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Clinical outcomes of challenging out-of-hospital hypothermia management: A retrospective assessment of DOKEI protocol

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A B S T R A C T

Background: Accidental hypothermia (AH) is a major cause of death in mountainous areas globally, and the second highest of mountaineering deaths in Japan, accounting for 37 % in Hokkaido. Managing AH is a significant challenge, particularly when adverse weather complicates the application of recommended rewarming and rapid transfer. To address this, the Hokkaido Police Organization (DOKEI) AH protocol was applied in Hokkaido's remote areas from 2011 to 2022, integrating high-temperature active external rewarming (HT-AER) with on-site sustained treatment.

Methods: This study retrospectively analyzed the rescue reports and hospital records of hypothermia patients treated postprotocol, excluding patients with cold exposure, undetectable vital signs at rescue, and inadequate documentation. Protocol adherence and outcomes—hypothermia stage, cardiocirculatory collapse, survival, and neurological status—were assessed.

Results: Among the 60 protocol-treated patients (19–74 years, 85 % male), 14 had stage 2 hypothermia, and 3 had stage 3 hypothermia. HT-AER was applied in 96.7 % of the patients. A total of 98.3 % of patients improved before handover without cardiac arrest (CA) or extracorporeal life support (ECLS). Comparatively, ten preprotocol patients (18–60 years, 70 % male) had two CAs, one fatal and six with no improvement.

Conclusion: The DOKEI AH protocol demonstrates feasibility in managing stages 1–3 hypothermia, enhancing survival and neurological recovery, and can offer a vital option in challenging AH rescue scenarios.

1. Introduction

Accidental hypothermia (AH), which involves a core temperature drop below 35 °C [1,2], contributes to mountaineering fatalities [3] and is Japan's second highest cause of mountaineering deaths at 14.8 % (81/548) and the leading cause at 34 % (12/32) of such deaths in Hokkaido, Japan, between 2011 and 2015 [4]. Historical data confirm this statistic, with hypothermia accounting for 16.7 % (16/96) of mountaineering fatalities in Denali from 1903 to 2006 and 15.2 % (5/33) of such deaths in Aconcagua Provincial Park from 2001 to 2012 [5,6]. Hypothermia occurs during high-elevation mountaineering and in northern or remote recreational areas [7] and often requires extended rescue times, and limited on-site resources can adversely affect patient outcomes.

AH is classified into mild, moderate, and severe categories based on core body temperature (Tc). Mild hypothermia ranges from 32 to 35 °C, moderate hypothermia from 28 to 32 °C, and severe hypothermia is below 28 °C [1,2]. Current guidelines recommend hospital transfer for moderate-to-severe cases of AH, emphasizing rapid patient transfer in some guidelines and reviews, coupled with active external rewarming (AER) and gentle horizontal patient handling [1,2,8]. However, following these guidelines is often not feasible under challenging conditions, including adverse weather conditions, limited night-time operations, or impractical helicopter rescues. Furthermore, in such scenarios, attempting immediate extrication of the patient may risk the safety of rescuers.

Abbreviations: AER, active external rewarming; AH, accidental hypothermia; AVPU, alert, voice, pain, unresponsive; CA, cardiac arrest; CPC, Cerebral Performance Category score; DOKEI, Hokkaido Police Organization; ECLS, extracorporeal life support; HT-AER, high-temperature active external rewarming; IHR, International Hypothermia Registry; ISS, injury severity score; RC, rescue collapse; RSS, revised Swiss System; SAR, search-and-rescue; Tc, temperature.

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A critical concern in rescuing AH patients is rescue collapse (RC), a sudden cardiocirculatory collapse that can manifest as witnessed cardiac arrest (CA) [9]. Risk factors for RC include decreased Tc, abrupt or rough body movement, and position changes affecting venous return [8]—which are often unavoidable factors during rescue operations. RC was reported in approximately one-third of patients with AH [10] in a French Alps study (17 of 48 patients with AH) [11] and in the International Hypothermia Registry (IHR) (51 of 201 patients with moderate-to-severe hypothermia) [12]. The IHR data revealed that patients with preserved cardiac activity had higher survival rates than those with CA (95 % vs. 36 %) [12]. These findings underscore the importance and difficulties of preventing RC and administering early continuous CPR and extracorporeal life support (ECLS) despite logistical challenges.

While in-hospital AER correlates with improved survival [12], its effectiveness in field rescue scenarios, especially for advanced-stage hypothermia patients, remains underreported. Guidelines and reviews describe prehospital rewarming methods, while case reports validate specific AER techniques, such as torso convective warm air therapy for an avalanche victim [13] and chemical heat blanket use in moderate hypothermia [14]. However, these resources are inaccessible in remote areas, underscoring the need for practical and effective out-of-hospital rewarming strategies.

In 2010, the Hokkaido Police Organization (DOKEI) search-and-rescue (SAR) team developed an AH management protocol addressing these challenges for patients with detectable vital signs upon initial ground contact, as this protocol was not created for patients who experienced CA before rescue [15]. Since its 2011 implementation, this protocol has strongly emphasized minimizing patient body movement and employing high-temperature active external rewarming (HT-AER) while ensuring rescuer safety.

The primary objective of this study was to present initial findings on the feasibility and clinical impact of the DOKEI AH protocol for patients with detectable vital signs in out-of-hospital settings and to compare its outcomes with those achieved before its implementation. Our study provides preliminary insights into the potential efficacy of the DOKEI AH protocol for promoting Tc recovery, reducing RC risks, and enhancing survival, contributing to advancements in the dialogue surrounding AH management in challenging out-of-hospital settings.

2. Materials and methods

2.1. Study design and setting

This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Sapporo Kojinkai Memorial Hospital. The IRB granted a waiver of informed consent due to the retrospective nature of the study and the use of anonymized data (approval number 2022–5). This retrospective observational case series describes the feasibility of an out-of-hospital DOKEI AH protocol and clinical outcomes in Hokkaido, Japan. DOKEI rescue data from January 2011 to December 2022 were obtained and supplemented with 12 years of pre-2011 data. We adhered to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for reporting observational studies (https://www.strobe-statement.org/).

2.2. Selection of participants

Researchers identified patients with AH in Hokkaido, Japan, between 1998 and 2022 (Fig. 1a). Patients with hypothermia were defined as individuals requiring hypothermic treatment in the mountains. The exclusion criteria were mechanisms of hypothermia onset other than cold exposure, undetectable vital signs upon rescue, initial contact not on the ground, rescue by other organizations or self-rescue, and lack of adequate documentation. Eligibility was determined by three authors (T.Ma., T.N., and T.S.) and independently validated by the other authors (K.O. and T.Mu.). DOKEI, the provider, serves Hokkaido Prefecture's mountainous area and offers a medically trained SAR service team that does not include a physician.

2.3. Interventions

2.3.1. Rescuer description, training, and equipment

Ground SAR teams, comprising two to eight members, consisting of well-trained police mountain search and rescue specialists, undergo annual updates and occasional first aid training and receive specific training on the new protocol before implementation. Team members have 1 to 30 years of experience, with commanders for at least 15 years in the field. Fig. 2b shows the materials distributed in the team backpacks for portability.

2.3.2. DOKEI AH protocol intervention

The DOKEI AH protocol intervention is shown in Fig. 2. Upon discovering a patient, the rescuers swiftly established shelters to prevent further environmental exposure (refer to Fig. 3, item ⑧, and Supplementary Video 1). To expedite the HT-AER use, the team carried pre-filled heat-retaining bottles with boiled water, which were promptly transferred into flexible bags (Platypus; Cascade Designs, Inc., USA) upon arrival at the site and applied to the patient's chest, over clothing or additional layers to prevent burns, regardless of the patient's position (see Supplementary Video 2). Hot water on-site was prepared using portable stoves and gas canisters, designed to function efficiently at high altitudes, windy conditions, and in cold temperatures. The water carried with the team was heated to boiling (100 °C) on-site, which is theoretically ≥95 °C in Hokkaido, considering its 2200 m altitude. Additional hot water bags were strategically placed on the torso and axillary regions, deliberately avoiding the back to prevent pressure-induced burns in the supine position, with hourly replacements using re-boiled water. The protocol also includes a multilayered enclosed wrapping technique, specifically designed for the on-site management and safer transport of patients with trauma or altered consciousness, using mountaineering gear to provide enhanced protection against heat loss and facilitate effective HT-AER (illustrated in Figs. 3b, c, d, and Supplementary Video 3). The wraps were carefully sealed, incorporating a small window for essential patient assessments and ventilation (Fig. 3c). This design, shaped by insights from real-world rescue experiences and previous studies, effectively prevents snow and rain intrusion during transport and mitigates heat loss through inadequately sealed wraps [15]. The rewarming approach combines high-tech and low-tech methods to maximize patient care in challenging out-of-hospital environments. The use of flexible water bags, pre-filled heat-retaining bottles, and the multilayered enclosed wrapping technique, which uses standard mountaineering gear, exemplifies a low-tech approach that is simple yet effective and particularly valuable in remote or resource-limited settings where more advanced equipment may not be available. In contrast, preparing additional hot water on-site using portable stoves and gas canisters illustrates a high-tech approach. This equipment ensures a reliable source of boiling water for continuous HT-AER application. Oxygen administration was indicated for patients with decreased levels of consciousness or trauma.

2.3.3. Protocol adherence

We tracked protocol deviations in terms of providing shelter, HT-AER, oxygenation, and feeding from 2011 to 2022. The SAR teams were allowed discretionary practical deviations to ensure safety under unpredictable on-site conditions. Deviations typically arise from operational challenges in hazardous conditions, equipment constraints, miscommunication among rescue organizations, prioritization during multiple casualty incidents, and specific patient issues. On-site periods were determined based on the patient's condition, weather, and logistics. Patients were airlifted if a helicopter became available, regardless of their hypothermia stage. Tc measurements

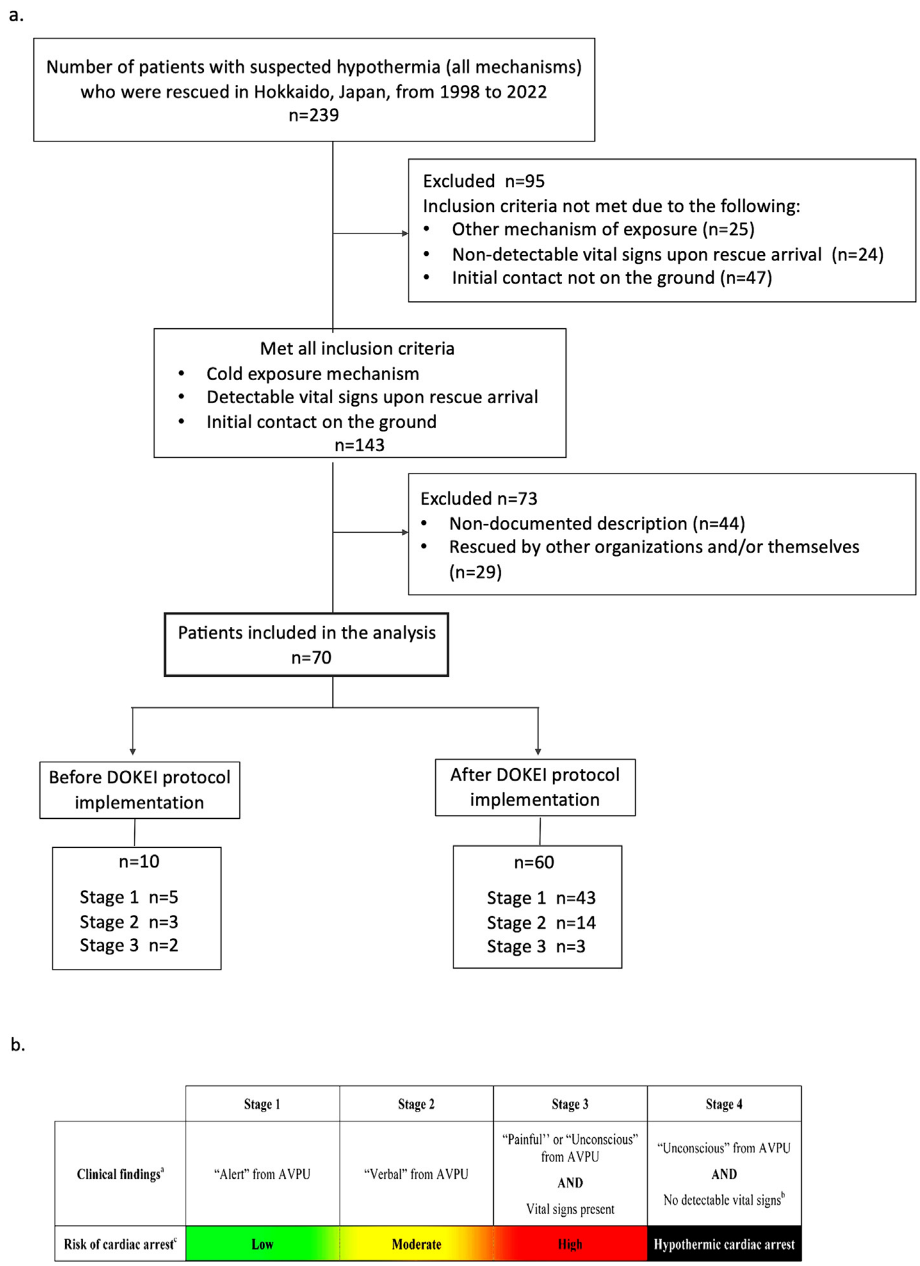

Fig. 1. Study Participant Selection and Hypothermia Staging.
(a) Flowchart of the inclusion and exclusion processes.
DOKEI, Hokkaido Police Organaization.
(b) Classification of the Revised Swiss Staging System for Hypothermia [18].

were unavailable between 2011 and 2017 due to the absence of labeled devices for accurate measurement of lower Tc in the field. In 2018, we addressed this challenge by introducing an epitympanum infrared thermometer (CE Thermo; NIPRO Co., Ltd., Japan) with an extended ear tip positioned near the tympanum and ear insulation [16,17]; we omitted this step as an adherence variable, considering the logistical infeasibility of equipping all initial response teams across Hokkaido's vast area.

2.4. Data collection and processing

The investigators designed and retrospectively completed a data collection sheet based on comprehensive DOKEI rescue reports. Anonymous records (1998–2022) included sex, age, nationality, medical history, callout date and time, weather, locality, symptoms, and signs at two time points (SAR arrival and handover), trauma, protocol actions, approach methods, transfer means, time lapse (SAR arrival, start of transfer, and handover), RC occurrence, and patient survival. Three authors (K.O., T.Ma, and T.Mu) determined the hypothermia stage at two time points (SAR arrival and handover) per the revised Swiss System (RSS) guidelines (Fig. 1b). The stage was determined by assessing the risk of CA based on vital signs and the level of responsiveness using the alertness, voice, pain, and unresponsiveness (AVPU) scale. Stage 1 indicates that the patient is alert; Stage 2 indicates that the patient responds to verbal stimuli; Stage 3 indicates that the patient responds only to painful stimuli; and Stage 4 indicates that the patient is unresponsive [18]. Discrepancies were resolved via discussion and on-site multiple-rescue interviews;

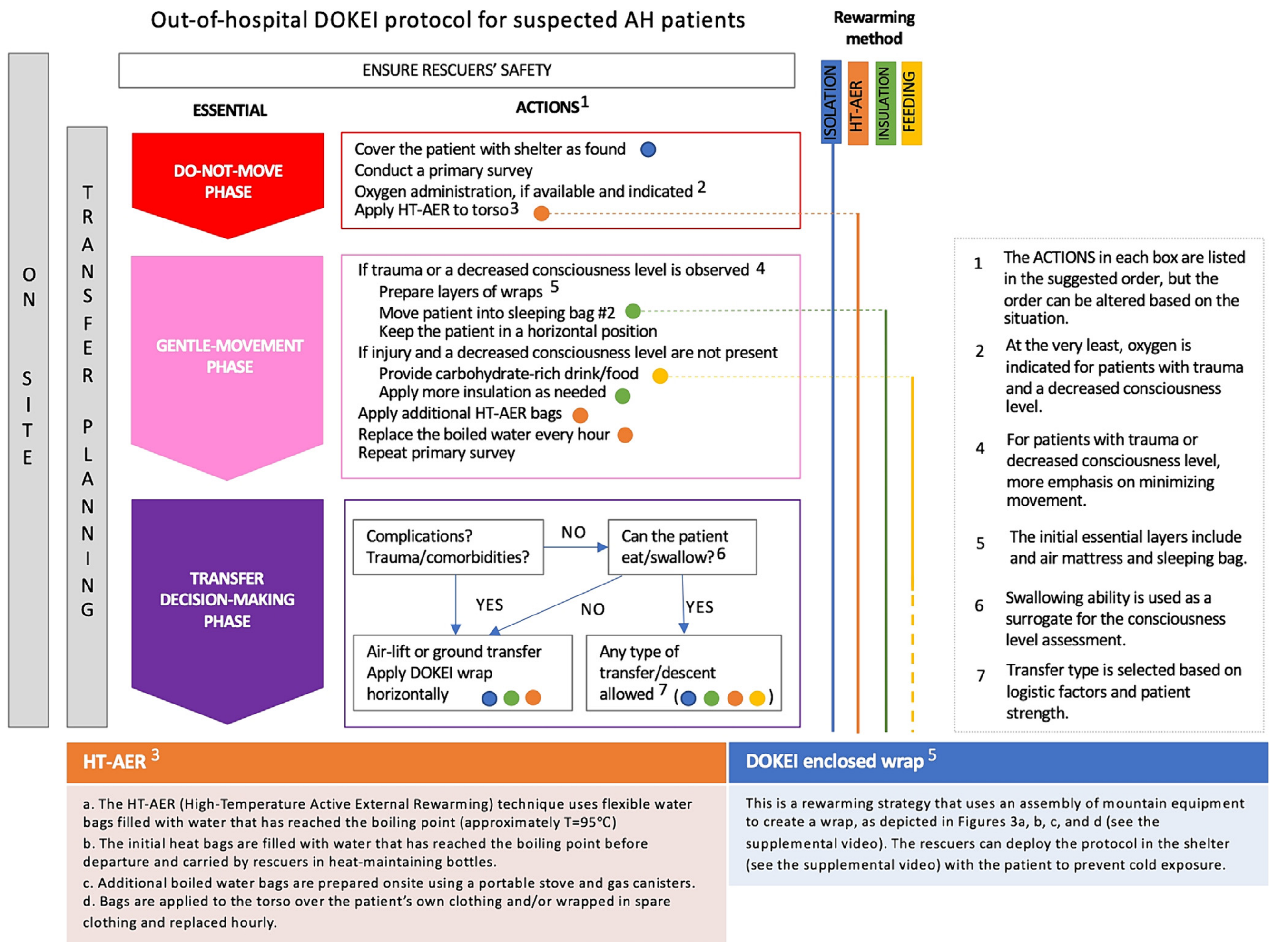

Fig. 2. Schematic representation of the DOKEI out-of-hospital protocol for individuals who require hypothermic treatment in mountaineous areas. AH, accidental hypothermia; HT-AER, high-heat active external rewarming.

unresolved cases were excluded from the analysis. Hospital course data were obtained for stage 3 patients at a greater risk of poor outcomes.

2.5. Outcomes

This study primarily assessed the feasibility of protocol implementation, including the rate of implementation of each protocol component, the reasons for nonimplementation, and the clinical outcomes. The outcomes included changes in the hypothermia stage from SAR arrival to handover, postrescue neurological status, RC occurrence, and overall survival. Changes in the hypothermia stage were categorized as "fully resolved" (return to normal), "improved" (one or two stages of improvement but not to normal), "no change" (remaining in the same stage), or "worsened" (deterioration). Neurological status was assessed using Stiell's cerebral performance category (CPC) score [19]. This assessment utilized SAR reports at handover and subsequent phone interviews by the rescue team, focusing on patients with Stage 3 AH at discharge from medical records and direct interviews by the authors. RC was defined as the occurrence of undetectable vital signs and unresponsiveness between SAR arrival and handover. Survival was evaluated at the time of the rescue operation: for patients who did not require hospital services, the assessment was at the rescue's end; for those who needed hospitalization or a hospital visit, the assessment was at discharge or postvisit.

2.6. Analysis

Continuous data are expressed herein as medians and ranges, while categorical variables are presented as counts and percentages. The data were analyzed using EZR 1.54 (Jichi Medical University, Japan), a modified version of R Commander [20].

3. Results

3.1. Characteristics of the study subjects

Between 1998 and 2022, 238 patients with suspected hypothermia were rescued. Of these patients, 76 were rescued before, and 162 were rescued after the DOKEI AH protocol was implemented. Among these patients, 70 patients, ten before and 60 after the DOKEI AH protocol implementation, had data available for analysis after applying the exclusion criteria (Fig. 1a). Between 1998 and 2010, the clinical outcome data were limited to 10 patients, possibly because of the rarity of cases and the stringency of the exclusion criteria. In 2009, a widespread incident involving 25 simultaneous hypothermia cases across several mountains necessitated extensive multiorganizational rescue efforts, significantly impacting data collection before 2010. Before and after the introduction of the protocol, the median (range) ages were 36 (18–66) and 36.5 (19–74) years, respectively, and the male-to-female ratios were 7/10 (70 %) and 51/60 (83.6 %), respectively. The participant characteristics are summarized in Table 1.

Fig. 3. Comprehensive illustration of the equipment used by the DOKEI ground SAR teams and enclosed wrapping with the HT-AER technique. (a) Ground search and rescue team equipment. Ground search and rescue team equipment for single-patient care is distributed across backpacks of two to eight rescuers, with 'A' encompassing all essential gear for initial response, including the streamlined 'B' set for two rescuers, facilitating swift deployment. The items included ① a portable 2.8-liter oxygen cylinder (300 liters of compressed oxygen), a nasal cannula/simple face mask, and a bag-valve mask. ② A portable stove with spare gas cartridges. ③ Carbohydrates. ④ Epitympanic thermometer. ⑤ Oral rehydration solution. ⑥ Preboiled water in two insulated bottles and corresponding empty water bags (Platypus; Cascade Designs, Inc., USA). ⑦ Urine bottle. ⑧ Shelter. ⑨ Hooded vest for rewarming with external access pockets in the chest and back for boiled water bags. ⑩ Rescue stretcher (Sked; Skedco, Inc., USA). ⑪ Patient's extra clothing: down jacket, fleece, base layers, and socks. ⑫ Additional preboiled water bottles and bags. ⑬ One durable plastic sheet (3.6 m × 5.4 m) with five 180 cm climbing slings. ⑭ Two connected aluminum-deposited mattresses (150 cm × 200 cm each). ⑮ Three air mattresses. ⑯ Three sleeping bags. ⑰ Climbing harness for patient in case. ⑱ Helmet for patient safety. HT-AER, high temperature-active external rewarming; SAR, search and rescue.
(b) Illustration and procedure of the DOKEI high temperature active external rewarming technique with an enclosed-wrapping method.[10]
1. Lay a blue tarp on the ground.
2. One air-filled air mat was placed in the center of 1 as a marker for the patient.
3. Lay connected aluminum mattresses on top of 2. (2 and 3 can be connected with Velcro.)
4. The first sleeping bag was placed in 3. The patient was placed in the second sleeping bag, flexible water bags filled with boiled water were placed on the patient's clothes, and the third was placed over the patient.
5. Two air-filled air mats were placed on each side of the patient.
6. Leave an opening on the face, wrap a blue sheet around the patient to grip both ends of the blue sheet and prevent the temperature from escaping.
Fig. 2d. Appearance of the finished Dokei enclosed wrapping.
The ends of the head and legs were tied with a clove hitch, and the chest, waist, and knees were tied with slings. During transport, a helmet was placed over the beanie on the patient. If the patient is under oxygen administration, a cylinder is placed within the wrapping.
(c) Inside a wrapping. (d) Photograph illustrating the transfer of Patient 1 with Stage 3 hypothermia.

3.2. Main results

3.2.1. Protocol feasibility

To assess the effectiveness of the DOKEI AH protocol under field conditions, we evaluated its feasibility across 60 hypothermia cases. The adherence rates for implementing shelter, HT-AER, and feeding protocols were 90 %, 96.7 %, and 85 %, respectively. Oxygen was administered in 55 % of patients where indicated. The primary reasons for not administering oxygen involved challenges in accurately assessing patients' consciousness levels—specifically, distinguishing between 'Alert' and 'Voice' states—particularly during the early stages of the protocol's implementation. Additional factors contributing to deviations included early equipment shortages, operational challenges such as prioritizing critically ill patients, coordination difficulties between rescue organizations, and patient-specific issues such as trauma or decreased consciousness that precluded feeding. Table 2 details these on-site actions, including deviation. Overall, the DOKEI AH protocol showed strong feasibility in real-world rescue scenarios,

Table 1
Patient characteristics before and after implementation of the DOKEI AH protocol.

Demographic			BEFORE	AFTER
Patients	Overall		10	60
		Stage 1	5	43
	By stage	Stage 2	3	14
		Stage 3	2	3
Age range in years	Overall		18–66	19–74
		Stage 1	18–61	19–74
	By stage	Stage 2	38–66	21–73
		Stage 3	34–38	25–36
Sex	Male, n(%)		7 (70)	51 (83.6)
Mechanism	Exposure		1	53
	Secondary to trauma		0	8
		ISS range		4–26

AH, Accidental Hypothermia; ISS, Injury Severity Score.

with notable adherence rates despite some challenges in oxygen administration.

3.2.2. Patient outcomes

We assessed the impact of the DOKEI AH protocol on patient outcomes. Among the 60 hypothermia cases analyzed after the protocol was implemented, 59 (98.3 %) exhibited full recovery or improvement, one remained unchanged due to limited resources, and no cases of RC or CA were reported, leading to a 100 % survival rate (Table 3A).

3.2.2.1. Group treated before DOKEI AH protocol implementation. Before the protocol's implementation, outcomes varied: two patients with Stage 1–2 fully recovered, six showed no change at handover, and of two with Stage 3 patients, one found half-immersed in a cold stream experienced RC after being pulled out but survived with a CPC score of 1, indicating good cerebral performance and a high probability of normal life after 65 min of CPR, and ECLS, with a Tc of 21.9 °C. Another RC that experienced 120 min of ground transfer amid adverse weather was airlifted after 17 h and did not survive (Table 3A).

3.2.2.2. Group treated after DOKEI AH protocol implementation. After the protocol's implementation, all patients achieved complete neurological recovery without clinical worsening, RC incidents, or ECLS. All stage 1 patients (43/43), including six with trauma, and 12/14 stage 2 patients, including one with trauma (injury severity score (ISS) 18), fully recovered at handover. One Stage 2 trauma patient (ISS 10) improved to Stage 1. Among the three Stage 3 patients without a previous medical history or on-site complications, one fully recovered, one improved to Stage 2, and one maintained the same stage for two days, demonstrating stability amidst the constraints of limited resources (Fig. 3e and Table 3B). No HT-AER-related burns or safety concerns were reported. Ambulatory capabilities were restored in half of the patients (30 out of 60), enabling them to self-ambulate during descent under rescuer supervision: 25/43 in Stage 1 and 6/14 in Stage 2. The median duration of on-site stay tended to increase with the severity of the hypothermia stage (Table 3C). Tc monitoring performed in one patient with Stage 1 hypothermia revealed an afterdrop of −0.4 °C, a thermodynamic concept defined as a continued decrease in the Tc after extraction from a cold environment, and the time to the nadir was 8 min. The Tc increased ten °C/h (0.5 °C/3 min) from the nadir to the onset of shivering and then 0.45 °C/h during shivering. These findings demonstrated the broad adaptability and effectiveness of the protocol across varying degrees of hypothermia severity.

3.2.3. Comparison of pre- and postprotocol implementation outcomes

A comparison of pre- and postimplementation data revealed significant improvements after protocol implementation, with no RCs or CAs. This finding contrasts with the preprotocol outcomes, where 20 % of the patients improved and 2 of 10 patients experienced RC/CA, with one fatality.

4. Discussion

This study assessed the feasibility and effectiveness of the DOKEI AH protocol in real-world rescue scenarios, addressing the gap in knowledge regarding effective hypothermia management in challenging, remote rescue conditions. Our results demonstrated the successful application of the protocol, even under adverse weather conditions, as it achieved significant clinical improvements in 59 out of 60 hypothermia patients with detectable vital signs and a 100 % survival rate without any instances of RC, clinical deterioration, or the need for ECLS. The protocol also notably restored ambulatory capabilities in half of the patients, underscoring its efficacy in facilitating recovery. There were no reported incidents of burns or other safety issues. This highlights our protocol's potential to enhance hypothermia management in mountainous terrains, where traditional methods may face limitations due to logistical constraints and environmental challenges.

Table 2
Protocol feasibility ($n = 60$).

Actions	YES	NO	The reasons of not implementation
Initiate the protocol at the discovery location without moving the patient	59	1	An instance required quick implementation once moving to a safer area because of severe wind conditions.
Shelter	54	6	Early in the protocol implementation, shelter equipment was unavailable for all rescue teams.
Oxygen indication	20	40	Oxygen was indicated: In patients with trauma and decreased consciousness level.
Oxygen administered according to indication	11	9	Of the 9 patients, reasons for not administered 5- commander's judgment 2-miscommunication between different rescue organizations 1-oxygen available but not brought to the site by mistake 1- no oxygen available
HT-AER	58※	2	1- The team was dedicated to caring for the critically ill partner.1- Challenging coordination of leadership roles among two different rescue organizations. ※ One case with a three-day transfer wait under bad weather limited fuel, affecting water boiling efficiency.
Feeding	51	9	4- Trauma 2- Remained with a decreased level of consciousness despite rewarming. 2- Declined due to nausea. 1- The team was dedicated to caring for the critically ill partner.
DOKEI-WRAP indication	27	33	
DOKEI-WRAP according to indication	27	27	Those who wanted to remain seated and were capable of doing so were not wrapped. Wrapping was performed for all trauma cases, all stage-3 hypothermia, during ground-transfer and waiting prolonged periods for feasible transfer. In one instance, the blue tarp was blown off due to severe high winds and replenished by the next team.

HT-AER, high-heat active external rewarming; DOKEI, Hokkaido Police Organization.

Table 3
Outcomes of DOKEI AH Protocol Application in Hypothermia Patients.

A. Patient outcomes before and after the DOKEI AH protocol implementation.

		BEFORE ($n = 10$)	AFTER ($n = 60$)
RSS stage change upon handover to medical personnel	Fully	2	56
	Improve	0	3
	No change	6	1
	Worsened※	2	0
※Details of worsened	RC/CA occurrence during rescue	2	0
	Survived after ECLS	1	0
	No-indication of ECLS and death confirmed	1	0
Number of survivals		9	60

B. Descriptions of three patients with stage 3 hypothermia.

	Patient 1	Patient 2	Patient 3
Age (years), Sex, nationality	34, man, Japanese	36, woman, Chinese	25, man, Japanese
Height and weight	165 cm, 52 kg	Not recorded	177 cm, 70 kg
On-site temperature and wind speed	−9 °C, 25 m/s on contact	−5.1 °C, 8.5 m/s on contact	A snow cave at −4 °C; outside −9 °C, >25 m/s on callout
From exposure to first contact	12:00, summiting and got lost 15:00, callout by his father at home 22:20, found	18:30, summiting and got lost 23:37, callout by an accompanying person due to altered consciousness 03:01 on the next day, found	08:15, callout on the fifth day of cold-exposed mountaineering on a remote island by an accompanying person. Bad weather hindered a helicopter flight for 2 days
Initial vital signs	Unresponsive to pain and occasional groaning with a palpable pulse when found	No response to pain and occasional groaning, with a palpable pulse of 40 beats/min when found	Unresponsive to pain with occasional groaning as reported by accompanying person
Before and during transfer interventions and clinical course	22:30, sheltered, enclosed-wrapped with HT-AER of multiple heat bags reboiled hourly. 23:20, started shivering 00:40, next day, responded well to verbal cues; could eat and drink 02:00, alert, expressed a desire for micturition. 06:50, transferred by ground in enclosed-wrapping with HT-AER and oxygen. 08:30, could walk to ambulance car.	03:01, sheltered, enclosed-wrapped with HT-AER of multiple heat bags reboiled hourly. 05:34, reacted to pain stimuli, heart rate of 60 beats/min; oxygen was administered. 06:05, 28.5 °C in the tympanum 06:30, could converse with slight confusion. 07:06, airlifted in enclosed-wrapping with HT-AER and oxygen.	In snow cave, enclosed in sleeping bag and aluminum foil blanket with HT-AER. Heat bag was reboiled occasionally due to limited resources under remote assistance from a physician and dispatchers, for 56 h. 2 days later, the patient was airlifted for 90 min to the hospital in enclosed-wrapping with HT-AER and oxygen. 40 min after boarding, 25 °C of body temperature (measurement type not specified).
Hospital course	Discharged the next day with CPC1.	Discharged 2 days later with CPC1.	29.1 °C of bladder temperature, GCS score 13 (E3V4M6), BP 103/50 mmHg, and sinus rhythm, 110 beats/min. Admitted to the ICU for 2 days without ECLS, developed penile and 10-finger frostbite resulting in all finger amputation and urethral reconstruction. Discharged with a CPC score of 1.
Laboratory data on admission	Potassium (mmol/L) 3.7, Glucose (mg/dL) 82, Cr (mg/dL) 0.57, CK (U/L) 19,130, PTA (%) 97, D-dimer (μg/mL) 0.15	No data available.	pH 7.22, BE (mmol/L) −19.9, Lactate (mmol/L) 1.5, Potassium (mmol/L) 5.0, Glucose (mg/dL) 71, Cr (mg/dL) 2.03, CK (U/L) 15,518, PTA (%) <100, D-dimer (μg/mL) 7.4

C. Duration of on-site stay (min) by hypothermia stage.

Group	n	Median	Range
Stage 1	43	78	13–800
Stage 2	14	207	8–755
Stage 3	3	490	249–4112

A: AH, accidental hypothermia.
B: GCS, Glasgow Coma Scale; BP, blood pressure; BE, base excess; Cr, creatinine; CK, creatine kinase; PTA, prothrombin activity

Our approach introduces two innovative elements: 1) prioritizing sustained on-site treatment, minimizing patient body movement beyond the guideline-recommended rapid transfer when this is impractical, and 2) applying boiled-water bags for rewarming, employing temperatures higher than the previously reported or unspecified temperature parameters in the existing guidelines. After protocol implementation, all three Stage 3 patients showed no RC, with two showing stage improvement and one remaining stable without worsening. These findings underscore the protocol's feasibility and potential to enhance patient stability and survival prospects when rapid evacuation is difficult.

The demonstrated success of these innovative elements, especially in stabilizing patients on site, deepens our understanding of the critical factors influencing the timing of safer transfers in hypothermia patients under varied environmental conditions and patient states. By prioritizing sustained on-site treatment, we aim to mitigate the risk of CA/RC during patient movement. Historical experiences have demonstrated that CA/RC incidents, especially when helicopter evacuation is not readily available, necessitate prolonged on-site CPR or extended waiting times, increasing the risks to both patients and rescue personnel. Although a recent study demonstrated that hypothermic CA is unlikely to occur in patients with a Tc above 30 °C without complications [21], the challenge of accurate Tc measurements in mountain rescue scenarios persists. The variability in individual responses to hypothermia further complicates the assessment of a patient's consciousness level as an indicator of CA risk [18,22,23], presenting difficulties in determining safe transport timing. To address these challenges, the DOKEI AH protocol begins by minimizing patient movement, which is applicable across all stages of suspected hypothermia upon rescue team arrival. After initiating treatment, we assessed patient alertness through their independent ability to eat, drink, and swallow without signs of aspiration when verbally responsive (A and V from AVPU) [23,24]. This indirect measure, serving as a gauge for allowing safer transfer initiation or patient ambulation where direct Tc measurement is unfeasible, offers a pragmatic alternative despite silent aspiration risks, with caloric intake aiding Tc recovery. Our findings revealed that the median time to ambulation significantly exceeded the current guidelines for delaying exercise within a 30-min observation period in the mild stage [2]. This time variation supports the foundational concept of requiring an on-site sustained period. At the same time, the actual duration may need to be adjusted based on each patient's status and rescue conditions. Our results underscore the variable nature of transport decisions, integrating patient status with environmental factors, helicopter availability, and transport time, highlighting the necessity for individualized patient care and reflecting the guidelines' provision for situational adjustments.

Successful on-site sustained care is achieved by integrating with the introduction of HT-AER, which effectively warms individuals, including stage 3 hypothermia, providing a viable solution for real-world applications, employing conductive heat delivery at higher temperatures than previously reported across a larger contact area, maximizing total body heat gain and minimizing heat loss. One Stage 3 patient's condition remained unchanged, highlighting the method's dependency on resources and suggesting the potential for further positive outcomes given sufficient resources. Previous studies on the field efficacy of AERs have primarily drawn on case reports, with systematic reviews indicating limited high-quality evidence to confirm their risks, often relying on expert consensus [25]. A controlled study involving five human subjects comparing AER methods, including hot water bags, charcoal heaters, and chemical heat pads, identified 55 °C hot water bottles as the most efficacious and highest temperature tested [26]. Some guidelines and reviews specify the torso as the site for AER [1,8], while some give priority to the axilla [2]. We primarily chose the chest in the torso, which targets a larger contact area and facilitates easier application and maintenance compared to the axillary region. Additionally, the strategic application of external heat to the torso mitigates the Tc afterdrop temperature and associated complications [27], aligning with evidence that providing more heat reduces the afterdrop temperature and increases the Tc warming rate in nonshivering immersion hypothermia [28]. This approach is particularly significant given the established correlation between Tc decrease and CA [8], with further evidence indicating that minimizing the afterdrop in moderate-to-severe hypothermia patients can lead to a reduction in morbidity and mortality. Given this background, we assessed the Tc recovery process using the HT-AER in our observations of a mild hypothermia patient. Tc monitoring demonstrated a reduced afterdrop and a quicker arrival at the nadir compared to those in the previous report (−0.4 °C/8 min vs. −1.7 °C/42 min) [26], followed by a rapid Tc increase and subsequent gradual increase during shivering. These findings suggest that HT-AER may shorten the afterdrop phase, reduce the total decrease in body temperature, and enhance Tc recovery even in mild-stage patients. Our HT-AER method aligns with research emphasizing the primary requirement for rewarming in response to decreased cellular metabolism in hypothermia patients [8,12], offering practical application in real-world settings, albeit resource dependent. The comprehensive outcomes observed in our 60-patient study are uncommon in the prehospital AER literature.

Given the protocol's high efficacy in mountainous areas, further exploration of the role of oxygen administration, particularly at higher altitudes, may be beneficial. As hypothermia progresses, decreased respiratory effort and lower oxygen pressure at altitude can exacerbate hypoxia. While tissue oxygen consumption decreases in hypothermia, oxygen demand rises during rewarming. Although this protocol did not specifically evaluate hypoxia at higher altitudes, considering the modest altitude of Hokkaido (2200 m), further assessment of the protocol's approach to oxygen administration at higher altitudes is warranted. Finally, we assessed the feasibility of the protocol, focusing on minimal patient movement, HT-AER application, and sheltering strategies. The high adherence rates observed in our study suggest that this approach is essential, practical, and consistently implementable across different hypothermia stages. Considering the dynamic nature of rescue scenarios—for which the patient stages are unknown until team arrival and strategies must quickly adapt to weather conditions, resource availability, and safety concerns—this approach involving the DOKEI AH protocol has significantly advanced our understanding of protocol feasibility in field settings, highlighting the importance of a protocol that is not only effective but also versatile enough to accommodate the complexities of emergency rescue operations. Furthermore, this protocol might be applicable not only for self-rescue in extreme weather conditions such as polar expeditions or high-altitude expeditions but also in more common scenarios involving isolated environments that require hypothermia management.

This study's retrospective design, the rare occurrence of AH, and the ethical constraints of controlled human studies in this context present inherent limitations, including challenges in establishing causality and generalizability. The variability in field conditions, including differences in equipment availability, environmental factors, and patient severity, introduces potential biases and affects data consistency. Additionally, the absence of standardized Tc measurements and the small sample size further limit the robustness and direct comparability of our findings. Despite these limitations, the consistent application of our protocol across various conditions and its association with positive outcomes underscore its potential value. Future prospective studies with larger sample sizes and standardized measurement techniques are needed to confirm these findings and refine the protocol's application.

5. Conclusions

The DOKEI AH protocol has demonstrated its feasibility and effectiveness in managing hypothermia under the challenging conditions of mountain rescues, achieving exceptional survival rates and significant clinical improvements without the need for advanced life support interventions. Key innovations in strategic, sustained on-site care and adaptable rewarming approaches have demonstrated that the ability to provide individualized, responsive treatment when applying standardized procedures is challenging. Although the retrospective nature of this study and the unique conditions of each rescue operation necessitate a cautious interpretation of our results, they also emphasize the importance of dynamic protocols that can suit individualized states and the complexities inherent in emergency rescue operations. Ongoing data collection and research are vital for validating the appropriate indications of this protocol.

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CRediT authorship contribution statement

Kazue Oshiro: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Takashi Matsumoto:** Writing – review & editing, Writing – original draft, Validation, Investigation, Data curation, Conceptualization. **Takeshi Nawa:** Writing – review & editing, Visualization, Validation, Investigation, Data curation. **Takayuki Sakuta:** Writing – review & editing, Writing – original draft, Validation, Investigation, Data curation. **Tomikazu Murakami:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Data availability

The data generated and analyzed in this study are not available to the public due to Japan's privacy laws and confidentiality agreements with research collaborators but are available upon reasonable request from the corresponding author and with the consent of the research collaborators.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Lott C, Truhlář A, Alfonzo A, Barelli A, González-Salvado V, Hinkelbein J, et al. European resuscitation council guidelines 2021: cardiac arrest in special circumstances. Resuscitation. 2021;161:152–219. https://doi.org/10.1016/j.resuscitation.2021.02.011.

[2] Dow J, Giesbrecht GG, Danzl DF, Brugger H, Sagalyn EB, Walpoth B, et al. Wilderness medical society clinical practice guidelines for the out-of-hospital evaluation and treatment of accidental hypothermia: 2019 update. Wilderness Environ Med. 2019;30:S47–69. https://doi.org/10.1016/j.wem.2019.10.002.

[3] Windsor JS, Firth PG, Grocott MP, Rodway GW, Montgomery HE. Mountain mortality: a review of deaths that occur during recreational activities in the mountains. Postgrad Med J. 2009;85:316–21. https://doi.org/10.1136/pgmj.2009.078824.

[4] Oshiro K, Murakami T. Causes of death and characteristics of non-survivors rescued during recreational mountain activities in Japan between 2011 and 2015: a retrospective analysis. BMJ Open. 2022;12:e053935. https://doi.org/10.1136/bmjopen-2021-053935.

[5] McIntosh SE, Campbell AD, Dow J, Grissom CK. Mountaineering fatalities on Denali. High Alt Med Biol. 2008;9:89–95. https://doi.org/10.1089/ham.2008.1047.

[6] Westensee J, Rogé I, Van Roo JD, Pesce C, Batzli S, Courtney DM, et al. Mountaineering fatalities on Aconcagua: 2001–2012. High Alt Med Biol. 2013;14:298–303. https://doi.org/10.1089/ham.2013.1018.

[7] Procter E, Brugger H, Burtscher M. Accidental hypothermia in recreational activities in the mountains: a narrative review. Scand J Med Sci Sports. 2018;28:2464–72. https://doi.org/10.1111/sms.13294.

[8] Paal P, Pasquier M, Darocha T, Lechner R, Kosinski S, Wallner B, et al. Accidental hypothermia: 2021 update. Int J Environ Res Public Health. 2022;19:501. https://doi.org/10.3390/ijerph19010501.

[9] Boué Y, Payen J-F, Brun J, Thomas S, Levrat A, Blancher M, et al. Survival after avalanche-induced cardiac arrest. Resuscitation. 2014;85:1192–6. https://doi.org/10.1016/j.resuscitation.2014.06.015.

[10] 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. https://doi.org/10.1089/ham.2010.1027.

[11] Debaty G, Moustapha I, Bouzat P, Maignan M, Blancher M, Rallo A, et al. Outcome after severe accidental hypothermia in the French Alps: A 10-year review. Resuscitation. 2015;93:118–23. https://doi.org/10.1016/j.resuscitation.2015.06.013.

[12] Walpoth BH, Maeder MB, Courvoisier DS, Meyer M, Cools E, Darocha T, et al. Hypothermic cardiac arrest - retrospective cohort study from the international hypothermia registry. Resuscitation. 2021;167:58–65. https://doi.org/10.1016/j.resuscitation.2021.08.016.

[13] Strapazzon G, Nardin M, Zanon P, Kaufmann M, Kritzinger M, Brugger H. 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. 2012;60:193–6. https://doi.org/10.1016/j.annemergmed.2011.11.015.

[14] Phillips D, Bowman J, Zafren K. Successful field rewarming of a patient with apparent moderate hypothermia using a hypothermia Wrap and a chemical heat blanket. Wilderness Environ Med. 2019;30:199–202. https://doi.org/10.1016/j.wem.2019.01.001.

[15] Oshiro K, Murakami T, Nishimura K. Hokkaido Police's hypothermia wrapping method: the reducing effect of heat loss and successful cases in mountain rescues. Japanese Journal of Mountain Medicine. 2015;35:48–54.

[16] Harasawa K, Kemmotsu O, Mayumi T, Kawano Y. Comparison of tympanic, esophageal and blood temperatures during mild hypothermic cardiopulmonary bypass: a study using an infrared emission detection tympanic thermometer. J Clin Monit. 1997;13:19–24. https://doi.org/10.1023/a:1007328005057.

[17] Strapazzon G, Procter E, Paal P, Brugger H. Pre-hospital core temperature measurement in accidental and therapeutic hypothermia. High Alt Med Biol. 2014;15:104–11. https://doi.org/10.1089/ham.2014.1008.

[18] Musi ME, Sheets A, Zafren K, Brugger H, Paal P, Hölzl N, et al. Clinical staging of accidental hypothermia: the revised Swiss system: recommendation of the International Commission for Mountain Emergency Medicine (ICAR MedCom). Resuscitation. 2021;162:182–7. https://doi.org/10.1016/j.resuscitation.2021.02.038.

[19] Stiell IG, Nesbitt LP, Nichol G, Maloney J, Dreyer J, Beaudoin T, et al. Comparison of the cerebral performance category score and the health utilities index for survivors of cardiac arrest. Ann Emerg Med. 2009;53:241–8. https://doi.org/10.1016/j.annemergmed.2008.03.018.

[20] Kanda Y. Investigation of the freely available easy-to-use software 'EZR' for medical statistics. Bone Marrow Transplant. 2013;48:452–8. https://doi.org/10.1038/bmt.2012.244.

[21] Frei C, Darocha T, Debaty G, Dami F, Blancher M, Carron PN, et al. Clinical characteristics and outcomes of witnessed hypothermic cardiac arrest: a systematic review on rescue collapse. Resuscitation. 2019;137:41–8. https://doi.org/10.1016/j.resuscitation.2019.02.001.

[22] Zafren K, Giesbrecht GG, Danzl DF, Brugger H, Sagalyn EB, Walpoth B, et al. Hypothermia evidence, afterdrop, and guidelines. Wilderness Environ Med. 2015;26:439–41. https://doi.org/10.1016/j.wem.2015.02.001.

[23] Barrow S, Ives G. Accidental hypothermia: direct evidence for consciousness as a marker of cardiac arrest risk in the acute assessment of cold patients. Scandinavian journal of trauma, resuscitation and. Emerg Med. 2022;30:13. https://doi.org/10.1186/s13049-022-01000-w.

[24] Fujiwara Y, Hase K, Nagashima F, Okishio N. Relationship between level of consciousness and resumption of full oral intake in patients with dysphagia in an Acute Care Hospital. The Japanese Journal of Dysphagia Rehabilitation. 2015;19:117–26. https://doi.org/10.32136/jsdr.19.2_117.

[25] Mydske S, Thomassen Ø. Is prehospital use of active external warming dangerous for patients with accidental hypothermia: a systematic review. Scand J Trauma Resusc Emerg Med. 2020;28:77. https://doi.org/10.1186/s13049-020-00773-2.

[26] Lundgren JP, Henriksson O, Pretorius T, Cahill F, Bristow G, Chochinov A, et al. Field torso-warming modalities: a comparative study using a human model. Prehosp Emerg Care. 2009;13:371–8. https://doi.org/10.1080/10903120902935348.

[27] Deussen A. Hyperthermia and hypothermia. Effects on the cardiovascular system. Anaesthesist. 2007;56:907–11. https://doi.org/10.1007/s00101-007-1219-4.

[28] Giesbrecht G, AM Steinman A. Immersion into cold water. Auerbach's Wilderness Medicine, 2-Volume Set, Mosby, St. Louis 7th ed. 2017. p. 162–97.