**WORKSHEET for Evidence-Based Review of Science for Emergency Cardiac Care**

**Worksheet author(s)**

| Hermann Brugger, MD  |
| Jeff Boyd, MBBS, ABEM, CCFP-EM |

**Date Submitted:** 2009/08/31

**Worksheet identifier:** ALS-SC-078A & B

**ALS Task Force review:** 2009/01/05

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**Clinical questions.**

“For avalanche victims in cardiac arrest (P), does a shorter time of burial (I), compared to longer time of burial (C), predict survival to hospital discharge (O)?”

“For avalanche victims in cardiac arrest that have been buried longer than 35 minutes (P), does the presence of a patent airway* (I), compared to absence of a patent airway (C), predict survival to hospital discharge (O)?”

("Patent airway - means an airway not obstructed by avalanche debris or by other means.)

“For avalanche victims in cardiac arrest who are found with a core temperature of less than 32 degrees C (P), does the presence of a patent airway (I), compared to absence of a patent airway (C), predict survival to hospital discharge (O)?”

“For avalanche victims in cardiac arrest (P), do lower levels of serum potassium (I), compared to higher levels of serum potassium (C), predict survival to hospital discharge (O)?”

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**Is this question addressing an intervention/therapy, prognosis or diagnosis?** Prognosis.

**State if this is a proposed new topic or revision of existing worksheet:** New Topic.

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**Conflict of interest specific to this question**

Do any of the authors listed above have conflict of interest disclosures relevant to this worksheet?

Commercial/industry: Nil.

Potential intellectual conflicts: Brugger has published studies on avalanche resuscitation examining time of burial and patent airway. He has not published studies focussing on core body temperature or serum potassium. Boyd has not published on prognostic factors.

At the outset Boyd worked independently on “time of burial” and “air pocket” and Brugger worked independently on “core temperature” and “serum potassium”. The work has subsequently been combined and submitted as one worksheet as the 4 factors answer the primary PICO question.

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**Search strategy (including electronic databases searched).**

- **PubMed:** (avalanche[All Fields]) x1067 (((hypothermia)) AND ((air pocket))) x8 ((("Hypothermia"[Mesh])) AND ((potassium)) AND survival) x20
- **EMBASE:** (avalanche {Including Related Terms}) (hypothermia {Including Related Terms}) x785
- **The Cochrane Library:** (avalanche in Title, Abstract or Keywords) (hypothermia in Title, Abstract or Keywords) x13
- **Hand Searching:** x17

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**State inclusion and exclusion criteria**

**Inclusion criteria:**

All demographics, study designs, animal and human, pertaining to snow avalanches that considered prognostic factors.

**Exclusion criteria:**

Avalanche term with genome, molecular, DNA, HIV, photons, electron, immunity, laparoscopy, cancer, paperwork (x1357)
<table>
<thead>
<tr>
<th>Duplicates (x404)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow avalanche articles not dealing with prognostic factors (x104)</td>
</tr>
</tbody>
</table>

- **Number of articles/sources meeting criteria for further review:**
  Forty one publications met criteria for detailed full text review. Subsequent new publications found on repeat search on 2008/09/16 added 4 to add up to a total of 45 articles that met criteria for full text review. Repeat search on 2009/03/01 found no new relevant publications. Repeat search on 2009/08/27 found no new articles but updated 1 reference, now published, that was previously in press.
Summary of evidence

The Summary of evidence is best considered for “time of burial” and “patent airway” in combination, and then “core temperature” and “serum potassium” separately.

“For avalanche victims in cardiac arrest (P), does a shorter time of burial (I), compared to longer time of burial (C), predict survival to hospital discharge (O)?”

“For avalanche victims in cardiac arrest that have been buried longer than 35 minutes (P), does the presence of a patent airway* (I), compared to absence of a patent airway (C), predict survival to hospital discharge (O)?”

*Patent airway - means an airway not obstructed by avalanche debris or by other means, equivalent to air pocket.

Supporting evidence table

<table>
<thead>
<tr>
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<tbody>
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<table>
<thead>
<tr>
<th>LOE</th>
<th>Study Type</th>
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<tbody>
<tr>
<td>1</td>
<td>LOE P1 include prospective comparative studies</td>
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<td>LOE P4 include retrospective descriptive studies</td>
</tr>
<tr>
<td>5</td>
<td>LOE P5 studies not directly related to the specific patient/population</td>
</tr>
</tbody>
</table>

Level of evidence

A = Return of spontaneous circulation
B = Survival of event
C = Survival to hospital discharge
D = Intact neurological survival
E = Other endpoint

Italics = Animal studies

* = overlapping patients
### Neutral evidence table

| Good | | | | | |
|------|---|---|---|---|
| Fair | | | | | |
| Poor | | | | | |

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**Level of evidence**

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### Opposing evidence table

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|------|---|---|---|---|
| Fair | | | | | |
| Poor | | | | | |

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Key studies

• Survival vs time of burial
  - Falk, 1994, p21 (n=442, 181 survivors (43%))

This landmark study demonstrated a non-linear relationship between time of burial and survival, described as the “survival curve”. Victims demonstrated an initial high rate of survival though after 15 minutes survival plummetted to only 30% at 35 minutes. The authors recognized that this pattern was similar to asphyxia from other causes and concluded that asphyxia was the cause of this steep decline for avalanche victims. They consequently hypothesized that survival beyond 35 minutes would not be possible without continued respiration and this would be exhibited by a patent airway. (A patent airway was the critical component of an “air pocket”, and the simpler factor of patent airway is used in this review.)

Neither this study nor other studies found any survivor from burial beyond 35 minutes that had a non-patent airway, despite resuscitation.

Victims that survive beyond 35 minutes exhibit a plateau pattern of survival, while becoming progressively more hypothermic, until 90 minutes of burial at which time they succumb to lethal hypothermia.
Summary outcomes

• **Survival versus time of burial and patent airway**
  (similar studies to Falk, 1994, p21)

No study described any any survivor from burial beyond 35 minutes that had a non-patent airway, despite resuscitation.

<table>
<thead>
<tr>
<th>Series</th>
<th>n</th>
<th>Survivors</th>
<th>Time survival curve*</th>
<th>30% survival</th>
<th>Patent airway after 35min†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brugger, 1992, p167§</td>
<td>332</td>
<td>150 (45%)</td>
<td>Yes</td>
<td>40 min</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Buser, 1993, p263‡§</strong></td>
<td>332</td>
<td>150 (45%)</td>
<td>Yes</td>
<td><strong>40 min</strong></td>
<td>Yes</td>
</tr>
<tr>
<td>Falk, 1994, p21§</td>
<td>442</td>
<td>181 (43%)</td>
<td>Yes</td>
<td>35 min</td>
<td>Yes</td>
</tr>
<tr>
<td>Brugger, 2001, p7§</td>
<td>638</td>
<td>334 (48%)</td>
<td>Yes</td>
<td>40 min</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Swiss, 1998, unpub‡§</strong></td>
<td>638</td>
<td>334 (48%)</td>
<td>Yes</td>
<td><strong>40 min</strong></td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Demonstrated similar non-linear survival curve pattern
†Confirmed a patent airway was necessary after 35 minutes burial, with no survivors in those with a non-patent airway
‡Same population as above, analysed independently by different investigators
§Incremental overlapping populations
Key studies

- Steady state development of hypoxia and hypercapnia in *air pocket*  
  - Brugger, 2003, p81 (LOE P5)

  This study demonstrated that hypoxia and hypercapnia achieve a steady state after 10 minutes, when breathing in simulated air pockets of different volumes. This finding suggests that long-term survival is possible as long as an air pocket, even as small as 1 litre, is present.

- Grissom, 2000, p2266 (LOE P5)

  This study indicated that deflection of expired air away from an air pocket may slow the development of hypoxia and hypercapnia.
“For avalanche victims in cardiac arrest who are found with a *core temperature* of less than 32 degrees C (P), does the presence of a patent airway (I), compared to absence of a patent airway (C), predict survival to hospital discharge (O)?”

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<tr>
<td>Good</td>
<td></td>
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<td>Danzl, 1987 ABC</td>
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<td>Walpoto, 1997 CD</td>
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<tr>
<td>Fair</td>
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<td></td>
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<td>Althaus, 1982 CD Oberhammer, 2008 CD</td>
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<tr>
<td>Poor</td>
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# Neutral evidence table

| Good | Brugger, 2001 BC*  
Brugger, 1992 BC*  
Locher, 1991 AC*  
Mair, 1994 AD |  
| Fair | Farstad, 2001 CD  
Ruttman, 2007 ACD  
Stalsberg, 1989 BCD | Komberger, 1996 BC |  
| Poor |  |  |  |

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*Italics = Animal studies*

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# Opposing evidence table

| Good | Grissom, 2008 E |  
| Fair | Grissom, 2004 E |  
| Poor |  |  |

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Key studies

• **Danzl, 1987, p1042**
  Multicenter Hypothermia Survey (N=401, CA=73, no avalanche). Significant difference in mortality with core temperature $\geq$ 32 degrees C (7.1%) vs < 32 degrees C (22.8%). No extracorporeal rewarming $\geq$ 32 degrees C.

• **Walpoth, 1997, p1500**
  Deep hypothermia (core temperature, < 28 degrees C) with circulatory arrest was found in 46 of 234 patients with accidental hypothermia (N=234, CA=46, avalanche n=1). CPB in 32 gave 15 long-term survivors. No CA > 28 degrees C.

• **Locher, 1996, p1275**
  Hypothermic avalanche victim study (N=32, avalanche n=32, CA n=19). Cooling rate between accident and arrival at hospital 3.0 degrees C/h. (range 0.75-5.8). Maximum cooling rate during snow burial 8 degrees C/h (approx. 32.3 degrees C at 35 minutes).

• **Oberhammer, 2008, p474**
  Case report, burial 100 min, 22 degrees C on extrication, full recovery, cooling rate of 9 degrees C/h (approx 31.8 degrees C at 35 minutes).
Summary outcomes

- Hypothermic avalanche victims in cardiac arrest with core temperature <32°C and extracorporeal circulation (ECC) rewarming - ROSC and Survival to discharge.

<table>
<thead>
<tr>
<th>Series</th>
<th>ROSC†</th>
<th>Survival to discharge</th>
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</thead>
<tbody>
<tr>
<td>Althaus, 1982, p492</td>
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<td>1</td>
</tr>
<tr>
<td>Mair, 1994, p47</td>
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</tr>
<tr>
<td>Fischer, 1997, p51</td>
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<td>Walpoth, 1997, p1500</td>
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<td>1</td>
</tr>
<tr>
<td>Ruttmann, 2007, p594</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22</strong></td>
<td><strong>7</strong></td>
</tr>
</tbody>
</table>

*Overlapping populations
†Includes victims that survived to discharge
“For avalanche victims in cardiac arrest (P), do lower levels of serum potassium (I), compared to higher levels of serum potassium (C), predict survival to hospital discharge (O)?”

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<td>大力支持, 1987 C</td>
<td>Locher, 1996 AC*</td>
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<td>Hauty, 1987 C</td>
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<td>Mair, 1994 AD</td>
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<td>Locher, 1991 AC*</td>
<td></td>
<td>Schaller, 1990 AC*</td>
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<tr>
<td>Dobson, 1996 CD</td>
<td></td>
<td>Oberhammer, 2008 CD</td>
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<td>Von Segesser, 1991 CD</td>
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* = overlapping patients

*Italics = Animal studies*
### Neutral evidence table

| Good |  | Farstad, 2001 CD  
Ruttman, 2007 ACD  
Silvfast, 2003 AC | Bender PR, 1995 E |
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Key studies

- **Locher, 1996, p1275**
  Hypothermic avalanche victim study (N=32, avalanche n=32, CA n=19). Admission K+ found as prognostic marker for survival to discharge. K+ in non-survivors 9.95 ± 4.9 (min 2.0/max 18) mmol/L versus survivors 4.25 ± 0.9 (min 3.1/max 6.4) mmol/L (P=0.003). 7 mmol/L proposed as cutoff level for survival.

- **Mair, 1994, p47**
  N=22, avalanche n=12, CA n=12. Admission K+ found prognostic marker for ROSC with 8.7 in non-survivors vs. 5.0 in survivors (P=0.005). All patients with ROSC had K+ <9 mmol/L.

- **Schaller, 1990, p264**
  N=24, avalanche n=9, CA n=9. K+ median 14.5 mmol/L (range 6.8 - 24.5) in 9 avalanche non-survivors vs 3.5 mmol/L (2.7 - 5.3) in 15 hypothermic patients from exposure with ROSC (p<0.01). Proposed K+ >10 mmol/L as a prognostic index.

- **Dobson, 1996, p483**
  Case report. Child with severe hypothermia (14.2 degrees C) from exposure with the highest serum K+ in a survivor in all hypothermia literature. Rt atrial K+ was 11.8 mmol/L upon thoracotomy and initiation of CPB.
# Background

**Evidence that asphyxia is the dominant cause of avalanche death**

### Supporting evidence table

<table>
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<th>Level of Evidence</th>
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<td>Butt, 1993 E</td>
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<td>Brugger, 2008 E</td>
<td></td>
<td>LOE P3 include retrospective comparative studies, meta-analyses and systematic reviews</td>
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<td>Boyd, 2008 E</td>
<td></td>
<td>LOE P4 include retrospective descriptive studies</td>
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<td>Hohlrieder, 2007 CE</td>
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<td>Hohlrieder, 2005 BE</td>
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<td>Ruttman, 2007 ACD</td>
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<td>Schaller, 1990 AC*</td>
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<td>Althaus, 1982 CD</td>
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<td>Oberhammer, 2008 CD</td>
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<td>Swiss [3], 1972 CD</td>
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<td>Althaus, 1982 CD</td>
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<td>Sumann, 2002 E</td>
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<th>3 LOE P3</th>
<th>4 LOE P4</th>
<th>5 LOE P5</th>
</tr>
</thead>
</table>

**Level of evidence**

A = Return of spontaneous circulation  
B = Survival of event  
C = Survival to hospital discharge  
D = Intact neurological survival  
E = Other endpoint  

*Italics = Animal studies*
REVIEWERS’ FINAL COMMENTS AND ASSESSMENT OF BENEFIT / RISK:

BACKGROUND
Worldwide, there is a median of 146 avalanche deaths per year while in North America deaths are increasing [LOE P3\(^{10}\)]. Complete burial renders a mortality risk of 55.2% using electronic location devices but 70.6% without [LOE P3\(^{12}\)]. Death is caused by asphyxia, trauma and hypothermia with asphyxia being the dominant cause [LOE P3\(^{7,11,27,34}\)].

Without an evidence-based structure avalanche victims in cardiac arrest are often under- or over-resuscitated. In a retrospective comparative study examining prognostic factors authors observed that resuscitation was “grossly inadequate” for some victims [LOE P3\(^{33}\)]. And, a case report of a young skier buried for 100 minutes at 3 metres depth described the lack of standard Basic Life Support (BLS) care by a professional medical team until the intervention of an emergency physician at the receiving hospital. This latter physician initiated appropriate resuscitation and re-directed the rescue helicopter to a trauma centre where cardiopulmonary bypass produced a return of spontaneous circulation (ROSC), after 150 minutes of cardiac arrest, with subsequent discharge from hospital without neurological impairment [LOE P4\(^{35}\)]. Conversely, aggressive resuscitation has been pursued by other rescuers since the report in 1982 of two avalanche victims recovering from cardiac arrest with long burials and evacuation times [LOE P4\(^{1}\)]. However, in 1990 investigators began examining prognostic factors expressing the need for triage to “limit delay of those who have a chance of survival and to avoid rewarming patients who are dead” [LOE P3\(^{38}\)]. On scene triage is crucial considering the resource-poor environment and that the median number of people involved per incident is four [LOE P3\(^{28}\), LOE P5\(^{4}\)]. This prompted the development of the first avalanche resuscitation algorithm, based on a literature review of 19 publications and consensus among mountain rescue physicians\(^{9}\).

New research on prognostic factors contributes to the evidence-based evolution of the avalanche resuscitation algorithm while the validity of each change is examined by a consensus of expert mountain rescue physicians, the ICAR MedCom [LOE P3\(^{16,8}\)]. Application of this approach has anecdotally prompted appropriate resuscitation [LOE P4\(^{35}\)] and improved survival from extracorporeal rewarming by excluding victims with no likelihood of success [LOE P3\(^{37}\), LOE P5\(^{41}\)].

PROGNOSTIC FACTORS

Time of burial
Analysis of 332 buried victims revealed a non-linear relationship between time of burial and survival [LOE P3\(^{13}\)] and this relationship has been confirmed with updated datasets and published in a graphical form, the “survival curve” [LOE P3\(^{10,16,19}\), LOE P5\(^{4}\)]. Survival remains high (91%) at 18 minutes but then plummets to 34% at 35 minutes. This parallels deterioration from acute asphyxia of any cause [LOE P3\(^{13}\)]. Beyond 35 minutes, however, the curve levels out until 90 minutes and survivors of this stage must be able to breathe while buried, with a patent airway. After 90 minutes there is a further decline due to hypothermia in combination with progressive hypoxia and hypercapnia [LOE P3\(^{19}\)]. The identification of this time/survival relationship and the likely inherent pathophysiology has provided a structure for resuscitation and driven further clinical and experimental research.

Patent airway (air pocket)
The longest burial reported for a survivor in the open was for 43 hours and 46 minutes, at a depth of 1.5m, and the significance of an air pocket was emphasized [LOE P4\(^{3}\)]. An air pocket is defined as - “Any cavity in front of the mouth and nose, no matter how small, provided the airway is clear. The categorical statement "no air pocket" can be made only if the mouth and nose of the victim are
hermetically sealed off by snow and/or the airway is completely blocked by snow or debris. Functionally, given that some air pockets may be so small to be hard to detect, the criterion may therefore be simplified to - the presence or absence of a patent airway. The relationship between a patent airway and survival after 35 minutes has been confirmed in a large number of retrospective studies although none have systematically examined the relationship [LOE P3\(^{10,13,19,25,31,40}\), LOE P4\(^{3,4,35,36}\)]. Importantly however, none have described survival beyond 35 minutes without a patent airway, 5 of which preceded publication of the algorithm [LOE P3\(^{13,19,31,40}\), LOE P4\(^{3}\)] and 8 that documented aggressive resuscitation of all victims in cardiac arrest [LOE P3\(^{10,13,19,25,31,40}\), LOE P4\(^{4,36}\)].

The physiology of gas exchange in an air pocket has been explored in simulated avalanche conditions using human subjects [LOE P5\(^{14,22,23,24}\)]. In a randomized crossover subject-blinded study the size of an air pocket was proven to determine the degree of hypoxia and that, despite the initial development of hypoxia and hypercapnia, a subsequent steady state indicated that long-term survival would be possible with only a small air pocket volume. In 2 other prospectively designed experimental studies in which subjects were buried in snow mounds, hypercapnia was shown to increase cooling rates [LOE P5\(^{22,24}\)]. The limitations to applying the findings of these simulated avalanche conditions, notably the absence of being tossed around during an avalanche and the lack of compression when buried in debris, has been discussed in an extensive editorial\(^{21}\).

Prior to 35 minutes of burial survival is deemed less dependent on breathing and standard BLS and ALS care for cardiac arrest should be initiated regardless of the presence or absence of an patent airway\(^8\).

**Core temperature**

Severe hypothermia and cardiopulmonary bypass resuscitation was documented in a case series of 2 avalanche victims, one of whom was buried for 5 hours under 7 metres of debris, received no resuscitation for the 70 minutes of evacuation and was found on arrival to be in asystole with a core temperature of 19\(^\circ\)C [LOE P4\(^1\)]. This patient recovered fully, was discharged and returned to his previous occupation. The authors ascribed his survival to a protective effect of hypothermia, an effect identified other authors [LOE P4\(^{45}\)].

Numerous studies, however, have demonstrated poorer outcomes for asphyxiated victims in cardiac arrest compared to those that have suffered other forms of environmental cooling, with extracorporeal circulation and rewarming [LOE P3\(^{20,31,32,37}\), LOE P4\(^{29}\)]. This reinforces the value of identifying a patent airway in burials longer than 35 minutes.

However, in some cases the time of burial is not known and a core temperature of 32\(^\circ\)C has been identified as a surrogate for 35 minutes burial\(^8\). The maximum cooling rate documented in a comparative study of hypothermic avalanche victims in cardiac arrest was 8\(^\circ\)C/h and this was similar to the rate of 9\(^\circ\)C/h in a case report [LOE P3\(^{32}\), LOE P4\(^{35}\)]. Thirty five minutes of cooling at this rate would reduce the core temperature to 32\(^\circ\)C. Experimental burials in trenches dug into snow mounds have exhibited far lower rates of cooling though subjects remained normothermic throughout, were not compressed in the dense debris of an avalanche deposit and were not exposed to the elements as they would have been in a rescue [LOE P5\(^{22,23,24}\), LOE P3\(^{21}\)].

Mortality was found higher with core temperatures less than 32\(^\circ\)C (22.8%) than ≥ 32\(^\circ\)C (7.1%) in the multicentre hypothermia survey [LOE P3\(^{17}\)].
A core temperature lower than 32°C coincides with the heart becoming more susceptible to ventricular fibrillation which may be promoted by hypoxia [LOE P4\textsuperscript{17}] and is therefore a poorer prognostic sign prompting evacuation to a more specialized centre, ideally with the ability of extracorporeal circulation and rewarming in the event of cardiac arrest. Above 32°C victims are not subject to irreversible cardiac arrhythmias from hypothermia per se and conventional CPR, defibrillation and IV medications are recommended in the avalanche algorithm as they are in Basic and Advanced Life support guidelines [LOE P2\textsuperscript{2}].

**Serum potassium**

The association of hyperkalaemia and non-survival in the general literature for accidental hypothermia was described in a case series of 11 severely hypothermia victims trapped in a snow cave by bad weather for 72h. Two survivors had K+ of <7mmol/L while 6 of the 9 non-survivors had K+ >10mmol/L [LOE P4\textsuperscript{26}]. Additionally, the 2 survivors had vital signs, bradycardias and core temperatures >22°C versus no vital signs, asystole and core temperatures of <8°C in 7 of the 9 non-survivors. The authors concluded the extreme hyperkalemia of levels over 10 mmol/L reflected irreversible cell lysis and was a grave prognostic sign. In 1995 in a systematic review of earlier trials the expert author proposed a level of 12 mmol/L as a prognostic sign for likelihood of survival [LOE P3\textsuperscript{30}]. The highest K+ documented in a survivor was 11.8mmol/L, described in a case report of a severely hypothermic 31 month old child in PEA [LOE P4\textsuperscript{18}].

Extreme hyperkalemia was associated with non-survival in 9 hypothermic avalanche victims compared to normal K+ in 15 hypothermic victims from other causes, of which all had ROSC though only 11 survived to hospital discharge [LOE P3\textsuperscript{38}]. Median K+ in the avalanche non-survivors was 14.5 mmol/L (range 6.8 to 24.5) versus 3.5 mmol/L (2.7 to 5.3) (p<0.01) in the non-avalanche ROSC group. Core temperatures were not significantly different. Additionally, all 9 avalanche victims were in cardiac arrest versus only 2 of the non-avalanche group. The authors concluded extreme hyperkalaemia was a reliable prognostic marker of death. However, an accompanying editorial was cautionary and concluded that "if a victim has probably sustained a severe anoxic event while still normothermic, is without pulse or respiration, and yields a serum potassium level greater than 10 mmol/L, the game may be over"\textsuperscript{5}.

Other studies have found extreme hyperkalemia to foretell non-survival and none described survival with levels over 12 mmol/L despite resuscitation [LOE P3\textsuperscript{31,32}]. Further studies have documented less extreme levels of hyperkalaemia in non-survivors, often less than 10 mmol/L, but importantly did not describe survival with levels over 12 mmol/L despite resuscitation [LOE P3\textsuperscript{38,39}, LOE P5\textsuperscript{6}].

Normal K+ (3.8 mmol/L) was found in 1 long term survivor of avalanche-related hypothermia and cardiac arrest and levels of 8.0 mmol/L or less in 3 additional victims that had ROSC but did not survive longer than 24h [LOE P3\textsuperscript{33}]. Of a total of 8 avalanche non-survivors 6 had K+ >9 mmol/L. The authors concurred that “a decision to continue or terminate resuscitation cannot be based on laboratory parameters” but concluded that K+ is a “valuable guide in identifying hypothermic arrest victims in whom death preceded cooling” and “can be used to confirm or question the decision to terminate based on clinical judgement”. They also concluded K+ may be a useful triage tool when multiple avalanche victims present.

The practical application of K+ in concert with other prognostic criteria is exemplified in the case report described above (in Background), of a young skier buried for 100 minutes at 3 metres depth, and whose K+ was found to be 4.3 mmol/L on arrival at a nearby hospital and that prompted initiation of appropriate resuscitation and re-direction to a trauma centre for cardiopulmonary bypass. This decision was based on not only the K+ level but that the victim had an identified 2 - 4L
air pocket with a patent airway, had vital signs and was initially in sinus rhythm prior to ventricular fibrillation[LOE P435].

KNOWLEDGE GAPS:
Other specific worksheets that would be helpful -
- prognostic factors of all-cause hypothermic victims in cardiac arrest
- for management issues
  - defibrillation and other ALS components - ALS_Electricity, etc..
  - accidental hypothermia - ALS_SC

Specific research required -
- prospective validation studies of patent airway, core temperature and serum potassium as prognostic factors with input to a management matrix for avalanche resuscitation.
- prospective measurement of avalanche victim's core body temperature on extrication.
- prospective studies on effectiveness of pre-hospital treatment of non-arrested hypothermic avalanche victims.
(This algorithm is included for information purposes, as it is the working guideline developed by the ICAR MedCom. However, it was not reviewed by the ILCOR ALS Task Force)

**ASSESSMENT OF THE EXTRICATED PATIENT**

- **Conscious?**
  - Yes: Start CPR, intubate
  - No: Suspect mild Hypothermia:
    - administer hot, sweet drinks
    - change clothing if practicable
    - transport to nearest hospital with intensive care unit

- **Breathing? Pulse?**
  - Yes: Continue CPR, follow standard ALS protocol
  - No: Suspect severe Hypothermia:
    - intubate, ventilate with warm humidified oxygen
    - transport to hospital with hypothermia experience or unit with extracorporeal rewarming

- **Start CPR, intubate**
  - Check burial time and/or core temperature
    - ≤ 35 min (≥ 32°C): Continue CPR, follow standard ALS protocol
    - > 35 min (< 32°C): ECG
      - Ventricular fibrillation
        - Asystole
          - Patent airway
            - Yes or uncertain
              - Profound hypothermia suspected:
                - continue CPR
                - VF: apply 3 DC shocks
                - transport to unit with extracorporeal rewarming
              - Asphyxia suspected:
                - continue CPR
                - transport to nearest hospital

- **Figure 1: Pre-hospital management of persons buried in an avalanche.**
  - In all cases: core temperature + ECG monitoring, spinal immobilization, gentle extrication, oxygen, airway warming, insulation, hot packs on trunk; 0.9% NaCl and/or 5% glucose only if an intravenous line can be established within a few minutes; trauma treatment if indicated.
  - If duration of burial is unknown core temperature may be a substitute.
  - Clinicians may consider stopping CPR at the scene if CPR during transport is associated with increased risk to the rescue team.
  - Transport to the nearest hospital for serum potassium measurement if hospitalisation in a specialist unit with cardiopulmonary bypass facilities is not logistically possible. If K⁺ exceeds 12 mmol/l, consider stopping resuscitation (after consideration of the use of depolarizing paralytics); if K⁺ is lower than, or equals, 12 mmol/l, continue CPR and transport the patient promptly to a specialist hospital for extracorporeal re-warming. ALS = advanced life support, CPR = cardiopulmonary resuscitation.
Citation List


Two cases of victims buried in avalanches that were in full cardiopulmonary arrest and were severely hypothermic but recovered to hospital discharge with full intellectual and physical abilities. Case 1 buried for 21/2 hours under several feet of debris but, on rescue, deteriorated into ventricular fibrillation with full cardiopulmonary arrest. Core temperature of 22C. Rewarmed with irrigation of pericardial sac after thoracotomy. Case 2 buried for 5 hours under 7m debris but full cp arrest on rescue and transported with no attempts resuscitation for 70min. Asystole and clinically dead and 19C rectal at hospital. CPB to 36C, ventricular fibrillation and defib to full recovery and RTW. Discusses tenfold ischaemic tolerance of brain at 20C. “Not to terminate resuscitative effort too early”. But, resuscitation of cardiac arrest (vf or asystole) in asphyxia only promising within a few minutes of arrest. “All of the patients lapsed into circulatory arrest the moment of rescue”. Reviews rewarming - best (+/- partial) bypass. No comment industry funding.


Systematic review of literature dealing with accidental hypothermia.


LOE P4. Fair. Supportive. Relevant. Time, air pocket. Avalanche n=1

Anecdotal case report of a female skier who survived complete burial for 43 hours 46 minutes at 1.5 m depth in an unprotected area. At extrication unconscious but breathing with palpable pulse, presenting a large air pocket surrounding head and chest. After 5 days discharge from hospital with minor frostbite of the finger tips. Governmental funding.


LOE P5. Good. Supportive. Indirectly Relevant. Time, air pocket. Avalanche n=1886

Annual proceedings of all documented avalanche accidents in Switzerland. Raw data for the analyses of survival function [9,12,15,18]. Governmental funding.


No abstract.


This is an editorial on Schaller's original retrospective case-control study. Auerbach observes that Schaller's controls were poorly matched to the hyperkalaemic avalanche study victims to the extent the study “amounts to anecdotal experience”. He concludes - “If a victim has probably sustained a severe anoxic event while still normothermic, is without pulse or respiration, and yields a serum potassium level greater than 10 mmol/L, the game may be over”. No comment industry funding.


Prevented asphyxia. Trend higher end-arrest K in non-ROSC (4.6 vs 9.4, p=.053) though 1 ROSC dog had post-CPR K over 10. Institutional funding.


Retrospective observational case series of avalanche fatalities in Western Canada. Asphyxia 75%, trauma 24% and hypothermia 1%. No industry funding.


No abstract.


Reviews earlier literature that demonstrated that hypothermic asystolic avalanche victims have a poorer resuscitation success rate as asphyxia seems to be the primary mechanism of death in 80% of such cases. First proposal of a novel algorithm that incorporates time of burial, core temperature, air pocket and serum K. Recommends 45min burial as cutoff without air pocket, similar to the survival curve studies [4, 10, 13, 16, 19]. No comment industry funding.


Original research presented on avalanche mortality and with a recalculated survival curve (observational case-control study). Extensive discussion of the implications of this survival curve wrt asphyxia and hypothermia and the significance of an air pocket as a survival need and prognostic factor after 35min burial. Support cited from a Swiss series that recorded many complete burials with only a small air pocket up to 2hr that were extricated alive. Review literature and discussion of lower survival in hypothermic avalanche victims due to asphyxia and thus the importance of air pocket as a prognostic factor for survival. Revision of algorithm to reduce cutoff to 35min (in accordance with survival function by Falk, 1994) beyond which air pocket becomes prognostic factor, considering evidence to date, and serum potassium cutoff lifted to 12mmol/L to comply with general hypothermia literature. No comment industry funding.


A meta-analysis of 3 studies of good quality. Asphyxia 93.5%, trauma 5.6% and hypothermia 0.9% as immediate cause of death. No industry funding.


Observational case-control study presenting original data on mortality of avalanche involvement and burial. No industry funding.


First observational case-control study of survival statistics in burial with publication survival curve and division of burial into phases according to pathophysiological considerations. Discussion of asphyxia vs hypothermia and introduction of air pocket concept. No comment industry funding.


Experimental study on air pocket using artificial cylindrical air spaces to better understand gas exchange mechanisms. Proved small air pocket adequate to maintain gas exchange. Funding institutional and not associated with avalanche safety devices.


No abstract.


Letter describing original statistics on burial depth demonstrating time-independent association with survival. No comment industry funding.


Multicentre prospective survey, with retrospective chart review for confirmation of details, comparing different prognostic factors. Mortality significantly different with core temperature >32°C (7.1%) compared to <32°C (22.8%). Core temperature <32°C are more susceptible to ventricular fibrillation. K+ significantly higher in fatalities (4.60 +/- 1.57 mEq/L) than survivors (4.10 +/- 0.80 mEq/L) (p<0.05). No comment industry funding.


LOE P4. Case report. Fair. Supportive. Relevant. Core temperature. K. Avalanche n=0. CA n=1
Case report of 31 month old child found in CA (PEA) with severe hypothermia. Rt atrial K = 11.8. CPB and survival to hospital discharge with no neurological impairment.


Observational case-control study on survival compared to time of burial. First English publication of survival curve. No comment industry funding.


Observational case-control study (n=22) on survival of hypothermia compared to the presence of asphyxia and other factors. Survival in the non-asphyxia group (n=11) was 63% compared to 5% in the asphyxia group (n=15) (P≤0.005). Median K 4.5 [3.5, 5.0] mmol/L in the non-asphyxia group (n=11) vs 6.5 [Q1 5.5, Q3 10.7] in the asphyxia group (n=15) (P=0.012). No comment industry funding.


Editorial to Reference [22] pointing out limitations of applying findings of simulations in experimental studies to real avalanche conditions. Also comment wrt conflict of interest.


LOE P5. Good. Supportive. Relevant. Time. Airpocket. Core temp. Avalanche (simulated) n=22. CA n=0

Experimental study on air pocket to determine if hypercapnia increases cooling. Pseudo-randomization by alternation and apparently blinded (though not explicitly described). Institutional funding of study.


Gas exchange study using artificial air pocket in sham burials. Industry funding of study and conflict of interest among authors considerable (see Editorial - reference [21])


LOE P5. Fair. Opposing (core temperature), supportive (air pocket). Relevant. Core temperature, air pocket. Prospective not randomized experimental study n=8.

Study on core temperature cooling rate by using artificial air pocket. May not really reflect cooling during avalanche burial, since subjects remained fully conscious and did not cool down to hypothermic values (~ 1.3°C below baseline). Reports a 20-hours-survival of a snowboarder, in the presence of an air pocket. Institutional funding of and commercial donation of equipment for study.

**LOE P3. Fair. Supportive. Indirectly relevant. Airpocket. Avalanche n=14/CA n=2.**

Documents 1 burial with an air pocket for 1hr that survived, CA not described, but 2 fatalities that were buried 40 and 60-90min that did not have an air pocket. They were initially resuscitated and 1 had ROSC. No comment industry funding.


**LOE P4. Good. Supportive. Indirectly relevant. K. Avalanche n=0. CA=9 ( 2 survivors not in CA).**

Case-series (n=11 (10 had CPB)). The two survivors (to hospital discharge) had serum potassium levels of <7mmol/L, 6 of 8 non-survivors had K>10mmol/L, 1 non-survivor >8 and 1 non-survivor K not reported suggesting irreversible cell lysis. Two survivors also had initial vital signs, sinus and nodal bradycardia, core temps 22 & 23.4C versus VSA in 9, asystole in 8 and VF in ending in asystole in 1, core temps <8 in 7 of 9 (remaining 2 had temps 12 and 19.7C). No comment industry funding.


Retrospective observational case series of non-fatal and fatal avalanche victims in Europe that identifies asphyxia, trauma and hypothermia as the 3 causes of cardiac arrest. No comment industry funding.


Study primarily to determine effect of transceivers. Demonstrated reduction of burial time was associated with reduction in mortality. No comment industry funding.


Retrospective study showing poor prognosis if asphyxia precedes hypothermia (no statistical analysis). No comment industry funding.


No abstract.

**LOE P3. Review. Supportive. Indirectly relevant. Potassium. Avalanche n=0.**

Analysis of previous studies, first proposal of K 12 mmol/L as criterion for irreversibility in arrested hypothermic patients. Institutional funding.


Observational case series. Found negative factors asphyxia, asystole, and K (n=123) if hypothermia is associated with asphyxia. No comment industry funding.


Overlapping patients with Locher et al., 1991. Observational case series of hypothermic avalanche victims. Maximum cooling rate of survivors during burial estimated 8°C/hour. K found as prognostic marker. K at hospital admission (n=22) in survivors 4.25 ± 0.9 (min 3.1/max 6.4) mmol/L vs non-survivors 9.95 ± 4.9 (min 2.0/max 18) mmol/L (P=0.003). 7 mmol/L proposed as cut-off for survival. Blocked airways in some of non-survivors described. No comment industry funding.


K (n=12) found useful prognostic marker for ROSC in avalanche victims with a cutoff of 9mmol/L with significant correlation (n = 22, 8.7 vs 5.0, p =0.005). Eleven of 12 in cardiac arrest on rescue and 12th arrested a few minutes later. Four had ROSC but only 1 survived to hospital discharge. That victim had cardiac arrest for 210min (?burial duration), core temp 24C and K 3.8. All 8 that had K over 9 had no ROSC and had evidence of asphyxia on autopsy (acute right heart failure). All four that had ROSC had K <9. All 8 that had no ROSC had no air pocket (but does not state whether 4 that had ROSC had air pockets). Recommend normal K “strong argument” for resuscitation. No comment industry funding.


Retrospective observational case series of fatal avalanche victims in Utah that identifies asphyxia and trauma as 2 causes of cardiac arrest. One author (Grissom) serves as consultant for production of device described in Discussion.


Observational case description of 1 survivor with air pocket and 1 non-survivor without air pocket (non-patent airway). Survivor buried 100min at 3m with air pocket. Core temp (epitympanic probe) 22C. Cardiac arrest approx 60min after rescue - VF but no defibrillation or CPR for 15min. K 4.3. Cardiac arrest for 150min before rewarmed and defibrillated. Cooling rate 9C/hr. Full recovery. Note - no resuscitative efforts to non-survivor. No industry funding.


This is a review but includes 2 new case reports. Firstly, he describes - “More recently, on January 24, 2000, at the resort of Schoppernau in Austria, a 25-year-old German snowboarder was buried for 20 hours, spending the night before being found by avalanche dogs. Although hypothermic, he too survived because of a large air space between his face and knees”. And - “Author’s note - Subsequent to this clinical update going to press, a landmark incident involving the artificial air pocket device occurred in the Canadian backcountry outside of Revelstoke, British Columbia. On February 10, 2002, a 44-year-old heli-skier wearing the survival device was buried along with 2 others after being hit from above by an avalanche. All 3 were buried instantly only a few feet from each other under almost 6 feet of debris for about 40 minutes. The individual wearing the artificial air pocket was able to place and maintain the mouthpiece during the struggle and breathe easily despite a complete inability to move after avalanche settlement. Snow packed his ears and nose but remained clear of his airway
because of the mouthpiece. Shortly before rescue he became unconscious, but was quickly revived when uncovered, without any resuscitation required. In contrast, the 2 companions not wearing the device were found dead from asphyxiation despite simultaneous recovery times and burial conditions. The event represents the first survival incident that is convincingly attributable to the air pocket device and will be reported more extensively in a future publication.” No comment industry funding.


Observational case-control study of ECMO, vs CPB, for hypothermia CA. Mixed avalanche and drowning in an asphyxial subgroup. Found, asphyxia most adverse factor for survival (relative risk: 0.09, 95% confidence interval: 0.01-0.60, P = .013) (. K (n=59) in survivors was 4.9 ± 1.9 mmol/L vs non-survivors 8.1 ± 4.3 mmol/L (P=0.14), but failed in the multivariate logistic regression analysis for potential predictors of survival (using RR & 95%CI). However, no avalanche subgroup investigated. No comment industry funding.


Observational case-control study of severely hypothermic victims. Group A of 9 avalanche victims were non-survivors and had median K of 14.5 mmol/L (range 6.8 to 24.5 though 7 of 9 victims over 12) vs group B of 15 non-avalanche victims with all 15 ROSC (though only 11 survivors and 4 non-survivors to hospital discharge) had K of 3.5 (2.7 to 5.3) (p<0.01). Significant difference also if groups analyzed for moderate hypothermia and severe hypothermia. Also observed K rise in 13 non-hypothermic patients dying in hospital from 5.44 +/- .33 to 7.2 +/- .47 after 1 hour (p<0.001).

All 9 of group A in CA on admission vs only 2 of 15 in group B. Group A pH median 6.57 (6.24 to 6.69) vs 7.27 (6.45 to 7.44) in group B (p<0.002). Lactates higher in group A. No correlation K and pH.

No significant differences in core temps between groups though only 2 avalanche victims of total 24 victims <20C (supports hypoxia vs hypothermia).

K (n=24) found as prognostic marker. Please see Auerbach’s accompanying editorial that is critical (above under “Auerbach”). No comment industry funding.


LOE P3. Good. Supportive. Indirectly relevant. K. Avalanche n=0. CA n=28, 3 responded to CPR alone, 2 head injury.

Case series. Median K (n=24) 3.6 (3.1-4.1) in survivors vs 5.0 (3.8-6.6) in non-survivors (levels “almost physiological”). Only 1 of 9 with K > 5.5 mmol/L and/or pCO2 > 11kPa survived. “Combination of paCO2 and K best predicted survival. No comment industry funding.


Seventeen soldiers completely buried, 16 no air pocket with times burial 80min - 74h and all dead despite resuscitation of 9. One survivor with air pocket and time burial 3h but not in CA.
Two kids, no air pocket with burial times 6 and 7h, ?resuscitation, dead. No comment industry funding.


Documents 2 burials and discusses the algorithm for the triage of arrested avalanche victims [8]. No comment industry funding.


Retrospective observational case series of winter fatalities in Alberta that included 15 fatal avalanche victims. Identifies asphyxia and trauma as 2 causes of cardiac arrest. No comment industry funding.


Collective literature review and meta-analysis. Shows mortality of hypothermia in relation to its origin. Higher mortality in avalanche and climbing victims than in other outdoor hypothermia. Unfortunately, does not differentiate avalanche from climbing victims in citing 6/19 survivors. Cardiopulmonary bypass rewarming suggested for arrested hypothermic patients with a reported return to previous level of function of survivors of 80%. No comment industry funding.


Case report of 1 survivor of accidental hypothermia presenting serum potassium 9.5 mmol/l at hospital admission and successfully rewarmed with CPB. No comment industry funding.


Cohort follow-up study of long-term outcome of 15 survivors. One avalanche victim in CA had core temp 19.6C rectal and was “normal” to follow-up. Ascribes good outcome to protective effect of deep hypothermia and absence of asphyxia. Also CPB, good rescue organization, young healthy victims. No comment industry funding.