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Improper monitoring and deviations from physiologic treatment goals in unconscious patients with brain injury in the early phases of emergency care

Graduate thesis in Medicine
Trondheim, December 2016
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2 ABSTRACT

**Introduction:** Traumatic brain injury (TBI), out-of-hospital cardiac arrest (OHCA) and intracerebral- and subarachnoid haemorrhage (ICH/SAH) are acute conditions that may impair brain circulation and oxygenation. Physiological variables such as blood pressure, oxygen saturation and end tidal CO\textsubscript{2}-levels need to be well regulated to prevent complications that may cause secondary brain injury. Adequate physiological monitoring in the pre-hospital and early hospital phase is demanding. The aim of this study was to observe the extent of physiological deviations and the degree of monitoring in patients with acute brain damage or -illness in the early phases of emergency care.

**Method and materials:** Patients with ICH/SAH, OHCA and severe TBI treated by the Physician-staffed Emergency Medical Service (P-EMS) and admitted to St Olav's Hospital between September and December 2016 were included. The patients’ physiological variables were monitored from the site of injury/illness until the first three hours in the intensive care unit (ICU). Physiological deviations were defined as deviations from predefined target values. Each patient and its physiological course are descriptively presented.

**Results:** 13 patients were included in the study, of which 38% survived. The most frequent condition was OHCA. The mean time without any monitoring of physiological variables was 9 minutes (range 0-29 min.). The proportion of five-minute periods without any monitoring in the prehospital phase was 29%, 47% and 56% for oxygen saturation, end-tidal CO\textsubscript{2} and systolic blood pressure, respectively. For the Emergency Department these proportions were 57%, 71% and 56%, respectively. Oxygen saturation was the physiological variable with the most deviations from the target value (mean 2.4, range 1-10), and was the most monitored value in the pre-hospital phase.

**Conclusion:** The patients in the study experienced frequent deviations in blood pressure, oxygen saturation and end tidal CO\textsubscript{2}-levels, both in the pre- and in-hospital phase. Physiological monitoring was often late initiated, and there was a considerable amount of missing observations in the period from site of injury to admittance to the ICU.
3 INTRODUCTION

Traumatic brain injury (TBI), out-of-hospital cardiac arrest (OHCA), intracerebral- and subarachnoid haemorrhage (ICH/SAH) are frequent acute conditions that may impair brain circulation.

The mortality rate of severe TBI is about 45%, and the annual incidence is 7 per 100 000 per year (1). It has been shown that a systematic approach to these patients which aims to prevent secondary brain injury may reduce mortality and improve cerebral outcome (2). In Norway, the incidence of intracerebral haemorrhage and SAH is 12.5 per 100 000 per year and 300-400 per year, respectively (3) (4). The mortality for these conditions is about 50%, and few survivors reach full functional recovery (4) (5). Patients who suffer from out-of-hospital cardiac arrest (OHCA) and achieve return of spontaneous circulation (ROSC) may have developed hypoxic-ischemic brain injury during resuscitation (6). In 2014, there were 1506 patients who experienced OHCA in Norway (7). Internationally, mortality of sudden cardiac arrest outside of hospital may exceed 90% and many survivors suffer from poor neurological outcome (8). Thus, these conditions affect a considerable amount of patients, and are all associated with a high risk of poor outcome.

ICH/SAH, OHCA and severe TBI may lead to circulatory disturbances that may cause reduced perfusion of the brain and increase the risk of secondary brain damage. In the pre-hospital environment these patients may be especially vulnerable when exposed to unfavourable physiological factors such as airway problems, hypoxia and hypotension – all are factors potentially negatively affecting survival and cerebral outcome. Physiological variables such as blood pressure, oxygen saturation and end tidal CO₂-levels need to be well regulated to prevent hypoxia, hypoperfusion and high intracerebral pressure (ICP). The treatment goals with respect to stabilization of physiological variables are similar in these patients, with the shared aim to optimize brain oxygenation and circulation. This group of patients should be monitored continuously or as often as possible throughout the whole pre-hospital course (9).

In order to adhere to treatment goals for circulation and respiration in the initial acute phase, adequate physiological monitoring is needed. However, establishing adequate physiological monitoring and intervening on unfavourable physiological factors in the pre-hospital and early hospital phase is demanding. Thus, the scope of unfavourable factors may be inadequately observed and documented. A study on pre-hospital doc-
umentation in motor vehicle accidents in South Eastern Norway showed that systolic blood pressure was documented in 53% of the cases by the ground Emergency Medical Services (ground-EMS) and in 84% of the cases by the air ambulance (10). A previous study on recording of vital variables in patients with TBI showed that systolic blood pressure was recorded in 71% of the patients, heart rate in 78%. However, this does not show the extent of measurements, or the time intervals without monitoring (11).

Several studies have addressed the extent of physiological deviations after admittance to hospital in these groups of patients. A previous study on deviations in patients with TBI in the ICU showed that 35% of the patients experienced hypotension during the first two days after admittance, while 20% experienced episodes of hypoxia (12). However, few studies have described the extent of physiological deviations in the pre-hospital phase. It is shown that deviations are crucial in this phase and may have an impact on patient outcome (13).

In this study we aim to observe the extent of monitoring of physiological variables and the extent of missing physiological data in patients with acute brain damage or illness in the early phases of emergency care. Further, we aim to identify the presence of physiological deviations throughout these phases.
4 METHODS AND MATERIAL

4.1 SETTING

The study was conducted as a prospective observational study at the Physician-staffed Emergency Medical Service (P-EMS) in Trondheim, Norway. Norway has an air ambulance service offering specialized medical assistance to acute, critically ill or injured patients. P-EMS Trondheim mainly covers the counties of Sør-Trøndelag and Nord-Trøndelag in Central Norway, and carried out 1043 missions by helicopter or car in 2015 (14). Serious medical illnesses account for approximately 70% of all call-outs, whereas combined surgical and trauma patients constitute approximately 30%.

When necessary, P-EMS is called out to assist other health care providers in the pre-hospital environment. At arrival, necessary treatment and monitoring should be initiated. Patients treated by P-EMS are transported by ambulance or helicopter to the Emergency Department (ED) of St. Olav’s Hospital. St. Olav’s Hospital is a 700-bed tertiary care hospital located in Trondheim, Norway. It serves a population of about 715,000, and has a wide range of medical and surgical specialties (15). After initial care and assessment, the patients included in this study are admitted to either the main Intensive Care Unit (ICU), the neuro ICU or the cardiac ICU.

4.2 PATIENTS

Patients of all ages with acute brain illness or –injury with reduced consciousness treated by P-EMS and admitted to St Olav’s Hospital between September and December 2016 were included. This encompassed patients with ICH/SAH, OHCA and severe TBI. Patients who died before arrival at the hospital were excluded.

4.3 REGISTRATIONS

Demographic data were collected from the patients’ medical records (DocuLive, Siemens Nixdorf Information Systems, Oslo, Norway), including further in-hospital course of events and relevant comorbidities according to the Charlson Comorbidity Index.
The patients were monitored for physiological variables from the site of injury/illness until the first three hours in the ICU, using the Tempus Pro Monitor (Remote Diagnostic Technologies, Basingstoke, UK) and/or Corpuls3 (GS Elektromed. Geraete, Kaufering, Germany). The Tempus Pro Monitor offers the ability to seamlessly register physiological variables from the start of pre-hospital treatment until arrival at the ICU, while other monitors are detached in the ED or during ambulance transport. In the ICU, physiological data were collected by an ICU electronic record system (Critical Care Manager, Picis, Wakefield, MA, USA). For patients included in the study where the Tempus Pro Monitor was not available, data were obtained by integrating pre-hospital data from monitors used by the ground-EMS (Corpuls3 monitors) and the P-EMS paper records. Data from the in-hospital phase of the treatment were collected by manual registrations in the ED as well as the ICU records, the Tempus Pro Monitor and the Corpuls3 monitor.

Glasgow Coma Scale (GCS) prior to intubation, systolic blood pressure, end tidal CO$_2$-levels and oxygen saturation were registered, both in the pre-hospital phase and in the ED, as well as in the first three hours in the ICU. In the pre-hospital period, episodes of hypoventilation, hypoxia or hypotension were registered according to the target values given in Table 1. Time untreated was defined as the amount of time passed before arrival of health care providers. Time unmonitored was defined as the time from arrival of health care providers to start of monitoring. The number of deviations was defined as the number of five-minute-periods where deviations were registered. Missing data was calculated as the number of five minute-periods where no monitoring took place.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic blood pressure</td>
<td>$\geq 90$ mmHg</td>
</tr>
<tr>
<td>Oxygen saturation</td>
<td>$&gt; 92%$</td>
</tr>
<tr>
<td>End tidal CO$_2$</td>
<td>$&lt; 45$ mmHg / 6 kPa</td>
</tr>
</tbody>
</table>
4.4 STATISTICS

Data was analyzed using the software Excel (Microsoft Corporation, Redmond, WA, USA) and the software Matlab (The Mathworks, Natick, MA, USA). The course of events is demonstrated by means of 3D-plots of physiological variables with a timeline for every patient, and deviations from treatment goals are marked with black lines below each variable.

4.5 ETHICS

The study was approved by the Regional Ethics Committee (REC) for Central Norway with reference number 2116/845.
5 RESULTS

Thirteen patients were included in the study. Demographic data for the patients included are presented in Table 2. The mean age was 54 years (range 1-89 years). The most frequent condition was cardiac arrest with ROSC (46%). In general, the patients had low comorbidity with a maximum Charlson comorbidity index score of 3.

Table 2. Demographic data

<table>
<thead>
<tr>
<th>ID</th>
<th>Condition</th>
<th>First GCS</th>
<th>Time untreated (min)</th>
<th>Time unmonitored (min)</th>
<th>Transportation time (min)</th>
<th>Charlson Comorbidity Index</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Traumatic head injury</td>
<td>3</td>
<td>8</td>
<td>14</td>
<td>25</td>
<td>0</td>
<td>Dead</td>
</tr>
<tr>
<td>2</td>
<td>Cardiac arrest with ROSC</td>
<td>3</td>
<td>12</td>
<td>3</td>
<td>29</td>
<td>3</td>
<td>Dead</td>
</tr>
<tr>
<td>3</td>
<td>Strangulation with ROSC</td>
<td>3</td>
<td>8</td>
<td>3</td>
<td>17</td>
<td>0</td>
<td>Dead</td>
</tr>
<tr>
<td>4</td>
<td>SAH</td>
<td>7</td>
<td>9</td>
<td>3</td>
<td>33</td>
<td>1</td>
<td>Survived</td>
</tr>
<tr>
<td>5</td>
<td>Cerebral haemorrhage</td>
<td>3</td>
<td>12</td>
<td>19</td>
<td>6</td>
<td>0</td>
<td>Dead</td>
</tr>
<tr>
<td>6</td>
<td>Prolonged convulsions</td>
<td>-</td>
<td>12</td>
<td>6</td>
<td>17</td>
<td>0</td>
<td>Survived</td>
</tr>
<tr>
<td>7</td>
<td>Cardiac arrest with ROSC</td>
<td>-</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>Survived</td>
</tr>
<tr>
<td>8</td>
<td>Cardiac arrest with ROSC</td>
<td>3</td>
<td>8</td>
<td>0</td>
<td>33</td>
<td>0</td>
<td>Dead</td>
</tr>
<tr>
<td>9</td>
<td>Drowning</td>
<td>-</td>
<td>78</td>
<td>18</td>
<td>-**</td>
<td>0</td>
<td>Survived</td>
</tr>
<tr>
<td>10</td>
<td>Cardiac arrest with ROSC</td>
<td>3</td>
<td>7</td>
<td>29</td>
<td>9</td>
<td>0</td>
<td>Dead</td>
</tr>
<tr>
<td>11</td>
<td>Cerebral haemorrhage</td>
<td>4</td>
<td>14</td>
<td>3</td>
<td>15</td>
<td>1</td>
<td>Dead</td>
</tr>
<tr>
<td>12</td>
<td>Cardiac arrest with ROSC</td>
<td>3</td>
<td>6</td>
<td>-*</td>
<td>35</td>
<td>3</td>
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</tr>
<tr>
<td>13</td>
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<td>3</td>
<td>12</td>
<td>-*</td>
<td>3</td>
<td>0</td>
<td>Survived</td>
</tr>
</tbody>
</table>

*Data from the monitoring done by the ground-EMS personnel could not be extracted.

** Transportation time is unknown

The number of observed deviations from the defined treatment goals and the percentage of missing data are shown in Table 3 for all patients included. The deviations and missing data from the out of hospital-environment and the ED are shown separately.

Table 3. Deviations from treatment goals

<table>
<thead>
<tr>
<th>ID</th>
<th>Saturation ≤ 92 % OOH</th>
<th>Saturation ≤ 92 % ED</th>
<th>ETCO₂ &gt; 45 mmHg / 6 kPa OOH</th>
<th>ETCO₂ &gt; 45 mmHg / 6 kPa ED</th>
<th>Systolic blood pressure &lt; 90 mmHg OOH</th>
<th>Systolic blood pressure &lt; 90 mmHg ED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dev. (%)</td>
<td>Mis. data (%)</td>
<td>Dev. (%)</td>
<td>Mis. data (%)</td>
<td>Dev. (%)</td>
<td>Mis. data (%)</td>
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<td>100</td>
<td>0</td>
<td>88</td>
</tr>
<tr>
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<td>92</td>
<td>2</td>
<td>8</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>11</td>
<td>0</td>
<td>26</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>68</td>
<td>4</td>
<td>67</td>
<td>0</td>
<td>100</td>
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<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>44</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>40</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>20</td>
<td>1</td>
<td>78</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>100</td>
<td>2</td>
<td>60</td>
<td>2</td>
<td>91</td>
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<tr>
<td>9*</td>
<td>10</td>
<td>33</td>
<td>0</td>
<td>100</td>
<td>0</td>
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</tr>
<tr>
<td>10</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>7</td>
<td>0</td>
<td>86</td>
<td>0</td>
<td>57</td>
</tr>
<tr>
<td>12</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>0***</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0***</td>
</tr>
</tbody>
</table>

Mean: 29,3 56,9 47,3 71,2% 55,6 56,2

Missing data is shown as a percentage of total monitoring time.

OOH: Out of Hospital
ED: Emergency Department

* end of out of hospital-phase is defined as time of Corpuls detachment
** from start of Tempus monitoring, physiological course prior to this is unknown
5.1 General Trends

The mean time untreated by health care personnel was 15 minutes (range 6-78 minutes). Ground-EMS personnel arrived at the site of injury prior to P-EMS in 12 patients. In two patients, ground-EMS personnel did not initiate any monitoring. The mean time unmonitored was 9 minutes (range 0-29 minutes). Monitoring was initiated at arrival in only one of the patients. The mean duration of transport was 22 minutes.

Oxygen saturation was the physiological variable that deviated most often in the pre-hospital phase, and was also the variable with the lowest percentage of missing data in this phase. All patients included in the study had one or more episodes of oxygen saturation < 92%. In some patients, monitoring of saturation was discontinued in a hypoxic phase. In the emergency room, hypotension was the deviation registered most often, and systolic blood pressure had the lowest percentage of missing data. Registrations of end tidal CO$_2$-levels in the ED were limited, with a mean missing data percentage of 71%. In both the pre-hospital phase and in the ED, end tidal CO$_2$-level was the variable with the lowest proportion of measurements.

Physiological variables for all patients are presented in Appendix 1, plots 1 to 13, from site of the event to the first three hours in the ICU.

5.2 Outcome

Eight patients (62%) died in the hospital. Among these, the average length of hospital stay was 4 days. Two patients underwent surgery. The mean duration of hospital stay in survivors was 10 days.
6 DISCUSSION

In patients with ICH/SAH, OHCA and severe TBI we found frequent deviations from physiological treatment goals, as well as a considerable amount of missing data in the time period from scene of accident/illness to admittance to the ICU.

The patients in the study had a considerable amount of physiological deviations, both in the pre- and in-hospital phase. Oxygen saturation deviated the most often. This is unfavorable as hypoxia in the acute phase is known to negatively affect outcome (16). Oxygen saturation was the most monitored variable, with a mean percentage of missing observations of 29% in the pre-hospital phase. It is worth noticing that for some of the patients, monitoring of oxygen saturation was discontinued at a time where the patients were hypoxic, leaving the patients hypoxic for an unknown amount of time. EtCO₂ had the lowest amount of deviations in the ED, but also the highest amount of missing data.

Hypotension is unfavorable for patients with severe TBI (17). Systolic blood pressure had a high frequency of missing observations, and 46% of the patients had one or more hypotensive episodes. However, in the majority of patients, only non-invasive blood pressure monitoring was performed. The accuracy of this method is uncertain, and clinical signs may be considered as more useful by the clinicians - a possible cause for few measurements (18). Also after admittance to the ICU, there are wide fluctuations in systolic blood pressure, which might occur as a result of the patients being in an unstable circulatory status before initial resuscitation with fluids had been given and vasopressors had been established.

Exposure to hypercapnia after brain injury is associated with a poor clinical outcome (19). In four patients, end tidal CO₂ was not monitored, and therefore, no deviations were registered. Patient 2 was, however, continuously monitored throughout the pre-hospital phase, and showed 11 deviations in EtCO₂ before arrival at the hospital. This agrees with the general observation that the variables that deviated the most were the variables most often registered. This shows that several deviations will remain unobserved if monitoring of physiological variables is lacking or insufficient.

It is challenging to maintain a continuous monitoring throughout the initial phase of treatment. In the majority of patients, monitoring was initiated several minutes after the start of medical care. Monitoring was not initiated by either P-EMS or ground-
EMS before a considerable amount of time had passed in some of the patients. When monitoring took place, this was often incomplete, with only some of the variables registered. It also occurred that patients were detached from the monitor after the initial establishment of monitoring devices, so that possible deviations remained undetected. Ground-EMS and P-EMS used separate monitors, which may cause some of the interruptions. However, it may be unlikely that detachment and attachment of equipment should take more than five minutes. The three patients monitored with the Tempus Pro Monitor had a lower percentage of missing observations. This monitor was connected throughout the clinical course until admission to the ICU without any interruptions. Still, the most frequent reason for lack of monitoring may be that the initial pre-hospital phase often is complex and the work load is high. In some cases, the physicians may prioritize other interventions before applying a monitor.

Occasionally, physiological variables in the emergency room were not registered. In the patients where monitoring was carried out, some data were not observed during radiological examinations and transport. The interval between registrations of data also varied highly. The pre-hospital documentation carried out using Corpuls3 and Tempus Pro was registered every minute, and gives more continuous clinical information. The Tempus Pro is the only monitor that registered and stored EtCO$_2$ in the ED.

This study has several limitations. Firstly, few patients were included in the study and they suffered from a wide range of medical conditions. This makes it difficult to draw specific conclusions regarding exposure to adverse physiological events and long-term outcome. Second, this was a one-center study. Therefore, this study can be considered as a pilot study giving preliminary information needed before commencing further studies. Third, non-invasive systolic blood pressure was documented in the pre-hospital phase and invasive systolic blood pressure in the early hospital phase, which may cause variations in the results. Fourth, two of the files from the ground-EMS could not be extracted, and in these cases, time unmonitored could not be estimated. Finally, with respect to EtCO$_2$ measurements, we defined hypercapnia (>6kPa) as a deviation from optimal physiology, but did not consider hypocapnia as a deviation, although this may also be harmful in these groups of patients. We considered possible gas leakage from the tube connections, differences in end-tidal and arterial CO$_2$ and poor circulation in patients with ROSC as potential sources of bias in this
regard, possibly missing episodes of hypocapnia due to hyperventilation. In cases where high EtCO$_2$ was measured, we considered none of these sources of bias to mask the presence of arterial hypercapnia.

To conclude, the patients in the study had frequent deviations in systolic blood pressure, oxygen saturation and end tidal CO$_2$-levels, both in the pre- and in-hospital phase. Our study demonstrates that there is a considerable time with missing observations in the period from the injury or start of illness to admittance to the ICU. It is challenging to maintain a continuous monitoring throughout the critical initial phase of treatment, and the start of monitoring is often delayed. Monitoring with the Tempus Pro Monitor, used throughout the pre-hospital and early in-hospital phase, resulted in more complete registrations of data. The routines for documentation of physiological variables in the pre-hospital phase and in the ED should be revised for this group of patients.
7 REFERENCES


8 APPENDIX 1

In this appendix, patient 1-13 and their physiological courses are presented in Figures 1-13, respectively.

8.1 PATIENT 1

Patient 1 suffered a traumatic brain injury. P-EMS arrived at the site of injury 14 minutes after the ground-EMS. The ground-EMS personnel did not initiate monitoring of physiological variables, leaving the patient unmonitored for several minutes. Monitoring started at the arrival of P-EMS, who used the Corpuls3 monitor. The patient experienced two episodes of hypoxia before arrival at the hospital, registered in the initial phase of treatment. There were no registered episodes of hypotension in the early phase - systolic blood pressure was registered once, measured to 152 mmHg, also in the initial phase.

During the transport the monitoring of physiological variables was discontinued and the patient was left unmonitored for the greater part of the transport period. End tidal CO$_2$-values and data from the monitoring of physiological variables in the ED, prior to admittance at the ICU, were not captured. The patient was admitted to the ICU where monitoring took place every 15 minutes. The patient died one day after admittance.

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**Figure 1** Oxygen saturation (blue line) and systolic blood pressure (red line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.2 Patient 2

Plot 2 presents the physiological course for patient 2, who suffered from cardiac arrest with ROSC. P-EMS arrived at the site of injury six minutes after the ground-EMS. One episode of hypoxia was registered before the hospital arrival, registered 16 minutes after the arrival of P-EMS. End tidal CO₂-levels were monitored continuously by P-EMS, registering 11 episodes of hypercapnia. The maximum CO₂-level was 101 mmHg (12,9 kPa).

End tidal CO₂-levels were monitored continuously, saturation was measured once, and there were no monitoring of systolic blood pressure in the pre-hospital phase. Data from the monitoring of physiological variables in the ED, prior to admittance at the ICU, were collected from the ICU-records. Two episodes of hypoxia, five episodes of hypercapnia and nine episodes of hypotension were registered in this phase, and the monitoring of EtCO₂ in the ER was missing 50% of the time. The patient was admitted to the ICU and died three days after admittance.

![Figure 2](image-url)  
*Figure 2* Oxygen saturation (blue line), systolic blood pressure (red line) and end tidal CO₂-levels (yellow line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.3 Patient 3

Plot 3 presents the physiological course of patient 3, who suffered from cardiac arrest due to strangulation and achieved ROSC. P-EMS arrived at the site of injury 7 minutes after the ground-EMS. Registration of physiological variables was initiated by the ground-EMS three minutes after arrival by the Corpuls3 monitor. The patient experienced one known episode of hypotension before arrival at the hospital, and one hypoxic episode. End tidal CO$_2$ was measured to hypercapnic levels two times in this phase.

Monitoring of saturation was initiated 12 minutes after start of treatment. Systolic blood pressure was measured three times before arrival at the hospital. Data from the monitoring of physiological variables in the ED, prior to admittance at the ICU, were collected from the ICU records. In this phase, two hypotensive events were registered. The patient was admitted to the ICU and died four days after admittance. The patient experienced prolonged hypotension after arrival in the ICU.

Figure 3 Oxygen saturation (blue line), systolic blood pressure (red line) and end tidal CO$_2$-levels (yellow line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.4 Patient 4

Plot 4 presents the physiological course of patient 4, who suffered from a subarachnoid haemorrhage. P-EMS arrived the site of injury 56 minutes after the ground-EMS personnel. The patient experienced five episodes of hypoxia and no known episodes of hypotension before arrival at the hospital.

Saturation was monitored the first 5 minutes after arrival of the ground-EMS personnel, followed by a period of 30 minutes without any registration of saturation. When the monitoring was re-initiated the saturation was registered to 90% and the patient remained hypoxic for the next 25 minutes. Systolic blood pressure was measured four times before arrival at the hospital and end tidal CO₂-levels were not captured. Data from the monitoring of physiological variables in the ED, prior to admittance at the ICU, were registered manually as well as the ICU-records. In this phase, the patient experienced four hypoxic and two hypotensive episodes. The patient was admitted to the ICU and discharged 31 days after the incident.

Figure 4 Oxygen saturation (blue line) and systolic blood pressure (red line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.5 Patient 5

Plot 5 presents the physiological course of patient 5, who suffered from a cerebral hemorrhage. P-EMS arrived at the site of injury two minutes after the ground-EMS. Monitoring of physiological variables, using the Corpuls3 monitor, was first initiated at the start of patient transport, several minutes after the ground-EMS personnel had arrived. The patient experienced one episode of hypoxia before arrival at the hospital. The first registration of saturation was 100%, but the patient quickly entered a hypoxic period that lasted for 5 minutes.

Systolic blood pressure was measured once and no episodes of hypotension were registered. End tidal CO₂ was not monitored. Saturation and systolic blood pressure were registered manually as well as from the ICU records in the ED, prior to admittance to the ICU. In this phase, the patient experienced one episode of hypoxia. The patient was admitted to the ICU and died the same day.

Figure 5 Oxygen saturation (blue line) and systolic blood pressure (red line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.6 Patient 6

Plot 6 presents the physiological course of patient 6, who suffered from prolonged convulsions. P-EMS arrived 22 minutes after the ground-EMS. The patient experienced one episode of hypoxia, registered in the initial phase of monitoring. No episodes of hypotension were registered before arrival at the hospital.

Saturation was monitored continuously and systolic blood pressure was measured twice. End tidal CO₂ was not monitored and data from the monitoring of physiological variables in the ED, prior to admittance at the ICU, were collected from the ICU records. In the ED, the patient experienced two episodes of hypoxia. The patient was discharged two days after admittance.

![Figure 6](image)

**Figure 6** Oxygen saturation (blue line) and systolic blood pressure (red line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.7 PATIENT 7

Plot 7 presents the physiological course of patient 7, who suffered from cardiac arrest with ROSC. The patient experienced one episode of hypoxia and one episode of hypercapnia before arrival at the hospital, but no episodes of hypotension were registered.

The first monitoring of end tidal CO$_2$ and saturation was performed respectively seven and twelve minutes after the arrival of ground-EMS. After nine minutes, the monitoring of saturation was discontinued for four minutes. When monitoring was reinitiated, the patient had a saturation of 79%. End tidal CO$_2$-levels were only measured for a period of four minutes shortly after the start of treatment. Data from the monitoring of physiological variables in the ED, prior to admittance at the ICU, were collected from the ICU records. In the ED, the patient experienced one hypoxic episode. The patient received surgery for the condition 15 days after admittance, and died after another three days.

Figure 7 Oxygen saturation (blue line), systolic blood pressure (red line) and end tidal CO$_2$-levels (yellow line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.8 **Patient 8**

Plot 8 presents the physiological course of patient 8, who suffered from cardiac arrest with ROSC. P-EMS arrived 34 minutes after the ground-EMS. In the initial phase, two hypercapnic episodes were registered.

Systolic blood pressure and saturation were not captured in the initial phase, and therefore, any possible episodes of hypotension or hypoxia in this period were not registered. Systolic blood pressure and saturation were captured manually in the ED, showing two episodes of hypoxia. The patient died 11 days after admittance.

![Figure 8](image.png) **Figure 8** Oxygen saturation (blue line), systolic blood pressure (red line) and end tidal CO$_2$-levels (yellow line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.9 Patient 9

Plot 9 presents the physiological course of patient 9, a case of drowning and hypothermia. P-EMS was the first resource at the site of injury, 34 minutes after the initial inquiry. They were not able to reach the patient, who was submerged unconscious in water for another 44 minutes. This made the total time untreated 78 minutes. The time of arrival at the hospital is not known. The first saturation monitoring was done 45 minutes after the start of treatment and the patient experienced 10 episodes of hypoxia before arrival at the hospital. Mean body temperature was 19.7°C.

Systolic blood pressure and data from the monitoring of physiological variables in the ED, prior to admittance at the ICU, were not captured. The patient was transferred to another hospital three days after admittance.

**Figure 9** Oxygen saturation (blue line) and end tidal CO₂-levels (yellow line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.10 **Patient 10**

Plot 10 presents the physiological course of patient 10. P-EMS arrived 11 minutes after the ground-EMS. The patient experienced five episodes of hypoxia, one episode of hypotension and three episodes of hypercapnia before arrival at the hospital.

The Tempus Pro monitor remained attached during the entire stay at the ER, securing a continuous monitoring of saturation, systolic blood pressure and EtCO$_2$ throughout the whole course. This gives no missing data in the in-hospital phase, as shown in Table 3. In the ED, the patient experienced one episode of hypoxia, four hypercapnic and nine hypotensive episodes. The patient was admitted to the ICU and died seven days after admittance.

![Figure 10](image)

**Figure 10** Oxygen saturation (blue line), systolic blood pressure (red line) and end tidal CO$_2$-levels (yellow line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.11 **Patient 11**

Plot 11 presents the physiological course of patient 11, who suffered from a cerebral haemorrhage. The patient experienced one episode of hypoxia before arrival at the hospital.

Data from the monitoring of physiological variables in the ED prior to admittance at the ICU were not captured. Therefore, any deviations from treatment goals in this period were not registered. The patient was admitted to the ICU and died two days after admittance.

![Patient 11](image)

**Figure 11** Oxygen saturation (blue line), systolic blood pressure (red line) and end tidal CO$_2$-levels (yellow line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
Plot 12 presents the physiological course of patient 12, who suffered from cardiac arrest. The Tempus Pro monitor was applied 33 minutes after the arrival of P-EMS, any other monitoring is unknown. The patient experienced three hypoxic and two hypotensive episodes before arrival at the hospital.

The Tempus Pro monitor stayed attached until admittance to the ICU. There was a continuous monitoring of saturation and EtCO₂ in the ED, giving no missing data. The monitoring of systolic blood pressure was discontinued for five minutes at the arrival at the ED, but was then resumed. Three episodes of hypoxia were registered in this phase. The patient was admitted to the ICU and died two days after admittance.

**Figure 12** Oxygen saturation (blue line), systolic blood pressure (red line) and end tidal CO₂-levels (yellow line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.
8.13 **PATIENT 13**

Plot 13 presents the physiological course of patient 13, who suffered from a traumatic head injury. The ground-EMS arrived the site of injury five minutes prior to P-EMS. The Tempus Pro monitor was applied seven minutes after the arrival of P-EMS and the physiological course prior to this could not be collected.

The Tempus Pro monitor was used during patient transport and in the early in-hospital phase until admittance to the ICU, securing a continuous registration of saturation, systolic blood pressure and EtCO₂. The patient experienced one episode of hypoxia in the ED. The patient was admitted to the ICU and submitted two days later.

![Plot 13](image)

**Figure 13** Oxygen saturation (blue line), systolic blood pressure (red line) and end tidal CO₂-levels (yellow line) are presented on the y-axis. Time and treatment course are presented on the x-axis. Deviations from treatment goals are marked with black lines under each variable.