hypothermia
how to adjust ventilation

G.R. Kleger, Medical Intensive Care Unit, Kantonsspital St.Gallen
19 OTTOBRE 1812
**new classification of hypothermia**

<table>
<thead>
<tr>
<th></th>
<th>old, „accidental“ h.</th>
<th>new, „clinical“ h.</th>
</tr>
</thead>
<tbody>
<tr>
<td>mild:</td>
<td>32-35°C</td>
<td>35-35.9°C</td>
</tr>
<tr>
<td>moderate:</td>
<td>28-32°C</td>
<td>32-34.9°C</td>
</tr>
<tr>
<td>severe:</td>
<td>&lt;28°C</td>
<td>&lt;32°C</td>
</tr>
</tbody>
</table>

*Martin RS. Injury associated hypothermia: An analysis of the 2004 National Trauma Data Bank. Shock 2005;31: 1345*
classification of hypothermia

accidental hypothermia

inadvertent hypothermia

therapeutic hypothermia
M.B. 1940

Piz Kesch 3418 m (11214 ft)
trauma center

26 °C

GCS 6 (1/1/4)

spontaneous ventilation, SaO₂ not measurable

HR 50/min, atrial fibrillation

MAP 65 mmHg
trauma center
mortality by accidental hypothermia

FIGURE 2. Number and rate* of hypothermia-related deaths, by age group and sex — United States, 2002

* Per 100,000 population.
classification of hypothermia

accidental hypothermia

inadvertent hypothermia

therapeutic hypothermia
temperature abnormalities at arrival in the ICU

design: prospective cohort
setting: French intensive care units participating in the Outcomerea group
patients: adults (>18yrs) admitted to an intensive care unit between April 2000 and November 2010. Patients undergoing therapeutic hypothermia were excluded

n = 10'962, median age 63 yrs
medical 8‘237 (75%), nonscheduled surgical 1‘507 (14%), scheduled surgical 1‘218 (11%)
mild hypothermia (35-35.9°C): 1‘046 (10%) not ventilated 302 (29%)
moderate hypothermia (32-35°C): 541 ( 5%) not ventilated  89 (16%)
severe hypothermia (<32°C): 72 ( 1%) not ventilated  13 (18%)
hypothermia was more common in surgical patients but the outcome was significantly worse in....

temperature abnormalities at arrival in the ICU

logistic regression modeling for case-fatality (medical admissions)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Odds Ratio (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>age (y)</td>
<td>1.03 (1.02-1.03)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SAPS II</td>
<td>1.06 (1.06-1.07)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>male</td>
<td>1.41 (1.23-1.62)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>hepatic disease</td>
<td>1.55 (1.20-2.00)</td>
<td>0.001</td>
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<tr>
<td>respiratory disease</td>
<td>1.34 (1.12-1.61)</td>
<td>0.002</td>
</tr>
<tr>
<td>dialysis</td>
<td>0.68 (0.51-0.90)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>not ventilated</td>
<td>1 (reference)</td>
<td>------</td>
</tr>
<tr>
<td>NIV</td>
<td>1.90 (1.50-2.40)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>invasive ventilation</td>
<td>1.49 (1.26-1.76)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>normothermia (36-38°C)</td>
<td>1 (reference)</td>
<td>------</td>
</tr>
<tr>
<td>mild hypothermia (35-35.9°C)</td>
<td>1.28 (1.01-1.63)</td>
<td>0.040</td>
</tr>
<tr>
<td>moderate hypothermia (32-34.9°C)</td>
<td>2.25 (1.68-3.02)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>severe hypothermia</td>
<td>3.49 (1.87-6.53)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

classification of hypothermia

- accidental hypothermia
- inadvertent hypothermia
- therapeutic hypothermia
hypothermia in ROSC after cardiac arrest

HACA. New Engl J Med 2002; 346: 549
hypothermia in ROSC after cardiac arrest

2001: 3 RCT
2005: 1 feasibility, quality
2006: 1 registry, 3 quality
2007: 1 RCT (pilot), 2 registry, 1 observational
2008: 2 observational, 1 registry, 2 quality
2009: 1 observational, 2 retrosp., 1 registry, 1 quality
2010: 1 RCT, 2 registry, 1 quality, 1 costeffectiveness, 1 retrosp.
2011: 1 registry, 1 survey
hypothermia in ROSC after cardiac arrest

Stub D. Circulation 2011;123:1428-1435
hypothermia in ROSC after cardiac arrest
summary 1

• prevalence of hypothermia outside the hospital, within the hospital but outside the ICU and at ICU admission is frequent

• incidence of hypothermia is increasing:
  – population demography (older age, multimorbidity)
  – hypothermia as a new strategy in various clinical conditions (post cardiac arrest, stroke, brain trauma)
  – installation of comprehensive centers (eg. stroke, post cardiac arrest, ECMO)

• most hypothermic patients are ventilated
ventilation of hypothermic patients

1) hypothermia induced metabolic changes
2) hypothermia induced dyscarbia (dysoxia)
3) hypothermia induced modifications in ventilatory mechanics
4) hypothermia and humidification
Bardutzky J. Energy expenditure in ischemic stroke patients treated with moderate hypothermia. Intens Care Med 2004; 30: 151
ventilation of hypothermic patients

1) hypothermia induced metabolic changes
2) hypothermia induced dyscarbia (dysoxia)
3) hypothermia induced modifications in ventilatory mechanics
4) hypothermia and humidification
cerebral vasoregulation

- CBF is regulated by metabolic activity, autoregulation (CPP) and pCO$_2$
  

- the coupling of metabolism and CBF in comatose survivors of cardiac arrest, treated with normothermia is preserved, but autoregulation is impaired
  
cerebral perfusion in moderate hypothermia

percent of patients requiring catecholamines to maintain mean arterial pressure greater than 65 mmHg

hypothermia:

- ↓ MAP
- ↓ cardiac output
- ↑ pulmonary vascular resistance
- ↑ peripheric vascular resistance including cerebrovascular resistance

may induce cerebral hypoxia

cerebral perfusion in moderate hypothermia

Laurens L. Preserved metabolic coupling and cerebrovascular reactivity during mild hypothermia after cardiac arrest. Crit Care Med 2010; 38: 1542

- MFV\textsubscript{(MCA)} ↓
- PI was high, R↑
- SjO\textsubscript{2} may be critical in the early phase
- no correlation between MAP and MFV\textsubscript{(MCA)}
cerebral perfusion in moderate hypothermia

Laurens L. Preserved metabolic coupling and cerebrovascular reactivity during mild hypothermia after cardiac arrest. Crit Care Med 2010; 38: 1542
cerebral vasoregulation

- preserved cerebrovascular CO$_2$-reactivity has been demonstrated in mild hypothermic patients after traumatic brain injury \textit{Lavinio A. Br J Anesth 2007}
- preserved metabolic coupling and cerebrovascular CO$_2$ reactivity has been demonstrated in mild hypothermia after cardiac arrest \textit{Laurens L. Crit Care Med 2010}
dyscarbia in the HACA-trial

- α-stat strategy
- target: normoventilation (\(\text{paCO}_2\) 40-45 mmHg, 5.3-6.0 kPa)
- but the CI 0.95 for the lower limit was 32 mmHg (4.2 kPa), temp. corrected 27 mmHg (3.6 kPa)

is dyscarbia in mild hypothermia relevant for cerebral perfusion?

- prospective randomized crossover study, n=8 with ROSC after cardiac arrest
- 33°C for 24 h

Protocol
1. baseline  
   (paCO₂ 4.5-5.5 kPa (pH-stat)  
   34-41 mmHg
2. hyperventilation  
   (paCO₂ 4.3 kPa (alfa-stat)  
   32 mmHg
3. normoventilation
4. hypoventilation  
   (paCO₂ 6.0 (pH-stat)  
   45 mmHg

Pynnönen L. Therapeutic hypothermia after cardiac arrest - cerebral perfusion and metabolism during upper and lower threshold normocapnia. Resuscitation 2011; 82: 1174
is dyscarbia in mild hypothermia relevant for cerebral perfusion?

Pynnönen L. Therapeutic hypothermia after cardiac arrest - cerebral perfusion and metabolism during upper and lower threshold normocapnia. Resuscitation 2011; 82: 1174
α- vs. pH-stat, cerebral perfusion

8 patients with large stroke (MCA) moderate hypothermia (33°C) for 72 h CBF measured by 133 Xe clearance ICP measurement daily random normoventilation with α- and pH-stat strategy

<table>
<thead>
<tr>
<th>Day</th>
<th>α-stat</th>
<th>pH-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>46</td>
<td>50</td>
</tr>
</tbody>
</table>

PaCO₂:
- Day 1: 40 ± 3, 47 ± 4
- Day 2: 41 ± 3, 48 ± 4
- Day 3: 39 ± 4, 49 ± 2 (mmHg)

ICP:
- Day 1: 9.1 ± 2.4, 10.4 ± 2.6
- Day 2: 11.0 ± 0.8, 12.8 ± 0.9
- Day 3: 15.2 ± 2.1, 21.1 ± 2.1 (mmHg)

α- vs. pH-stat, cerebral oxygen tension

9 children with severe traumatic brain injury
PbrO₂, ICP and CPP monitoring within 24 h after trauma
crossover α- vs. pH-stat strategy to obtain paCO₂ 35 mmHg for 6 h

Figure 1. Change of brain tissue oxygen tension
during alpha-stat and pH-stat periods

Figure 2. Brain tissue oxygen tension (PbrO₂)
(95% CI) during pH- and alpha-stat management

Schibler A. Increased brain tissue oxygen tension in children with traumatic brain injury
Using temperature-corrected guided ventilation during prophylactic hypothermia.
Crit Care Resusc 2012; 14: 20
the arterial to end-tidal CO$_2$ gradient

n=19, ASA 1+2, post elective intracranial surgery evaluation at 36, 34, 32°C normo, hyper and hypoventilation (steered by paCO$_2$ uncorr. = $\alpha$-stat)

<table>
<thead>
<tr>
<th>temp. °C</th>
<th>paCO$_2$ mmHg uncorr</th>
<th>paCO$_2$ mmHg corr</th>
<th>PET CO$_2$ mmHg</th>
</tr>
</thead>
<tbody>
<tr>
<td>normoventilation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.8±0.2</td>
<td>36.3±2.6</td>
<td>34.3±2.5</td>
<td>32.4±3.4</td>
</tr>
<tr>
<td>34.0±0.1</td>
<td>37.7±2.6</td>
<td>32.8±2.2</td>
<td>29.9±3.1</td>
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<tr>
<td>32.0±0.2</td>
<td>37.9±2.9</td>
<td>30.1±2.3</td>
<td>27.9±4.3</td>
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<tr>
<td>hyperventilation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.7±0.3</td>
<td>30.8±2.0</td>
<td>29.0±1.8</td>
<td>26.1±2.6</td>
</tr>
<tr>
<td>33.6±0.2</td>
<td>31.9±2.4</td>
<td>27.2±2.1</td>
<td>24.2±3.3</td>
</tr>
<tr>
<td>32.2±2.9</td>
<td>25.5±0.3</td>
<td>22.5±4.0</td>
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</tr>
<tr>
<td>hypoventilation</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>35.8±0.2</td>
<td>42.5±3.1</td>
<td>40.3±3.0</td>
<td>38.7±2.8</td>
</tr>
<tr>
<td>33.8±0.2</td>
<td>43.1±3.2</td>
<td>37.2±2.9</td>
<td>35.8±4.0</td>
</tr>
<tr>
<td>32.0±0.3</td>
<td>44.1±3.2</td>
<td>35.1±2.4</td>
<td>33.4±4.2</td>
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</table>

the arterial to end-tidal CO$_2$ gradient


ETCO$_2$ is valid to estimate corrected normoventilation in hypothermia
α or pH-stat: danger of hypoxia

<table>
<thead>
<tr>
<th></th>
<th>baseline</th>
<th>hyperventilation</th>
<th>hypoventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>paO₂ uncorr. (kPa)</td>
<td>13.8 (11.5-18.0)</td>
<td>12.6 (10.5-17.3)</td>
<td>14.0 (12.2-17.6)</td>
</tr>
<tr>
<td>paO₂ corr. (kPa)</td>
<td>10.9 (8.9-15.0)</td>
<td>10.0 (8.1-14.4)</td>
<td>11.6 (9.5-14.6)</td>
</tr>
</tbody>
</table>

Pynnönen L. Therapeutic hypothermia after cardiac arrest - cerebral perfusion and metabolism during upper and lower threshold normocapnia. Resuscitation 2011; 82: 1174
ventilation of hypothermic patients

1) hypothermia induced metabolic changes
2) hypothermia induced dyscarbia (dysoxia)
3) hypothermia induced modifications in ventilatory mechanics
4) hypothermia and humidification
effects of hypothermia on lung compliance

19 anesthetized sheep with open thorax: pressure to inflate 1L of air

Deal CW. Effects of hypothermia on lung compliance. Thorax 1970; 25; 105
effects of hypothermia on respiratory parameters in ventilated patients

ventilation of hypothermic patients

1) hypothermia induced metabolic changes
2) hypothermia induced dyscarbia (dysoxia)
3) hypothermia induced modifications in ventilatory mechanics
4) hypothermia and humidification
humidification during artificial ventilation in hypothermia

n=12, ROSC after CA neuroprotective hypothermia (33°C) prospective, cross-over, randomized HME vs. active HME vs. HH

Lellouche F. Under-humidification and over-humidification during moderate induced hypothermia with usual devices. Intens Care Med 2006; 32: 1014
Lellouche F. Under-humidification and over-humidification during moderate induced hypothermia with usual devices. Intens Care Med 2006; 32: 1014
• reduction in metabolism and CO₂ production has to be considered
• hyperventilation induced cerebral hypoxia is a threat and may be prevented by steering ventilation with temperature corrected paCO₂, or by increasing the target paCO₂ (uncorrected)
• ETCO₂ can be used to adapt ventilation in mild and moderate hypothermia
• respiratory mechanics is poorly influenced by mild to moderate hypothermia
• HME performance is reduced in hypothermia
but.....
<table>
<thead>
<tr>
<th>#Screening</th>
<th>Status</th>
<th>Locked</th>
<th>Start</th>
<th>Time</th>
<th>Comment</th>
<th>Select</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHSTG003</td>
<td>Dead</td>
<td>2012-03-02 02:09</td>
<td>204 days</td>
<td>Temperature measurement: oesophageal (impossible</td>
<td>Add Comment</td>
<td></td>
</tr>
<tr>
<td>CHSTG004</td>
<td>Dead</td>
<td>2012-03-09 06:45</td>
<td>196 days</td>
<td>Add Comment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHSTG005</td>
<td>Dead</td>
<td>2012-03-19 05:36</td>
<td>187 days</td>
<td>19.3.12, 14:00: Patient taken to 36°C because of...</td>
<td>Add Comment</td>
<td></td>
</tr>
<tr>
<td>CHSTG007</td>
<td>Dead</td>
<td>2012-04-03 15:37</td>
<td>171 days</td>
<td>Add Comment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHSTG008</td>
<td>Dead</td>
<td>2012-04-08 12:03</td>
<td>166 days</td>
<td>Add Comment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHSTG009</td>
<td>Dead</td>
<td>2012-04-25 21:36</td>
<td>149 days</td>
<td>Add Comment</td>
<td></td>
<td></td>
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<tr>
<td>CHSTG011</td>
<td>Dead</td>
<td>2012-05-04 17:43</td>
<td>140 days</td>
<td>Add Comment</td>
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<td></td>
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<tr>
<td>CHSTG012</td>
<td>Dead</td>
<td>2012-05-10 15:41</td>
<td>134 days</td>
<td>10.05.12 21:30 Patient take to 36°C because of...</td>
<td>Add Comment</td>
<td></td>
</tr>
<tr>
<td>CHSTG019</td>
<td>Dead</td>
<td>2012-08-19 03:23</td>
<td>34 days</td>
<td>Add Comment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHSTG020</td>
<td>Dead</td>
<td>2012-09-06 18:14</td>
<td>15 days</td>
<td>Add Comment</td>
<td></td>
<td></td>
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<tr>
<td>CHSTG021</td>
<td>Dead</td>
<td>2012-09-12 13:23</td>
<td>9 days</td>
<td>Technical problems with Coolgard -&gt; Temperature c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHSTG002</td>
<td>Discharged from Hospital</td>
<td>2012-02-28 12:58</td>
<td>206 days</td>
<td>Add Comment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHSTG001</td>
<td>Discharged from Hospital</td>
<td>2012-01-27 09:37</td>
<td>238 days</td>
<td>this patient is not withdrawn</td>
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<td></td>
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<tr>
<td>CHSTG006</td>
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<td>186 days</td>
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<tr>
<td>CHSTG010</td>
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<td>2012-04-29 21:01</td>
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<tr>
<td>CHSTG013</td>
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<td>2012-05-18 23:13</td>
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<tr>
<td>CHSTG014</td>
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<tr>
<td>CHSTG016</td>
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<td>2012-08-04 14:57</td>
<td>48 days</td>
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<tr>
<td>CHSTG017</td>
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<td>2012-08-07 22:36</td>
<td>45 days</td>
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<tr>
<td>CHSTG018</td>
<td>Discharged from Hospital</td>
<td>2012-08-11 00:47</td>
<td>42 days</td>
<td>Add Comment</td>
<td></td>
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</table>
How to Manage Hypothermia After CPR: