No	5	Lack of precise information, patient died
Brunette et al.[29]	63	Male	29.4	Exposure	Yes	1	
Pasquier et al.[6]	28	Female	28.4	Immersion	No	5	
Steedman et al.[30]	29	Male	28.3	Immersion	Unknown	Unknown	Pure hypothermia

[a] CPC and their corresponding cerebral characteristics: 1 = normal or slightly diminished cerebral function, 2 = moderate cerebral disability, 3 = severe cerebral disability, 4 = coma or vegetative state, 5 = brain dead.

hypothermic cardiac arrest is likely to occur is crucial because it allows immediate risk assessment of hypothermic patients for CA based on their body temperature. A study with data including unwitnessed CA patients would not have provided a good estimate of the body temperature at which CA would likely occur due to the likelihood that their body temperatures would have fallen by the time they were measured. Our study provided a realistic estimate to the critical core temperature, thus we were able to identify a vulnerable group with a considerable risk of rescue collapse and cardiac arrest.

The indications for ECLS rewarming of hypothermic CA patients with a body temperature >28 °C are still controversial according to experts because these patients might suffer from CA as a result of other causes, which could contribute to their poor clinical outcome.[2] Indeed, some ECLS centres have already set the temperature cut-off for ECLS at ≤ 28 °C. [32] In the present study, four of the nine witnessed hypothermic CA patients with a body temperature of exactly 28 °C survived after ECLS rewarming, all with favourable neurological outcome. These results may support the current recommendations that consider hypothermic patients with a temperature <28° at high risk of CA and therefore advise to transport them to a centre capable of providing ECLS.[1,2,33] To be noticed, only five patients had a body temperature > 28 °C, suggesting that CA due to hypothermia at a body temperature > 28 °C is possible, albeit unlikely. The highest body temperature of a patient surviving a witnessed hypothermic CA in the absence of associated risk factors for CA was 29.4 °C.[29] Our results therefore support the idea that the risk of cardiac arrest is unlikely to be solely attributed to hypothermia at a body temperature >30 °C.[2]

Regarding the management of cardiac arrest due to accidental hypothermia, our results therefore suggest that potentially hypothermic CA victim with a body temperature < 30 °C should be considered for ECLS rewarming. In the out-of-hospital setting, we believe that this 30 °C temperature cut-off may be reliable for considering transporting hypothermic CA patients to hospital for rewarming. Regarding the hospital hypothermic CA management guidelines, we would rather recommend using a more comprehensive approach for determining if a patient qualifies for ECLS instead of solely relying on a temperature cut-off. One such approach would be the use of the HOPE score, which is currently under external validation.[6] Of course, for cases in which other factors could contribute to CA in a mildly hypothermic patient (> 30 °C),[27,16,17] hypothermia would still have to be considered and treated appropriately if judged appropriate, while taking account of the fact that hypothermia has a protective effect on the brain and heart.[1]

The second key contribution of this study is the description of the initial cardiac rhythm of witnessed hypothermic CA patients. Although VF is often cited as the initial detected cardiac rhythm of hypothermic CA patients,[34] our study highlights the fact that asystole might be the first recorded cardiac rhythm in a substantial proportion (30%) of rescue collapse patients. The lack of recognition that CA can be occurring in hypothermic patients with an asystole cardiac rhythm, following mobilisation and prior to monitoring, might lead to an underestimation in the survival potential of patients.[24] For this reason, it is suggested that patients should be monitored before mobilization.[35] Of note, neither the presence of asystole as the first cardiac rhythm after CA, not the fact that CA had been witnessed in hypothermic CA patient were predictive of poorer outcomes in a recent study.[6] Since asystole might be the first cardiac rhythm in a substantial proportion of hypothermic CA patients and it occurs frequently following the handling of patients, awareness of asystole as the first cardiac rhythm in hypothermic CA patients could be important in the management of hypothermic patients as well. Specifically, it might improve the detection of CA due to rescue collapse. It can help with determining the duration of no flow and low flow. The latter is especially critical because it is a predictive factor of hypothermic cardiac arrest.[6,11,36] Ultimately, awareness that asystole can be the first cardiac rhythm in hypothermic CA patients and may have a good prognosis can improve the selection of patients who would benefit from ECLS rewarming.

The third key contribution of this study is the clinical description of patients who experienced CA due to rescue collapse. It has been shown that suitable thermometers, notably low-reading thermometers, are often not achievable in certain settings.[37,38] It has been proposed that the clinical Swiss Staging model should be used in such situations in which reliable core temperature measurements are not available.[39] Estimation of temperature using clinical parameters has, however, been shown to be suboptimal.[39] In particular, the misclassification of patients with a body temperature < 24 °C as clinical stage 3 (< 28–24 °C) on the Swiss Staging system could result in the underestimation of CA risk in patients and serious consequences.[4] The only parameter which may be relevant in identifying hypothermic patients with a lower risk of CA appears to be level of consciousness. Out of the 24 patients whose GCS scores were recorded, only 4 had a GCS > 8 with the highest GCS being 10. These results therefore suggest that CA is less likely to occur in hypothermic patients with a normal level of consciousness. Hence, the state of consciousness of hypothermic patients might be a simple, practical clinical parameter that can help identify hypothermic patients with a lower risk of CA on-scene. However, as unfortunately the clinical parameters (HR, RR, BP, GCS) were available only in 12–24 of analysed patients, these conclusions must be interpreted with caution.

Limitations

Our study suffers from several limitations. The first limitation is the amount of missing data. Furthermore, some information might be inaccurate. This limitation is, however, due to the retrospective nature of a systematic review. It was especially notable for the unpublished cases that were taken from the HOPE study[6] in which vital signs were typically not included in the cases description. A second limitation is the high risk of systematic bias of our data that may arise not only because of the missing data we have already mentioned, but also through publication, and selection bias. To take account of this, we decided to forego statistical inference in favour of simple clinical inference. A third limitation is related to the reported body temperature of the hypothermic patients that were included in this study. We could not be always certain that effective devices were used properly. The use of an inappropriate device or a delayed measurement could potentially underestimate the core body temperature of hypothermic CA patients as a further drop may have followed CA. Finally, the excessively long time period of data collection from 1987 to 2018 can potentially be a limitation as triage criteria and out-of-hospital treatment may have changed over time. Overall, additional prospective studies would have to be conducted to validate our statements in this study.

Conclusions

In our study of 214 witnessed hypothermic cardiac arrest patients, we observed that CA occurred at a mean temperature of 23.9 °C. We did not find cases in which witnessed CA patients with temperatures $>30°$ or a GCS score >10 were believed due solely to hypothermia in the literature. The first recorded cardiac rhythm after CA in hypothermic patients was found to be asystole in 30% of the cases. Most patients (73%) survived witnessed hypothermic CA and 89% of the survivors have good neurological outcome. Taken together, our findings improve our understanding on hypothermic cardiac arrest and they provide important information that can be incorporated into the international clinical management guidelines for accidental hypothermia.

Conflict of interest statement

None.

Source of funding

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2019.02.001.

REFERENCES

1. Truhlar A, Deakin CD, Soar J, et al. European Resuscitation Council Guidelines for Resuscitation 2015: Section 4. Cardiac arrest in special circumstances. Resuscitation 2015;95:148–201.
2. Paal P, Gordon L, Strapazzon G, et al. Accidental hypothermia-an update : the content of this review is endorsed by the International Commission for Mountain Emergency Medicine (ICAR MEDCOM). Scand J Trauma Resusc Emerg Med 2016;24:111.
3. Brugger H, Durrer B, Elsensohn F, et al. 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 2013;84:539–46.
4. Pasquier M, Zurron N, Weith B, et al. Deep accidental hypothermia with core temperature below 24 degrees c presenting with vital signs. High Alt Med Biol 2014;15:58–63.
5. Giesbrecht GG, Hayward JS. Problems and complications with cold-water rescue. Wilderness Environ Med 2006;17:26–30.
6. Pasquier M, Hugli O, Paal P, et al. Hypothermia outcome prediction after extracorporeal life support for hypothermic cardiac arrest patients: the HOPE score. Resuscitation 2018;126:58–64.
7. Boue Y, Payen JF, Brun J, et al. Survival after avalanche-induced cardiac arrest. Resuscitation 2014;85:1192–6.
8. Mair P, Brugger H, Mair B, Moroder L, Ruttmann E. Is extracorporeal rewarming indicated in avalanche victims with unwitnessed hypothermic cardiorespiratory arrest? High Alt Med Biol 2014;15:500–3.
9. Bogle LB, Boyd JJ, McLaughlin KA. Triaging multiple victims in an avalanche setting: the Avalanche Survival Optimizing Rescue Triage algorithmic approach. Wilderness Environ Med 2010;21:28–34.
10. Debaty G, Moustapha I, Bouzat P, et al. Outcome after severe accidental hypothermia in the French Alps: a 10-year review. Resuscitation 2015;93:118–23.
11. Safar P. Resuscitation after Brain Ischemia. In: Eds GAaSP, editor. Brain failure and resuscitation. New York: Churchill Livingstone; 1981. p. 155–84.
12. Lexow K. Severe accidental hypothermia: survival after 6 hours 30 minutes of cardiopulmonary resuscitation. Arctic Med Res 1991;50:112–4.
13. Piacentini A, Volonte M, Rigamonti M, Guastella E, Landriscina M. Successful prolonged mechanical CPR in a severely poisoned hypothermic patient: a case report. Case Rep Emerg Med 2012;2012381798.
14. Khorsandi M, Dougherty S, Young N, et al. Extracorporeal life support for refractory cardiac arrest from accidental hypothermia: a 10-year experience in Edinburgh. J Emerg Med 2017;52:160–8.
15. Weuster M, Haneya A, Panholzer B, et al. The use of extracorporeal membrane oxygenation systems in severe accidental hypothermia after drowning: a centre experience. ASAIO J 2016;62:157–62.
16. Tay S, Lee IL. Survival after cardiopulmonary arrest with extreme hyperkalaemia and hypothermia in a patient with metformin-associated lactic acidosis. BMJ Case Rep 20122012:.
17. Schure PJ, de Gooijer A, van Zanten AR. Unexpected survival from severe metformin-associated lactic acidosis. Neth J Med 2003;61:331–3.
18. Winkler B, Jenni HJ, Gygax E, et al. Minimally invasive extracorporeal circulation resuscitation in hypothermic cardiac arrest. Perfusion 2016;31:489–94.
19. Maeder MB, Lischke V, Berner A, Reisten O, Pietsch U, Pasquier M. A patient with polytrauma, hypothermia and cardiac arrest after delayed mountain rescue. CMAJ 2018;190:E1263.
20. Kosinski S, Darocha T, Jarosz A, et al. Clinical course and prognostic factors of patients in severe accidental hypothermia with circulatory instability rewarmed with veno-arterial ECMO - an observational case series study. Scand J Trauma Resusc Emerg Med 2017;25:46.

21. Hohlrieder M, Kroesslhuber F, Voelckel W, Lutz M, Mair P. Experience with helicopter rescue missions for crevasse accidents. High Alt Med Biol 2010;11:375–9.
22. Moroder L, Mair B, Brugger H, Voelckel W, Mair P. Outcome of avalanche victims with out-of-hospital cardiac arrest. Resuscitation 2015;89:114–8.
23. Hill JG, Hardekopf SJ, Chen JW, et al. Successful resuscitation after multiple injuries in the wilderness. J Emerg Med 2013;44:440–3.
24. Strapazzon G, Beikircher W, Procter E, Brugger H. Electrical heart activity recorded during prolonged avalanche burial. Circulation 2012;125:646–7.
25. Papenhausen M, Burke L, Antony A, Phillips JD. Severe hypothermia with cardiac arrest: complete neurologic recovery in a 4-year-old child. J Pediatr Surg 2001;36:1590–2.
26. Binnema R, van der Wal A, Visser C, Schepp R, Jekel L, Schröder P. Treatment of accidental hypothermia with cardiopulmonary bypass: a case report. Perfusion 2008;23:193–6.
27. Nagamine T. Complete recovery from cardiac arrest caused by risperidone-induced hypothermia. Innov Clin Neurosci 2016;13:28–31.
28. Silfvast T, Pettilä V. Outcome from severe accidental hypothermia in Southern Finland—a 10-year review. Resuscitation 2003;59:285–90.
29. Brunette DD, McVaney K. Hypothermic cardiac arrest: an 11 year review of ED management and outcome. Am J Emerg Med 2000;18:418–22.
30. Steedman DJ, Rainer T, Campanella C. Cardiopulmonary resuscitation following profound immersion hypothermia. J Accid Emerg Med 1997;14:170–2.
31. Tintinalli JE, Stapczynski JS, Ma OJ, Meckler GD, Cline DM. Chapter 209: Hypothermia. In: Ltd M-HE, editor. Tintinalli's emergency medicine: a comprehensive study guide, 8e.
32. Darocha T, Kosinski S, Jarosz A, et al. The chain of survival in hypothermic circulatory arrest: encouraging preliminary results when using early identification, risk stratification and extracorporeal rewarming. Scand J Trauma Resusc Emerg Med 2016;24:85.
33. Brown DJ, Brugger H, Boyd J, Paal P. Accidental hypothermia. N Engl J Med 2012;367:1930–8.
34. Zafren K, Giesbrecht GG, Danzl DF, et al. Wilderness Medical Society practice guidelines for the out-of-hospital evaluation and treatment of accidental hypothermia. Wilderness Environ Med 2014;25:425–45.
35. Pasquier M, Blancher M, Zen Ruffinen G, Hugli O. Does rescue collapse mandate a paradigm shift in the field management of avalanche victims? High Alt Med Biol 2015;16:171–2.
36. Chen Y-S, Lin J-W, Yu H-Y, et al. Cardiopulmonary resuscitation with assisted extracorporeal life-support versus conventional cardiopulmonary resuscitation in adults with in-hospital cardiac arrest: an observational study and propensity analysis. Lancet 2008;372:554–61.
37. Henriksson O, Bjornstig U, Saveman BI, Lundgren PJ. Protection against cold — a survey of available equipment in Swedish pre-hospital services. Acta Anaesthesiol Scand 2017;61:1354–60.
38. Karlsen AM, Thomassen O, Vikenes BH, Brattebø G. Equipment to prevent, diagnose, and treat hypothermia: a survey of Norwegian pre-hospital services. Scand J Trauma Resusc Emerg Med 201363.
39. Deslarzes T, Rousson V, Yersin B, Durrer B, Pasquier M. An evaluation of the Swiss staging model for hypothermia using case reports from the literature. Scand J Trauma Resusc Emerg Med 2016;24:16.