Association between Blood Glucose and cardiac Rhythms during pre-hospital care of Trauma Patients – a retrospective Analysis

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Abstract

Background: Deranged glucose metabolism is frequently observed in trauma patients after moderate to severe traumatic injury, but little data is available about pre-hospital blood glucose and its association with various cardiac rhythms and cardiac arrest following trauma.

Methods: We retrospectively investigated adult trauma patients treated by a nationwide helicopter emergency medical service (34 bases) between 2005 and 2013. All patients with recorded initial cardiac rhythms and blood glucose levels were enrolled. Blood glucose concentrations were categorised; descriptive and regression analyses were performed.

Results: In total, 18,879 patients were included, of whom 185 (1.0%) patients died on scene. Patients with tachycardia (≥100/min, 7.0 ± 2.4 mmol/L, p < 0.0001), pulseless ventricular tachycardia (9.8 ± 1.8 mmol/L, p = 0.008) and those with ventricular fibrillation (9.0 ± 3.2 mmol/L, p < 0.0001) had significantly higher blood glucose concentrations than did patients with normal sinus rhythm between 61 and 99/min (6.7 ± 2.1 mmol/L). In patients with low (≤2.8 mmol/L, 7/79; 8.9%, p < 0.0001) and high (>10.0 mmol/L, 70/1271; 5.5%, p < 0.0001) blood glucose concentrations cardiac arrest was more common than in normoglycaemic patients (166/9433, 1.8%). ROSC was more frequently achieved in hyperglycaemic (>10 mmol/L; 47/69; 68.1%) than in hypoglycaemic (≤4.2 mmol/L; 13/31; 41.9%) trauma patients (p = 0.01).

Conclusions: In adult trauma patients, pre-hospital higher blood glucose levels were related to tachycardic and shockable rhythms. Cardiac arrest was more frequently observed in hypoglycaemic and hyperglycaemic pre-hospital trauma patients. The rate of ROSC rose significantly with rising blood glucose concentration. Blood glucose measurements in addition to common vital parameters (GCS, heart rate, blood pressure, breathing frequency) may help identify patients at risk for cardiopulmonary arrest and dysrhythmias.

Keywords: Trauma, Cardiac arrest, Tachyarrhythmia, Bradyarrhythmia, Pre-hospital care, Blood glucose
levels. This information, in addition to vital parameters, could be helpful since measurement of blood glucose is simple, rapid, and inexpensive and may complement clinical assessment of patients at increased risk at the accident site.

The primary outcome of this study was the level of blood glucose observed during various cardiac rhythms in adult trauma patients. Secondary outcome parameter was blood glucose and its association with the rate of cardiac arrest and ROSC on scene. In addition, we also evaluated the predictive value of blood glucose in trauma patients who suffered cardiac arrest during emergency treatment.

Methods
Study design, inclusion and exclusion criteria
A retrospective analysis of data from pre-hospital missions conducted by the Helicopter Emergency Medicine Service (HEMS) of Allgemeiner Deutscher Automobil Club (ADAC) in Germany was performed. A nationwide, multicentre study including all 34 ADAC helicopter bases was conducted and all trauma patients treated by ADAC-HEMS between 1 January 2005 and 31 December 2013 were screened for inclusion. Inclusion criteria were adult trauma patients (≥18 years) treated by HEMS, in whom initial cardiac rhythms and blood glucose concentrations were documented. Exclusion criteria were interhospital transfers and incomplete or incongruent data recording (demographic data, cardiac rhythm, vital signs, injury pattern, trauma causes and courses). The study was approved by the Ethics Committee of the Medical Association of the Saarland and by the Institutional Review Board.

Data processing
The following parameters were routinely recorded according to the predefined emergency physician dataset (Minimaler Notarzt-Datensatz, MIND2 [8]) within the observational database of the ADAC (LIKS® (Luftrettungs-, Informations- und Kommunikations-System)): demographic data, first vital parameters (heart rate, breathing frequency, systolic blood pressure) upon arrival of the professional rescuers, Glasgow Coma Scale (GCS) [9]), trauma mechanism, clinical evaluation of injury severity of the following body regions: head/brain, neck, face, chest, abdomen, thoracic and lumbar spine, pelvis, upper and lower extremities (1 = no injury, 2 = minor injury, 3 = moderate injury, 4 = severe injury, not life-threatening, 5 = severe injury, life-threatening, 6 = critical injury, life-threatening, 7 = deadly injury), whole injury pattern (1 = single injury, 2 = multiple injuries, 3 = polytrauma defined as life-threatening multiple trauma), the modified National Advisory Committee for Aeronautics (NACA) Index [10], 0 = no injury, 1 = minor injury, no intervention by a physician necessary; 2 = minor to moderate injury, ambulatory evaluation, 3 = moderate to severe injury, not life-threatening, in-patient care necessary, 4 = severe injury, potentially life-threatening, emergency physician care necessary, 5 = acute life-threatening injury, 6 = apnoea and circulatory arrest/resuscitation, 7 = deceased; of note: we included only patients who were alive on arrival of the HEMS emergency physician at the accident scene). In addition, the given volume, type of drugs administered, and rescue intervals were recorded.

Blood glucose measurement
Blood glucose (in mmol/L) was measured at the scene with varying point-of-care devices that differed in accuracy and manageability. In most cases, glucose was measured from blood drawn immediately after venous access before any drug or volume administration. Blood glucose concentrations were categorised in groups: ≤2.80 mmol/L (50 mg/dL), 2.81–4.20 mmol/L (51–75 mg/dL), 4.21–5.55 mmol/L (76–100 mg/dL), 5.56–7.50 (101–135 mg/dL), 7.51–10.0 mmol/L (135–180 mg/dL), 10.01–15.0 mmol/L (181–270 mg/dL) and > 15.0 mmol/L (> 270 mg/dL). Hypoglycaemia and hyperglycaemia limits are not consistently defined to date and differ strongly in the literature. The thresholds of 2.80 (50 mg/dL), 4.2 mmol/L (75 mg/dL) and 5.55 mmol/L (100 mg/dL) are commonly used to define various stages of hypoglycaemia; whereas the threshold of 10 mmol/L (180 mg/dL, hyperglycaemia) is commonly used to define hyperglycaemia in pre-hospital emergency medicine and in-hospital intensive care medicine. The values between 5.56 mmol/L (> 100 mg/dL) and 7.50 mmol/L (135 mg/dL) are regarded as physiological blood glucose concentrations following normal nutritional intake; values exceeding 15 mmol/L (270 mg/dL) are defined as excessive hyperglycaemia [4, 5, 11–13].

Cardiac rhythm analysis
Although automatic interpretation of some ECG findings is offered by most ECG devices, the binding diagnosis was performed by the emergency physician on service following immediate monitoring on site. Emergency physicians were trained during their practical year, of which four months were in internal medicine and another four months in anaesthesiology, during five years of specialisation (most of them in anaesthesiology and intensive care medicine), during their post-graduate training in emergency medicine (subspecialty qualification emergency medicine) including minimum 100 missions with ground EMS before applying for further training with HEMS. [14]. Routinely, a 3-lead ECG was established for initial rhythm diagnosis. In patients with signs of ischaemia an additional 12-lead ECG was written.
Bradyarrhythmia in adults was defined according to current guidelines as a heart rate ≤ 60 beats per minute [15]. Regular supraventricular bradycardia matches sinus bradycardia. Irregular supraventricular bradycardia included atrial fibrillation with slow ventricular response and sinus rhythms with relevant ventricular or supraventricular extrasystole. Ventricular bradycardia included ventricular escape rhythm, sinus arrest, sino-atrical exit block, high-grade second- and third-degree atrioventricular block, broad complex escape rhythm, and idioventricular rhythm.

Tachyarrhythmia in adults was defined as a heart rate > 100 beats per minute [15]. Regular tachycardia included sinus tachycardia, atrial tachycardia, paroxysmal supraventricular tachycardia, narrow-complex tachycardia, atrioventricular nodal re-entry tachycardia, sino node re-entry, junctional tachycardia, Wolff-Parkinson-White syndrome. Irregular supraventricular tachycardia included focal atrial tachycardia, atrial fibrillation with rapid ventricular response as well as sinus tachycardia with relevant supraventricular and ventricular extrasystole. Ventricular tachycardia defined perfusing ventricular tachycardia.

Normofrequent arrhythmia included sinus rhythm with ventricular and supraventricular extra beats and irregular supraventricular arrhythmia with normofrequent ventricular response.

Cardiac rhythms associated with cardiac arrest were asystole, pulseless electrical activity (non-shockable rhythms), and ventricular fibrillation and pulseless ventricular tachycardia (shockable rhythms) [15]. Cardiac arrest was diagnosed according to ECG rhythm analysis (asystole, pulseless electrical activity (PEA), ventricular fibrillation or pulseless ventricular tachycardia), NACA score of 6 or 7, and documented as cardiopulmonary resuscitation. ROSC was measured when spontaneous circulation occurred during cardiopulmonary resuscitation on site. Successful cardiopulmonary resuscitation was defined by both a documented ROSC and a NACA score of 6 on admission.

Statistical analysis
Statistical analysis was conducted with IBM SPSS Statistics (Release 24.0, 2016, Armonk, NY, USA). The Shapiro-Wilk test was used to test for normal distribution. Following descriptive analysis, the Mann-Whitney U test was used to compare group differences and the chi-square test was performed to detect frequency differences. For the prediction of cardiac arrest (NACA score 6 or 7) we applied a generalised additive model [16] using common vital parameters for model 1 (heart rate, respiratory frequency, systolic blood pressure, GCS) and for model 2 common vital parameters and blood glucose on site. More precisely, the effects of the predictor variables were modelled using penalised regression splines [17] to be able to identify potentially nonlinear relationships between cardiac arrest states with changing vital parameters. The models were estimated using the statistical environment R [18] and the recommended mgcv package [19]. Integrated discrimination improvement (IDI) and net reclassification improvement (NRI) were used to assess the improvement of outcome prediction comparing model 1 and model 2 (STATA/MP, release 13, College Station, TX, USA). Confidence intervals (CI) in this study were 99%. A p value of 0.01 was deemed to be statistically significant.

Results
Patient population
Of 51,936 trauma patients, 28,152 patients with recorded ECG findings and glucose concentrations were eligible; 18,879 trauma patients fulfilled the inclusion criteria and were enrolled (13,185 (69.8%) were male; mean age 50 ± 20 years). In 58.5% (11,039/18,879) of the trauma patients ECG findings were within normal limits, in 31.6% (5958/18,879) ECG showed tachycardia and 5.7% (1072/18,879) had bradycardia. Cardiac arrest was diagnosed in 466 (2.5%) of the trauma patients; 185 patients (1.0%) died on the scene (Fig. 1, Table 1), and 3064 (16.3%) patients had single injuries (predominantly severe to life-threatening head injuries), while 13,031 (69.0.1%) patients had multiple injuries, and 2784 (14.7%) patients were polytraumatised.

Blood glucose and cardiac rhythms
Patients with tachycardia (≥100/min, 7.0 ± 2.4 mmol/L, p < 0.0001), pulseless ventricular tachycardia (9.8 ± 1.8, mmol/L, p = 0.008) and patients with ventricular fibrillation (9.0 ± 3.2 mmol/L, p < 0.0001) had higher blood glucose than did patients with normal sinus rhythm of 61–99/min (6.7 ± 2.8 mmol/L). Patients with asystole (6.7 ± 2.4 mmol/L) or pulseless electrical activity (PEA, 6.6 ± 2.3 mmol/L) and bradycardia (6.9 ± 2.4 mmol/L) had comparable blood glucose levels. (Table 1).

Blood glucose and cardiac arrest
The frequency of patients with cardiac arrest was highest in patients with either hypoglycaemia (≤4.2 mmol/L; 31/641; 4.8%, ≤2.8 mmol/L; 7/779; 8.9%) or hyperglycaemia (> 10 mmol/L; 68/1270; 5.6%, > 15 mmol/L; 16/264; 6.1%) and lowest in patients with blood glucose of > 4.2–7.5 mmol/L (262/13,780; 1.9%). (Fig. 3) In 80% (174/218) of the patients with asystole or pulseless electrical activity a life-threatening polytrauma was diagnosed, whereas 20 (60.6%) of the 33 patients with ventricular fibrillation or ventricular tachycardia suffered from a single injury.
Especially in polytraumatised patients, pre-hospital blood glucose showed a significantly U-shaped association with the rate of patients with cardiac arrest ($p < 0.0001$), with the lowest rate of cardiac arrest being in patients with blood glucose at 5.56–7.5 mmol/L (112/1340, 8.4%) and the highest rate in hypoglycaemic patients ($\leq 4.2$ mmol/L, 26/82, 31.7%). This U-shaped pattern was less marked in patients with a single injury and was not observed in patients with multiple injuries. (Fig. 2) This U shape was also found in all age categories ($p < 0.0001$). In patients $\leq$40 years the rate of cardiac arrest was higher with hyperglycaemia ($> 10$ mmol/L, 14/178, 7.9%; $> 15$ mmol/L, 4/40, 10.0%), whereas in patients $> 40$ years the rate of cardiac arrest was higher with blood glucose levels $< 4.2$ mmol/L (22/363, 6.1%).

Prevalence of dysrhythmias and cardiac arrest was related to age. Analysing age and blood glucose for their combined association to cardiac arrest revealed that young age $< 40$ years and high blood glucose as well as age $> 65$ years and low blood glucose indicate an increased risk for cardiac arrest in all trauma patients. (Fig. 3) No significant differences were seen between mean peripheral oxygen saturation in bradycardia, tachycardia or in normofrequent rhythms.

In patients with minimal circulation (heart rate $> 30$/min and systolic blood pressure $> 40$ mmHg; $n = 18,633$) on arrival of the emergency physician, pre-hospital blood glucose non-significantly improved the prediction of cardiac arrest (surrogate parameters NACA score 6 or 7, area under the curve 0.881 with common vital signs, 0.886 for common vital signs and blood glucose; IDI $p = 0.03$, NRI $p = 0.68$ in all patients) in comparison to prediction by common vital signs alone (heart rate, breathing frequency, Glasgow Coma Scale, blood pressure).

### Blood glucose and ROSC

Blood glucose was measured in 466 patients with pre-hospital traumatic cardiac arrests. The frequency of ROSC (NACA score 6) in all patients with cardiac arrest (NACA score 6 or 7) increased with...
<table>
<thead>
<tr>
<th>Blood glucose</th>
<th>Age</th>
<th>Cardiac arrest in relation to initial glucose concentration</th>
<th>ROSC in relation to initial glucose concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 4.20 mmol/L</td>
<td></td>
<td>≤ 4.20 mmol/L</td>
<td>4.21 – 10.0 mmol/L</td>
</tr>
<tr>
<td>Normal sinus rhythm</td>
<td>6.7 ± 2.1</td>
<td>50.9 ± 19.4</td>
<td>0/372 0%</td>
</tr>
<tr>
<td>Shockable rhythms</td>
<td></td>
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<tr>
<td>Ventricular fibrillation</td>
<td>90 ± 32</td>
<td>&lt; 00001</td>
<td>64.2 ± 12.9</td>
</tr>
<tr>
<td>Non-shockable rhythms</td>
<td>98 ± 18</td>
<td>0.008</td>
<td>58.5 ± 12.5</td>
</tr>
<tr>
<td>Asystole</td>
<td>6.7 ± 24</td>
<td>0.69</td>
<td>48.8 ± 19.4</td>
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<tr>
<td>Bradynhythmia</td>
<td>66 ± 23</td>
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<td>57.2 ± 20.4</td>
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<tr>
<td>Tachynhythmia</td>
<td>6.9 ± 24</td>
<td>0.036</td>
<td>58.0 ± 20.5</td>
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<tr>
<td>Normofrequent Arrhythmia</td>
<td>70 ± 24</td>
<td>&lt; 00001</td>
<td>45.8 ± 19.3</td>
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<tr>
<td>Other</td>
<td>8.0 ± 31</td>
<td>&lt; 00001</td>
<td>77.3 ± 11.2</td>
</tr>
<tr>
<td>Pacemaker ECG</td>
<td>81 ± 31</td>
<td>&lt; 00001</td>
<td>76.5 ± 9.6</td>
</tr>
<tr>
<td>Myocardial infarction ECG</td>
<td>72 ± 12</td>
<td>0.051</td>
<td>69.1 ± 15.4</td>
</tr>
</tbody>
</table>

ROSC: return of spontaneous circulation; ECG: electrocardiogram, p in comparison to patients with normofrequent sinus rhythm
rising blood glucose: from 13/31 (41.9%) in patients with blood glucose ≤4.2 mmol/L, to 221/366 (60.4%) in patients with blood glucose of 4.2–10.0 mmol/L, to 47/69 (68.1%) in patients with blood glucose of > 10 mmol/L. The rate reached even 100% in younger patients (18–40 years) with excessive hyperglycaemia (> 15 mmol/L). (Fig. 3).

Only 43 (54%) of 79 patients with hypoglycaemia ≤2.8 mmol/L and 166 (26%) of 641 patients with hypoglycaemia ≤4.2 mmol/L received iv glucose therapy. In hypoglycaemic patients with cardiac arrest and documented iv glucose administration, there was a trend towards higher survival rate in comparison to hypoglycaemic patients without documented glucose administration: hypoglycaemia ≤4.2 mmol/L: cardiac arrest 31 patients, of whom six received iv glucose, four of them survived to hospital admission (ROSC) = 66.7%, 25 received no iv glucose, eight of them survived to hospital admission (ROSC) = 32%, p = 0.174.

Discussion
In this retrospective analysis of 18,879 trauma patients we demonstrate that prehospital dysrhythmia was associated with significantly deranged blood glucose concentrations. Patients with cardiac arrest presented with blood glucose concentrations in a U-shaped manner. This was especially evident in polytraumatised patients ≤40 years with either hypoglycaemia (32%) or hyperglycaemia (15%). Furthermore, the rate of ROSC correlated positively with initial blood glucose levels.

In cardiac arrest patients with high-frequency rhythms such as tachycardia or ventricular fibrillation we observed significantly higher blood glucose levels than in patients with pulseless electrical activity and asystole. To put it another way, 77.4% of cardiac arrest patients with hypoglycaemia (≤4.2 mmol/L) presented with asystole or pulseless electrical activity, whereas only one patient presented with ventricular fibrillation. The heart relies primarily on augmented glucose utilisation to meet...
energetic needs for force generation. Increased heart
work, usually elicited by catecholamines, increases
carbohydrate oxidation because of activation of the
pyruvate dehydrogenase complex [21]. Amazingly,
administration of i.v. glucose was recorded in only half of
the patients with severe hypoglycaemia and in only
one-quarter of the patients with moderate hypoglycaemia.
Except in patients with diabetes mellitus, acute hypergly-
caemia following trauma is mainly a consequence of dis-
stress causing a hypothalamic-hypophysic-renal stress
response modulated by trauma severity, incidence of shock,
and age [22–24]. Haemorrhagic shock and hypoxaemia be-
long to the strongest stressors in mammals, triggering high-
est levels of cortisol and catecholamines [24–26]. They lead
to release of pro-inflammatory cytokines in the liver [27,
28], trigger glycogenolysis, and gluconeogenesis by degrad-
ation of muscle lactate, glucoplastic amino acids, and
glycerol in liver and kidneys, and lipolysis [29–31]. Simul-
taneously, tumor necrosis factor α induces a peripheral
insulin resistance [32]. This stress response-induced hyper-
glycaemia supports initial steps of immune defense and
wound healing. In addition, hyperglycaemia leads to a
higher concentration gradient to tissues with disturbed
microcirculation and increased need, especially in the brain
following injury [33–35], which eases glucose uptake. Over
and above this, hyperglycaemia may improve cardiac func-
tion and resistance during stress and osmotic effects coun-
teract blood loss [36–39].

In severely injured patients who were found to be hyper-
glycaemic on arrival of the emergency physician,
circulation presumably lasted long enough to develop a
stress response. In contrast, patients with asystole or
pulseless electrical activity had less time for a physical
stress response. This assumption is supported by the fact
that 80% of the patients with asystole or pulseless elec-
trical activity were polytraumatised, whereas patients with
ventricular fibrillation or ventricular tachycardia had suf-
f ered a single injury in 60% of the cases in our study.
The potentially positive effects of hyperglycaemia in
the acute post-traumatic situation are accompanied by
negative sequelae from prolonged hyperglycaemia known as “diabetes of injury” [40, 41], which seems to
be more pronounced than diabetes mellitus-induced
hyperglycaemia. [42, 43].
The high frequency of hypoglycaemic patients in car-
diac arrest needs further investigation. The prevalence of
diabetes mellitus among adults in the German popula-
ation averages about 7–8%, with increasing prevalence
depending on age [44]. Theoretically, in some of the dia-
betic trauma patients hypoglycaemia may have been a
consequence of anti-hyperglycaemic drug overdose from
insulin or anti-diabetic drugs. In addition, hypoglycaemia
in non-diabetic patients could have resulted from exten-
sive shivering due to hypothermia, due to exposure to
cold and wet environment, but also from chronic liver
disease, intoxication, or severe liver and kidney trauma
[22, 23, 45–48].
The finding that the rate of successful resuscitation
attempts correlated with blood glucose levels, especially in
polytraumatised and young patients, raises the question
whether blood glucose levels need to be increased dur-
ing CPR in patients with traumatic cardiac arrest. Some
studies support the hypothesis that hyperglycaemia
could be beneficial during cardiac arrest: Nehme et al.
observed that diabetes affects at least one in five patients
who have had an out-of-hospital cardiac arrest and is as-
associated with poorer survival and 12-month functional
recovery. In contrast, a mild-to-moderate elevation of
pre-hospital blood glucose level was associated with im-
proved survival and functional recovery, which were
independent of diabetes status [49]. Mentzelopoulos
found better outcome by administering – among others
- blood glucose-increasing steroids for resuscitation of
in-hospital cardiac arrest [50]. In animal studies, hyper-
glycaemia during cardiac arrest led to greater cerebral
oxygenation [51], and blood glucose-increasing glucagon
administration during cardiac arrest improved survival
rate, cardiac function, and neurological outcome [52, 53].
Hyperglycaemia was associated with reduced myocardial
infarction size and improved systolic function during
myocardial ischaemia [37]. In traumatised patients and
patients with sepsis, glucose uptake in macrophage-rich
tissues is significantly increased [54]. A substantial
hyperglycaemia level may overcome local or general
microcirculation disturbances (injuries, sepsis, ischaemia) by increasing the concentration gradient, which facilitates non-insulin-dependent glucose uptake. These positive findings are accompanied by a long list of publications with negative results regarding hyperglycaemia and outcome in several diseases and critical conditions [2, 55–60]. Russo et al. retrospectively investigated clinical outcome in relation to mean blood glucose during the first 96 h after hospital admission in comatose survivors of out-of-hospital cardiac arrest with an initial shockable rhythm. They found that higher mean blood glucose levels during the first 96 h after admission were associated with increased rates of death and severe neurological dysfunction [61]. However, initial blood glucose level could be a surrogate marker of ischaemic insult severity during cardiac arrest [62].

After all, measuring blood glucose during pre-hospital care of trauma patients is easy, rapid, inexpensive and may yield additional information to estimate or complement clinical assessment of a patient’s pre-hospital situation as a whole.

Limitations
Limitations of this study are its retrospective design, although all data were collected prospectively. In our study about 46% of the trauma patients were excluded mostly due to missing prehospital glucose measurement or ECG rhythm documentation (Fig. 1). Thus, we cannot exclude selection bias, especially in the more severe cases in which HEMS physicians focus on supporting vital functions rather than on lab investigations. Patients in category NACA 7 were more numerous in the excluded population than in study patients.

In addition, we have no in-hospital data. In particular, we lack information on the frequencies of confirmed diagnoses and injury patterns, the in-hospital course of blood glucose concentrations and the ultimate outcome. However, this does not affect the core parameters of our study, initial ECG and on-site blood glucose concentrations. Worse, there is no on-site information available about pre-existing diseases such as diabetes, which probably influenced the course. The prevalence of diabetes in the German population is quoted as being 7–8% [44]. Accordingly, about 1500 patients in the study population may have been diagnosed with diabetes. We do not know the frequency of study patients with diabetes complicated by vascular and end-organ damage and we cannot tell how many of them were under anticoagulation therapy or had taken anti-diabetic drugs. Furthermore, our results regarding outcome of hypoglycaemic trauma patients do not consider administration of glucose in half of them. The extent to which oral anti-diabetic drugs or insulin may influence blood glucose concentrations during trauma and shock is not known and may vary individually with the time of drug ingestion/administration, the extent of oral carbohydrate intake, and the individual patient’s stress response. In recent studies it was reported that stress-induced hyperglycaemia rather than diabetic hyperglycaemia is associated with higher mortality in trauma [42, 43].

Another problem may arise from differences in point-of-care devices and with either venous or capillary blood measurements when haemodynamic shock developed. Routinely, blood glucose concentrations in pre-hospital trauma patients were measured from blood drawn from venous access before any drug or volume administration. However, we cannot exclude that in selected cases capillary blood glucose was measured by ear or finger sticks. The literature shows contradictory conclusions regarding the impact of venous vs. capillary blood glucose measurements, the existence of shock or the administration of catecholamines. In addition, the limited precision of point-of-care devices is well-known, especially when blood glucose concentrations are extremely high or low [63–65]. In this study, measurements of blood glucose concentration were conducted while establishing the initial iv access and before drug administration, for which reason the influence of external catecholamines (e.g. in the context of cardiopulmonary resuscitation) can be excluded as far as possible.

Conclusions
In adult trauma patients, higher pre-hospital blood glucose levels were related to tachycardic and shockable rhythms. Cardiac arrest was more frequently observed in hypoglycaemic and hyperglycaemic pre-hospital trauma patients. The rate of ROSC rose significantly with initial blood glucose. Blood glucose measurements in addition to common vital parameters (GCS, heart rate, blood pressure, breathing frequency) may help identify patients at risk for cardiopulmonary arrest and dysrhythmias. Therefore, it may be prudent to routinely measure blood glucose concentration during initial emergency care in pre-hospital trauma patients.

Abbreviations
ECG: electrocardiogram; GCS: Glasgow Coma Scale; HEMS: Helicopter Emergency Medicine Service; IDI: integrated discrimination improvement; NACA: National Advisory Committee for Aeronautics; NRI: net reclassification improvement; PEA: Pulseless electrical activity; ROSC: Return of spontaneous circulation

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Availability of data and materials
All data that support the findings of this study are available from the corresponding author upon reasonable request.
Authors’ contributions

JK and SS conceived the study, examined data quality, analysed data and drafted the manuscript. WL analysed data and revised the manuscript substantially. HU and NU provided statistical advice on study design and analysed the data. MvN and DW revised the manuscript. TS collected data and controlled data quality. All authors contributed substantially to its revision. No author has a potential conflict of interest with regard to the content of this manuscript. The study was supported by departmental resources only. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This retrospective study was approved by the Ethics Committee of the Medical Association of the Saarland (Ärztekammer des Saarlands, No. 69/14, 24/04/2014, Chairman Prof. Dr. med. Gerd Rettig-Stürmer) and by the Institutional Review Board.

Consent for publication

The manuscript does NOT contain any patient’s personal data. All data used in this analysis were anonymised and thus the Ethical Committee withdraw the requirement for patients or next of kin to consent to take part in the trial. Therefore, the authors state: “Not applicable in this section”.

Competing interests

The authors declare that they have no competing interests.

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