



Commentary and concepts

Delayed and intermittent CPR for severe accidental hypothermia[☆]

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ABSTRACT

Introduction: Cardiac arrest (CA) in patients with severe accidental hypothermia (core temperature <28 °C) differs from CA in normothermic patients. Maintaining CPR throughout the prehospital period may be impossible, particularly during difficult evacuations. We have developed guidelines for rescuers who are evacuating and treating severely hypothermic CA patients.

Methods: A literature search was performed. The authors used the findings to develop guidelines.

Results: Full neurological recovery is possible even with prolonged CA if the brain was already severely hypothermic before CA occurred. Data from surgery during deep hypothermic CA and prehospital case reports underline the feasibility of delayed and intermittent CPR in patients who have arrested due to severe hypothermia.

Conclusions: Continuous CPR is recommended for CA due to primary severe hypothermia. Mechanical chest-compression devices should be used when available and CPR-interruptions avoided. Only if this is not possible should CPR be delayed or performed intermittently. Based on the available data, a patient with a core temperature <28 °C or unknown with unequivocal hypothermic CA, evidence supports alternating 5 min CPR and ≤5 min without CPR. With core temperature <20 °C, evidence supports alternating 5 min CPR and ≤10 min without CPR.

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1. Introduction

In severe accidental hypothermia (core temperature <28 °C), cardiac arrest (CA) is common.¹ Management guidelines differ from guidelines for normothermic patients: (1) in ventricular fibrillation (VF), no more than three shocks should be delivered until the core temperature is >30 °C²; (2) epinephrine and other drugs should

be withheld until the core temperature reaches 30 °C; and (3) CPR should not be terminated prematurely as patients can make a full recovery, even after protracted CPR.^{3–5} Whilst it is true that “some people are cold and dead”, it is a guiding principle in hypothermic CA that unless there is pathology incompatible with life, “no one is dead until warm and dead.” The priority is to protect the brain, as the heart usually restarts after rewarming.

Current guidelines recommend that CPR be started as soon as CA is diagnosed and continued until commencing extracorporeal rewarming. In the field, attempting to maintain CPR throughout the evacuation may be hazardous or impossible, particularly in difficult terrain. CPR quality deteriorates in experimental and clinical studies with transport.^{6,7} Mechanical CPR-devices should be used during prolonged or difficult evacuation because high

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quality manual CPR is impossible.⁸ However, these devices are not always immediately available. Current CPR guidelines emphasise the importance of minimising no-flow time, but in difficult conditions, interruption of manual CPR may be unavoidable. The Wilderness Medical Society has recently endorsed delayed and interrupted CPR in these circumstances, but is not explicit about timing.⁹ We propose guidelines for severely hypothermic CA patients when continuous CPR is impossible. A limitation is that these guidelines are not based on controlled studies but on a literature review with inherent risk of reporting bias as cases with negative outcome may have been underreported.

2. Materials and methods

The literature was searched by two authors (LG, PP) from 1946 to present (last access was on 6th January 2015) using PubMed using the following Medical Subject Headings (MeSH): circulatory arrest, deep hypothermic induced intermittent perfusion (14 references found); hypothermic circulatory arrest intermittent perfusion (44); circulatory arrest, deep hypothermia induced and intermittent perfusion (13); deep hypothermic circulatory arrest reperfusion (167); circulatory arrest, deep hypothermia induced neuroprotection (28); circulatory arrest, deep hypothermia induced cerebral protection (185); intermittent cerebral perfusion (199); accidental hypothermic cardiac arrest (140); cardiac arrest extracorporeal rewarming (94); avalanche cardiac arrest (32); extracorporeal membrane oxygenation hypothermia (153), and ischaemia reperfusion brain hypothermia (457). Papers were only included if they were relevant to the subject and written in English or German.

A secondary search was performed of the citations listed in the papers highlighted in the original search. Every case report of severe accidental hypothermia was searched for an indication of whether CPR was performed continuously or intermittently. Thus, the final list of references cited in this manuscript ($n=22$ in the print and $n=87$ in the online-only version) includes original research and cases.

3. How long can the brain tolerate CA?

Evidence from surgery using hypothermic CA shows that full neurological recovery is possible if the brain has been cooled to $\sim 18^\circ\text{C}$ before CA. Two of the main factors affecting outcome are brain temperature and patient age. Even at $15\text{--}20^\circ\text{C}$, there is a limit to how long the brain can tolerate CA without sustaining damage. Although cellular oxygen-consumption decreases by 6–7% per 1°C decrease in core temperature, it is still $\sim 16\%$ of baseline at 15°C . Normothermic CA $>4\text{--}5$ min leads to permanent neurologic damage. However, the duration of CA after which full neurological recovery is possible doubles for every $\sim 8^\circ\text{C}$ temperature decrease. Children can make a full recovery after 40 min of CA at 18°C ,¹⁰ but patients >60 years cooled to a core temperature of $12\text{--}15^\circ\text{C}$ tolerate only ~ 25 min of CA.¹¹ After 60 min of hypothermic CA most people suffer neurological damage.

3.1. Surgical neuro-protective strategies for hypothermic CA

Surgeons can operate quickly to minimise hypothermic CA^{12,13} or maintain continuous systemic or selective cerebral circulation with low-flow cardiopulmonary bypass.^{14,15} When continuous low-flow is not possible, intermittent perfusion has been shown to protect against brain damage. In an animal study of CA at 18°C , intermittent circulation for 10 min every 20 min prevented cerebral anaerobic metabolism for 120 min. In another study, 1 min of intermittent perfusion every 15 min was effective. Intermittent

perfusion in humans improves neurological outcome when compared with hypothermic CA alone.

3.2. Case reports of severe hypothermic CA with delayed or intermittent CPR

A 42-year-old man was carried into a crevasse by an avalanche. By the time rescuers arrived, he was unconscious, pulseless and apnoeic. ECG revealed asystole; pupils were dilated and fixed. Rectal temperature was 19°C . No attempt was made to resuscitate the patient on site. He was flown to a nearby hospital where, 70 min after rescue, CPR was commenced. The patient was rewarmed with cardiopulmonary bypass and recovered fully.¹⁶

A 57-year-old woman became lost during a snowstorm. Soon after rescuers arrived, she developed VF, unresponsive to defibrillation. The decision was made to perform CPR during evacuation, but it was impossible to move and perform CPR simultaneously. A sequence with 1 min of 100 manual chest compressions alternating with 1 min walking to reach the road was followed for 25 min. She received CPR for a total of 5 h. Mechanical CPR was used only during the last hour of transportation. The patient's core temperature at hospital admission was 16.9°C . She was rewarmed with ECMO and recovered, although with mild cognitive impairment.

A 29-year-old skier was caught in an avalanche. When found, he was unconscious but breathing spontaneously. Core temperature was 22°C . VF developed after extrication but continuous CPR was not applied during the 15 min flight to the nearest hospital. The patient was rewarmed with cardiopulmonary bypass and made a full recovery.¹⁷

3.3. Suggested guidelines for delayed or intermittent CPR during evacuation

Although immediate, continuous CPR is the objective, there are occasions when this is impossible. There are many case reports of hypothermic CA in which prolonged continuous manual CPR was likely to have been suboptimal. Stroke volume and cerebral blood flow are directly related to depth of chest compressions.¹⁸ Manual CPR quality degrades after 2 min¹⁹ due to rescuer fatigue and by 7 min, only half of compressions are performed correctly with inadequate compression depth and rate resulting in poorer outcome.²⁰ CPR is also suboptimal when evacuating a casualty on a stretcher, transferring the casualty into and out of a vehicle and at altitude.

In severe hypothermic CA, inefficient continuous CPR during evacuation is potentially worse than intermittent good-quality CPR. Although there are differences between the quality of the circulation delivered by extracorporeal devices and manual CPR, with its unavoidable variability, if delivered effectively and with sufficient duration and frequency, intermittent CPR has the potential to provide the same effect as intermittent perfusion. Our proposed guidelines are based on available data with the aim of ensuring sufficient brain perfusion to maximise the chance of full recovery.

3.3.1. Core temperature

In applicable studies and case reports, patients had a core temperature of $<28^\circ\text{C}$. We consider patients with core temperature $<28^\circ\text{C}$ to be the target population for intermittent CPR. If oesophageal temperature monitoring is not available, temperature should be measured using an insulated low-reading epitympanic thermometer during effective CPR.²¹

3.3.2. Duration of CPR

Current CPR guidelines use 2-min cycles of chest compressions to prevent fatigue. This allows time for rhythm recognition during the change of rescuers. Studies in normothermic patients and animals have shown that although carotid artery flow starts within

seconds of starting CPR, it takes over 1 min of sustained CPR for flow to plateau and >5 min for cerebral tissue oxygen tension to rise above the ischaemic threshold.²² During hypothermia, cerebral metabolism is markedly reduced, so adequate perfusion of the brain will be re-established earlier. It is likely that 1 min of CPR is not long enough.³ We believe that a minimum of 5 min of continuous CPR, changing rescuers every 2 min, is a practical compromise that provides reasonably sustained blood flow to the brain before another period of CA. During CPR, the casualty should be ventilated with oxygen.

There are concerns about the potential adverse effects of intermittent CPR from repeated changes between oxidative and anaerobic metabolism which could conceivably cause recurring ischaemia-reperfusion injury, particularly in patients whose temperature is nearer 28 °C than 20 °C. There has been no specific research into the effects of repeated episodes of ischaemia-reperfusion, but there is evidence from animal studies that moderate hypothermia (mid-low 30s) is effective in suppressing neuronal injury caused by single episodes. Lower temperatures provide greater brain protection. Beneficial effects are present whether hypothermia is applied only to the head or systemically. These occur by multiple mechanisms including maintenance of a lower cerebral metabolic rate, reduction of ATP consumption and an increased rate of ATP recovery, suppression of processes that cause cellular damage, and enhanced recovery after reperfusion. There may be a narrow therapeutic time window for the application of hypothermia during “experimental” ischaemic brain injury with improved results occurring when hypothermia is applied at the same time as ischaemia. The best outcome is when hypothermia precedes CA, which is why surgery is performed in this sequence.

For patients with accidental hypothermia, there is evidence that ischaemic brain injury is influenced by peripheral signalling. Peripheral organ ischaemia can induce brain inflammation and injury. Peripheral cooling, even without a reduction in brain temperature, can reduce brain injury after CA and CPR. This could protect the brain in accidental hypothermic arrest when the whole body is cold.

3.3.3. Patient age

Evidence demonstrates that younger patients tolerate longer periods of CA than older ones, that physical peak is reached in the mid to late 20s, and that in many clinical areas, outcomes decline after early to mid-30s. Thus, it is likely that the elderly will tolerate delayed and intermittent CPR less well than younger patients.

3.3.4. Frequency of CPR sessions

The number of CPR interruptions will depend on terrain difficulties and transport issues, but it is useful to delineate how long CPR can be safely interrupted. This will help with evacuation decisions. If conditions mandate a longer hands-off period, rescuers should attempt to revert to the recommended timing as soon as possible. Using the available data, interpreted conservatively due to uncertainties and applying a safety factor of two for time overruns, we estimated an acceptable duration of periods without CPR.

3.3.5. Proposed guidelines for a patient with likely hypothermic CA (pulse should be checked for 60s)

- With hypothermic CA, start immediate, continuous CPR, minimise interruptions and apply mechanical chest compression as soon as possible.
- Measure core temperature to confirm severe hypothermia.
- Only when continuous CPR is impossible should rescuers consider performing delayed or intermittent CPR:
 - CPR can be delayed by up to 10 min to allow rescuers time to move the casualty to a safer location.

- If core temperature is 20–28 °C, perform at least 5 min CPR and ≤5 min without CPR.
- If core temperature is <20 °C, perform at least 5 min CPR and ≤10 min without CPR.
- If core temperature is unknown, perform at least 5 min CPR and ≤5 min without CPR.
- Resume continuous CPR as soon as feasible.

4. Conclusions

Immediate continuous CPR is recommended for CA due to primary severe hypothermia. Mechanical chest-compression devices should be used when available and CPR-interruptions avoided. If this is not possible, CPR can be delayed or performed intermittently. Based on available data, a patient with a core temperature <28 °C or unknown with unequivocal hypothermic CA, evidence supports alternating 5 min CPR and ≤5 min without CPR. With core temperature <20 °C, current evidence supports alternating 5 min CPR and ≤10 min without CPR.

Conflict of interest statement

No conflicts of interest to declare.

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Appendix A. Supplementary data

A fully referenced version of this paper is available online as supplementary material, at <http://dx.doi.org/10.1016/j.resuscitation.2015.02.017>.

References

1. Brown DJA, Brugger H, Boyd J, Paal P. Accidental hypothermia. *N Engl J Med* 2012;367:1930–8.
2. Soar J, Perkins GD, Abbas G, et al. European Resuscitation Council Guidelines for Resuscitation 2010. Section 8. Cardiac arrest in special circumstances: electrolyte abnormalities, poisoning, drowning, accidental hypothermia, hyperthermia, asthma, anaphylaxis, cardiac surgery, trauma, pregnancy, electrocution. *Resuscitation* 2010;81:1400–33.
3. Boue Y, Lavolaire J, Bouzat P, Matraxia S, Chavanon O, Payen J-F. Neurologic recovery from profound accidental hypothermia after 5 hours of cardiopulmonary resuscitation. *Crit Care Med* 2014;42:e167–70, <http://dx.doi.org/10.1097/CCM.0b013e3182a643bc>.
4. Meyer M, Pelurson N, Khabiri E, Siegenthaler N, Walpoth BH. Sequela-free long-term survival of a 65-year-old woman after 8 hours and 40 minutes of cardiac arrest from deep accidental hypothermia. *J Thorac Cardiovasc Surg* 2014;147:E1–2.
5. Lexow K. Severe accidental hypothermia: survival after 6 hours 30 minutes of cardiopulmonary resuscitation. *Arct Med Res* 1996;50:112–4.
6. Wik L, Kramer-Johnsen J, Myklebust H, et al. Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. *JAMA* 2005;293:299–304.
7. Ødegaard S, Olasveengen T, Steen PA, Kramer-Johansen J. The effect of transport on quality of cardiopulmonary resuscitation in out-of-hospital cardiac arrest. *Resuscitation* 2009;81:843–8.
8. Dembeck A, Sonntag J, Liechti B, Becker M. Reanimation in alpinem Gelände – der etwas andere Einsatz. *Notfall Rettungsmed* 2012;15:51–7.
9. Zafren K, Giesbrecht G, Danzl D, et al. Wilderness Medical Society Consensus Guidelines for the out-of-hospital evaluation and treatment of accidental hypothermia. *Wilderness Environ Med* 2014, <http://dx.doi.org/10.1016/j.wem.2014.09.002>.
10. Gaynor JW, Nicolson SC, Jarvik GP, et al. Increasing duration of deep hypothermic circulatory arrest is associated with an increased incidence of postoperative electroencephalographic seizures. *J Thorac Cardiovasc Surg* 2005;130:1278–86.
11. Svensson LG, Crawford ES, Hess KR, et al. Deep hypothermia with circulatory arrest. Determinants of stroke and early mortality in 656 patients. *J Thorac Cardiovasc Surg* 1993;106:19–28.

12. Percy A, Widman S, Rizzo JA, Tranquilli M, Elefteriades JA. Deep hypothermic circulatory arrest in patients with high cognitive needs: full preservation of cognitive abilities. *Ann Thorac Surg* 2009;87:117–23.
13. Ziganshin BA, Rajbanshi BG, Tranquilli M, Fang H, Rizzo JA, Elefteriades JA. Straight deep hypothermic circulatory arrest for cerebral protection during aortic arch surgery: safe and effective. *J Thorac Cardiovasc Surg* 2014;148:888–900.
14. Newburger JW, Jonas RA, Wernovsky G, Wypij D, et al. A comparison of the perioperative neurologic effects of hypothermic circulatory arrest versus low-flow cardiopulmonary bypass in infant heart surgery. *N Engl J Med* 1993;329:1057–64.
15. Bellinger DC, Jonas RA, Rappaport LA, et al. Developmental and neurologic status of children after heart surgery with hypothermic circulatory arrest or low-flow cardiopulmonary bypass. *N Engl J Med* 1995;332:549–55.
16. Althaus U, Aeberhard P, Schupbach P, Nachbur BH, Muhlemann W. Management of profound accidental hypothermia with cardiorespiratory arrest. *Ann Surg* 1981;195:492–5.
17. Oberhammer R, Beikircher W, Hörmann C, et al. Full recovery of an avalanche victim with profound hypothermia and prolonged cardiac arrest treated by extracorporeal re-warming. *Resuscitation* 2008;76:474–80.
18. Klouche K, Weil MH, Sun S, Tang W, Povoas H, Bisera J. Stroke volumes generated by precordial compression during cardiac resuscitation. *Crit Care Med* 2002;30:2626–31.
19. McDonald CH, Heggie J, Jones CM, Thorne CJ, Hulme J. Rescuer fatigue under the 2010 ERC guidelines, and its effect on cardiopulmonary resuscitation (CPR) performance. *Emerg Med J* 2013;30:623–7.
20. Vadeboncoeur T, Stolz U, Panchali A, et al. Chest compression depth and survival in out-of-hospital cardiac arrest. *Resuscitation* 2014;85:182–8.
21. Strapazzon G, Procter E, Paal P, Brugger H. Pre-hospital core temperature measurement in accidental and therapeutic hypothermia. *High Alt Med Biol* 2014;15:1–8.
22. Imberti R, Beelinzona G, Ricardi F, Pagani M, Langer M. Cerebral perfusion pressure and cerebral tissue oxygen tension in a patient during cardiopulmonary resuscitation. *Int Care Med* 2003;29:1016–9.