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SHORT COMMUNICATION

Feasibility and evaluation of high-fidelity simulation education for acute clinical toxicology

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To prepare medical students appropriately for the management of toxicological emergencies, we have developed a simulation-based medical education (SBME) training in acute clinical toxicology. Our aim is to report on the feasibility, evaluation and lessons learned of this training. Since 2019, each year approximately 180 fifth-year medical students are invited to participate in the SBME training. The training consists of an interactive lecture and two SBME stations. For each station, a team of students had to perform the primary assessment and management of an intoxicated patient. After the training, the students completed a questionnaire about their experiences and confidence in clinical toxicology. Overall, the vast majority of students agreed that the training provided a fun, interactive and stimulating way to teach about clinical toxicology. Additionally, they felt more confident regarding their skills in this area. Our pilot study shows that SBME training was well-evaluated and feasible over a longer period.

KEYWORDS
clinical toxicology, education, pharmacology teaching, pharmacotherapy, simulation-based medical education

1 | INTRODUCTION

Poisoning is globally one of the leading causes of intentional and unintentional injury-related death.[1] According to the 2020 report of the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA), acute drug intoxications constitute a significant burden on emergency health services in the European Union with opioids being among the most commonly implicated drug classes followed by stimulants and cannabis.[2] As stated in the key learning outcomes for clinical pharmacology and therapeutics (CPT) education in Europe,[3] it is important that medical graduates have acquired the knowledge and skills to accurately assess, timely diagnose and appropriately manage toxicological emergencies. However, medical students and junior doctors lack confidence in managing toxicological emergencies, which may be due to a lack of education in clinical toxicology during the undergraduate medical curriculum.[4,5] Indeed, the complex nature of toxic exposures, the diversity of toxic agents and the acute and dynamic presentations make clinical toxicology a challenging subject to team to medical students through traditional didactic methods alone.

In recent decades, simulation-based medical education (SBME) has emerged as an important tool to bridge the gap between theoretical knowledge and practical application. SBME offers a safe and controlled environment where learners can practice clinical skills, critical thinking and teamwork. SBME can consist of a variety of modalities including standardized patients, computerized case scenarios, virtual reality, mannequins or a combination of these methods.[6] Regarding CPT education, previous studies showed that the use of simulation

The principle investigator of this study is David Brinkman.

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mannequins is useful for teaching the basic pharmacology of neuromuscular,[7] inotropic,[8] antiarrhythmic,[9] anaesthetic[10] and autonomic agents[11] as well as opioids and anticonvulsants.[12,13] However, studies on SBME for clinical toxicology education are rare. Only two previous studies described the use of simulation mannequins for teaching clinical toxicology to pre-clinical medical students.[14,15] Since 2019, we have implemented SBME to teach and train acute clinical toxicology in a fun and interactive way to clinical medical students of the undergraduate medical curriculum at the Amsterdam University Medical Centers. With the goal to inform and inspire teachers, we report on the feasibility, evaluation and lessons learned of our SBME training for acute clinical toxicology.

What is already know about this subject?

- Medical graduates should have acquired the knowledge and skills to accurately assess, timely diagnose and appropriately manage toxicological emergencies.
- Medical students and junior doctors lack confidence in managing toxicological emergencies, which may be due to a lack of education in clinical toxicology.
- Simulation-based medical education might be useful for teaching acute clinical toxicology, but it is rarely used during the undergraduate medical curriculum.

What this study adds?

- Simulation-based medical education for teaching acute clinical toxicology is feasible, well-evaluated and improves students' confidence.
- Simulation-based medical education is a valuable addition to the teaching repertoire of teachers in clinical pharmacology and therapeutics.

2 | METHODS

2.1 | Design and participants

This longitudinal study involved fifth-year medical students of four academic years (2019, 2020, 2022 and 2023) from the Amsterdam University Medical Centers (AUMC), location VUmc. Every year, four symposia with cross-disciplinary themes are organized for fifth-year medical students of AUMC. Since 2019, one of these symposia has been dedicated to acute clinical toxicology. This symposium includes a 4-h programme with an interactive lecture about toxidromes and a SBME training (Figure 1). The cohort, typically consisting of 180 students, is divided into eight groups (A to H) of 20–25 individuals each. Initially, groups A to D attend the interactive lecture while groups E to H participate in the SBME training. At the midpoint, the groups switch activities. Study participation was voluntary, anonymous and bore no impact on their academic progress. The Medical Ethical Committee of the AUMC approved the study (Approved Project no. 2023.0642). Informed consent was obtained from all respondents in 2023. Informed consent was not deemed necessary for the respondents in the other years since the questionnaire was anonymous and part of the general curriculum evaluation. There was no face-to-face training in 2021 due to the COVID-19 pandemic.

2.2 | SBME training

The primary aim of the SBME training was to enable students to accurately assess, timely diagnose and appropriately manage toxicological emergencies. The SBME training involved five 15-min interactive sessions (here called stations), which are followed by the student groups in rotation (Figure 1). At the simulation station, five students were selected to perform the primary assessment and management of a high-fidelity mannequin simulating either opioid or amphetamine intoxication (Laerdal SimMan® 3G, Wappingers Falls, NY), designed to replicate real-life clinical responses, while their classmates observed (Appendix A). Teachers offered guidance as necessary and led the subsequent debriefings using a teaching manual based on the current national guidelines.[16–20] At the drug charades station, the students engaged in a game similar to 'Who Am I?', where they guess drug names from a deck of cards using yes/no questions, aiming to identify as many as possible within a set timeframe.

2.3 | Questionnaire

Every year, students were asked to complete a general questionnaire (Questionnaire A) about the symposium distributed online by the university. Two Likert-type questions within this questionnaire specifically relate to the SBME training. Additionally, students from cohort 2019 and cohort 2023 were asked to fill out a second, more detailed questionnaire (Questionnaire B) about their opinion of the SBME training (all Likert-type questions). In 2023, questions were added about students' prior experience with SBME training, their confidence in managing intoxicants, their preferred education method (i.e., SBME training, lectures, or a combination of both) and the quality of the training. Moreover, an open text field was available to share their overall impressions and feedback of the training.

2.4 | Data analysis

The statistical software SPSS (version 26, IBM, Armonk, NY, USA) and Microsoft Excel 2016 (Microsoft, Albuquerque, NM, USA) were used to analyse the data using descriptive statistics. Likert-type questions are expressed as a percentage (percentage of participants selecting a

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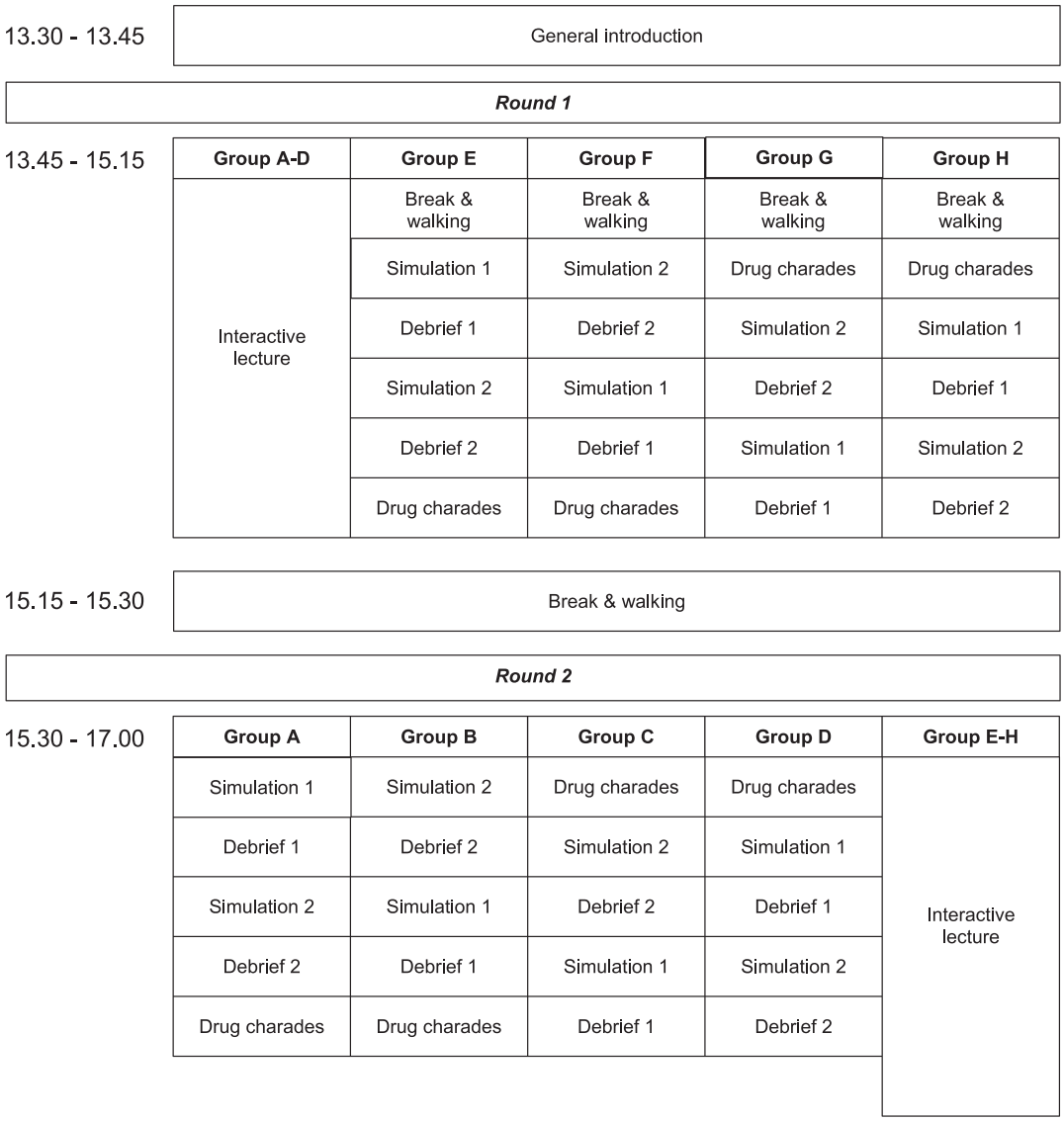

FIGURE 1 Programme for the symposium Acute Clinical Toxicology.

given answer option out of the total participant count). The open-response questions underwent thematic analysis.[21] The initial categorization of responses into themes and subthemes was performed by author P.S.W. These thematic categories were then deliberated upon with author D.J.B. to reach a mutual agreement on their definitive description and terminology.

3 | RESULTS

In total, 181 medical students participated in the symposium in 2019, 168 in 2020, 188 in 2022 and 193 in 2023. The response rate for Questionnaire A ranged from 16% to 79% and for Questionnaire B was 99% in 2019 and 73% in 2023. The results of Questionnaire A are shown in Table 1 and of Questionnaire B in Table 2. Every year, the vast majority (≥90%) of the students (completely) agreed that the training was educational and the teachers were knowledgeable. In 2023, 62% of the students reported that they had prior experience in SBME with an average of 5.5 h (ranging from 1 to 40 h). In both 2019 and 2023, the vast majority (≥90%) of students (completely) agreed that the training was fun and that it should be a compulsory part of the education at the start of the clinical rotations. In 2023, 93.6% of the students (completely) agreed the quality of the training was good and 83.9% of the students (completely) agreed that they feel more confident regarding the assessment of an intoxicated patient after the training. When asked about their educational preference, 32.4% of the students reported that they prefer more SBME training than lectures, 59.9% want as much SBME training as lectures and 7.7% want more lectures than SBME training. Recurring themes on the open-ended question 'what did you like about the SBME training?' in 2023 were practical application of theoretical knowledge (40 times, for example, 'direct application of knowledge from the lecture improved the retention of knowledge'), interactive nature (37 times, for example, 'nice to work with an interactive mannequin'),

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TABLE 1 Results of Questionnaire A.

	Year (*n*; response rate)	Completely disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Completely agree (%)
The training was educational	2019 (114; 63%)	0	0.9	7.0	43.9	48.2
	2020 (133; 79%)	0.8	0	6.0	37.6	55.6
	2022 (40; 21%)	0	0	2.5	42.5	55.0
	2023 (31; 16%)	3.2	0	0	29.0	67.7
The teachers were knowledgeable	2019 (114; 63%)	0	1.8	7.0	67.5	23.7
	2020 (133; 79%)	0	0.8	8.3	60.9	30.1
	2022 (41; 22%)	0	0	0	19.5	80.5
	2023 (31; 16%)	0	0	0	29.0	71.0

TABLE 2 Results of Questionnaire B.

	Year (n; response rate)	Completely disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Completely agree (%)
The training was fun	2019 (180; 99%)	0	1.1	2.8	21.1	75.0
	2023 (143; 74%)	0.7	0	1.4	59.4	38.5
The training should be a compulsory part of the clinical rotations	2019 (181; 100%)	0	1.1	0.6	24.9	73.5
	2023 (142; 74%)	0.7	0	3.5	33.8	62.0
I feel more confident regarding the assessment of an intoxicated patient after the training than before	2023 (143; 74%)	0.7	1.4	14.0	60.1	23.8
The quality of the training was good	2023 (141; 73%)	0.7	0.7	5.0	63.1	30.5

clinical relevancy (22 times, for example, 'prepares you for the real situation') and fun character (20 times, for example 'use of a mannequin is fun!'). On the last question 'how could we improve this SBME training?' in 2023, recurring themes were smaller groups (49 times), more time per station (26 times), more SBME training throughout the curriculum (17 times) and putting the lecture before the stations (10 times).

4 | DISCUSSION

To our knowledge, this is the first study to report about the use of SBME for teaching acute clinical toxicology to undergraduate clinical medical students. Overall, our SBME training provided a fun, interactive and stimulating way to teach students about this subject. Students appreciate the connection between theory and practice, feel more confident regarding the assessment of an intoxicated patient after the SBME training and agree that the training should be a compulsory part of the clinical rotations. Our pilot study shows this innovative SBME training was well-evaluated and feasible over a longer period.

As addressed earlier, a big advantage of SBME is that students can practice rare and high-risk scenarios where they may have limited exposure during their clinical clerkships. It can help address the ethical concerns surrounding patient safety by allowing students to improve their skills in a simulated environment prior to engaging with real patients.[22,23] While SBME shows great promise, it is rarely used for undergraduate CPT education in general. A previous study showed that only 4% of the EU medical schools use a form of SBME for basic pharmacology education and 21% for CPT education.[24] A reason for this could be because of the time-consuming and resource-intensive nature of this teaching method such as the necessity for high-fidelity mannequins, trained instructors and sufficient teaching time. To tackle this problem, we organized the training in one afternoon, focused on just two scenarios, divided the students in relatively large groups of 20–25 participants, provided group debriefing and asked help from student-assistants (i.e., medical students from different study years who help with teaching activities).[25] Another way to reduce the time-consuming nature is to make the cases available for other teachers by using an online platform such as the European Open Platform for Prescribing Education (EurOP2E).[26]

Our results are aligned with previous studies involving preclinical medical students and residents. Halm et al. and Lammers et al. reported that the self-confidence in clinical toxicology of second-year medical students increased after completing a SBME training.[14,15] Maddry et al. showed that emergency medicine residents had greater long-term knowledge retention in clinical toxicology after a SBME training compared to a traditional lecture.[27] Similarly, Keenan et al. and Thomas et al. showed that emergency residents had increased comfort with managing respectively an opioid and lithium overdose after a SBME training.[28,29] Combined with the results of our study, these findings suggest that SBME could provide a valuable addition to

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the teaching repertoire of CPT teachers, especially since an increasing number of medical schools already have simulation mannequins available. Already in 2014, more than 80% of medical schools in the United States had an incorporated simulation-based instruction within all 4 years of the undergraduate curriculum.[30] In order to successfully incorporate SBME into the medical curriculum, it is important that students get accustomed to this method from an early stage.[31] Students should be able to repetitively practice their skills using a wide variety of patient scenarios and increasing level of difficulty throughout the medical curriculum. Since CPT teachers are usually not expert in acute care, we recommend that trainings in acute clinical toxicology are given together with acute care specialists such as emergency medicine doctors, anaesthesiologists and/or intensivists. Based on the feedback provided by the students, future trainings should entail smaller groups, more time per station and different toxicological emergencies to enhance the breadth of students' exposure and preparedness.

Our results should be interpreted in the light of some limitations. First, the response rates to the questionnaire provided by the university (Questionnaire A) decreased throughout the years which is probably related to the fact that students were less motivated. Second, this study was performed in a single centre and involved a single undergraduate programme, which may limit the generalizability of the findings. Third, the absence of a control group (e.g., a cohort taught through traditional methods) limits the ability to compare the effectiveness of SBME against other teaching methods. Fourth, since this study assesses students' responses and confidence levels directly after the training, it does not investigate the long-term retention of knowledge and skills. Fifth, we acknowledge that selection and non-responder bias is an inevitable limitation of voluntary questionnaires.

5 | CONCLUSION

Our results suggest that the implementation of SBME could be a valuable tool to improve learning enhancement and overall satisfaction in acute clinical toxicology of clinical medical students. Its integration into undergraduate medical curricula requires strategic planning, resource allocation and curriculum development. Future studies could include multiple institutions and a control group to validate the results across diverse educational settings and focus on the long-term impact in clinical practice to provide a more robust evaluation of SBME. Also, future iterations of the training could explore ways to optimize resource use and investigate the scalability of the SBME for larger groups or institutions with limited resources.

AUTHOR CONTRIBUTIONS

All authors contributed to study design, data collection and analysis and writing of the report. All authors contributed to data interpretation and approved the final version of the submitted report.

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CONFLICT OF INTEREST STATEMENT

All authors declare that they had no financial support. There are no financial relationships with any organizations that might have an interest in the submitted work in the previous 3 years.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX A: TEACHING MANUAL FOR SIMULATION CASES

Clinical scenario station 1

Mrs. Y, 25 years

Short handover:

A female patient was found unconscious by her friend near the portable toilets at a music festival. There are no signs of a trauma. Her friend does not know what happened and also does not know whether she has been intoxicated. She does not know anything about her medical history or medication use. In the patient's pocket her driver's licence, some festival tokens and a mobile phone with an empty battery were found.

ABCDE assessment:

The information below is only given when the student performs the required steps. The questions in cursive are optional.

Airway: no airway obstruction, no suspicion of cervical spine injury.

Breathing: no cyanosis, symmetric chest movement on both sides. Respiratory rate 22/min, oxygen saturation 98% on room air. Normal breath sounds, no added sounds. Trachea in midline, no subcutaneous emphysema. If an arterial blood gas is requested: slightly lowered pH, slightly elevated PaO2, slightly reduced PaCO2, slightly reduced bicarbonate.

- *Is there any action required for this arterial blood gas?* It shows a mild metabolic acidosis with an attempt to compensate through hyperventilation. Fluid resuscitation and cooling the body temperature are important to reduce the cause of the metabolic acidosis (see further).

Circulation: sweaty, warm extremities. Capillary refill time is 4 s. Soft heart sounds, no murmurs. Blood pressure is 159/98 mmHg. Heart rate is 119/min, regular equal. If connected to the monitor: sinustachycardia. If an ECG is requested: sinustachycardia, no signs of myocardial infarction/ischaemia or arrhythmias. Establish an IV line.

- *Is action required for this blood pressure?* The patient is hypertensive, but there are no signs of a hypertensive crisis (no signs of blurred vision, confusion, nausea and vomiting etc.). No direct pharmacological actions are required to lower to blood pressure.
- *Is action required for this heart rate?* The patient has tachycardia. It is important to perform an ECG paying special attention to sinustachycardia, myocardial ischaemia/infarction and signs of arrhythmias. No direct pharmacological actions are required to lower to heart rate.

Disability: patient is severely agitated. Pupils are wide, equal in size, both reactive to light. Glasgow Coma Scale: E2M4V3 (E: eyes open in response to pain, M: flexion to withdraw from pain, V: inappropriate words). Glucose level 5.1 mmol/L.

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◦ *Glasgow Coma Scale score is 9, what does that mean?* It indicates that the patient has a reduced level of consciousness, a moderate vegetative state. It is important to find the cause of it as soon as possible and treat it appropriately. The patient does not need to be intubated right away because the airway is patent and breathing not endangered but close observation is required.

Exposure: dry mucous membranes, body temperature of 40.7°C (tympanic). No visible external injuries.

◦ *Is action required for this body temperature?* Yes! Hyperthermia is associated with high mortality and morbidity. Core temperature should therefore be reduced to below 39 degrees Celsius as quickly as possible. Passive and active cooling are essential (undressing, moistening the skin, cooling mattress, cold IV fluids, ice bath if available, etc.). If hyperthermia is refractory to these measures, intubation and sedation or extra corporal membrane oxygenation (ECMO) should be considered.

If requested by the students (although it takes some time before the results are available):

- Urine toxicology screen (only gives a qualitative outcome, not when or how much is used): Amphetamines +; Cocaine +; Benzodiazepines −; Cannabis −; Tricyclic antidepressants −; Opiates −; Paracetamol −.
- Laboratory tests: sodium 118 mmol/L, potassium 4.0 mmol/L, creatinine 123 μmol/L, urea 7.7 mmol/L, haemoglobin 8.4 mmol/L, platelet 210 × 10^9/L, white blood cells 11.0 × 10^9/L, CRP 17 mg/L, slightly elevated liver enzymes, creatinine kinase 12 000 U/L, lactate 5.1 mmol/L, ethanol level <0.1 mg/L.

Toxidrome:

Sympathomimetic: hypertension, tachycardia, hyperthermia, dilated pupils, diaphoresis.

Working diagnosis:

Sympathomimetic toxidrome due to mixed amphetamine and cocaine intoxication with signs of acute organ failure (CNS, acute kidney injury).

Treatment:

Focus on symptomatic treatment; it is crucial to address hyperthermia (high mortality and morbidity) and hyponatraemia (risk of cerebral oedema with seizures):

1. Treat hyponatraemia with moderately severe symptoms with 100 mL 3% NaCl in 20 min. Goal: increase sodium ≥ 5 mmol/L. Check sodium after 1, 6 and 12 h. If there is also hypovolaemia continue with 0.5–1.0 mL/kg of 0.9% NaCl (watch out for overcompensation).
2. Treat hyperthermia with passive and active cooling (see previously).
3. Treat acute kidney injury with fluid resuscitation (compensate hyponatraemia first, see 1).
4. Reduce the amount of drug that is absorbed: gastric lavage is not useful in this case because the timeline is unknown (should be done within 1 h of ingestion). Activated charcoal combined with laxatives may be considered through nasal gastric tube.

Clinical scenario station 2

Mr. X, age unknown

Short handover:

A male patient was found unconscious next to a bench in a park. There are no signs of a trauma. We do not know anything about his medical history or medication use. In the patient's pocket, a pack of cigarettes and a lighter were found.

ABCDE assessment:

The information below is only given when the student performs the required steps. The questions in cursive are optional.

Airway: no airway obstruction, no suspicion of cervical spine injury.

◦ *Is action required?* Intubation is not required right now as the airway is patent.

Breathing: central cyanosis is present, symmetric chest movements with slow and long breaths. Respiratory rate 5/min, oxygen saturation 72% on room air. Normal breath sounds, no added sounds. Trachea in midline, no subcutaneous emphysema. If blood gas is requested: low pH, low PaO2, increased paCO2, slightly increased bicarbonate.

◦ *What action is required?* The patient has respiratory failure with both a problem in oxygenation and ventilation. A nasal cannula or non-rebreather mask might improve oxygenation but both probably have little effect on ventilation. Start with bag mask ventilation to improve the oxygenation and ventilation. In the meanwhile, think about the underlying cause (consider naloxone?). Intubation is the next step if no quick improvement is made.

Circulation: cold extremities, no mottling. Capillary refill time is 6 s. Soft heart sounds, no murmurs. Blood pressure is 90/60 mmHg. Heartrate is 58/min, regular equal. If connected to the monitor: sinusbradycardia. If an ECG is requested: sinusbradycardia, no signs of myocardial infarction/ischaemia or arrhythmias. Establish an IV line.

◦ *Should we administer fluids?* The low blood pressure might indicate dehydration and a need for fluid resuscitation.

Disability: pinpoint pupils, equal in size, both reactive to light. Glasgow Coma Scale: E2M1V2 (E: eyes open in response to pain, M: no motor response, V: incomprehensible sounds). Glucose level is 5.6 mmol/L.

◦ *Glasgow Coma Scale score is 5, what does that mean?* It indicates that the patient has a reduced level of consciousness, a severe

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vegetative state. It is important to find the cause of it as soon as possible and treat it appropriately.

- *What do the pinpoint pupils tell you?* This might be an indication of an opioid intoxication. Opioids lead to a constriction of the pupils via stimulation of the parasympathetic nervous system.

Exposure: body temperature of 35.4°C (tympanic). No visible external injuries. Decreased bowel sounds.

- *How do we increase the body temperature of the patient?* Use passive (blanket, increasing room temperature, removing wet cloths etc.) and active heating (forced air warmer, warmed IV fluids, etc.).

If requested by the students (although it takes some time before the results are available):

- Urine toxicology screen (only gives a qualitative outcome, not when or how much is used): Amphetamines −; Cocaine −; Benzodiazepines −; Cannabis −; Tricyclic antidepressants −; Opiates +; Paracetamol −.
- Laboratory tests: sodium 136 mmol/L, potassium 4.0 mmol/L, creatinine 82 μmol/L, urea 6.9 mmol/L, haemoglobin 8.2 mmol/L, platelet 342 × 10^9/L, white blood cells 5.0 × 10^9/L, CRP 5 mg/L, normal liver enzymes, ethanol level <0.1 mg/L.

Toxidrome:

Opioid: low respiratory rate, pinpoint pupils, low blood pressure and heart rate, low body temperature and decreased bowel sounds.

Working diagnosis:

Opioid toxidrome with respiratory depression.

Treatment:

1. Naloxone (an opioid receptor antagonist) should be given IV or IM as soon as possible to treat the respiratory depression. Naloxone should be titrated, because it has an immediate effect and may lead to (possibly dangerous) withdrawal symptoms. It is important to monitor the patient's respiratory rate while titrating. It is important to mention that naloxone has a short elimination half-life, therefore a continuous infusion should be considered after giving a bolus.
2. Active and passive heating of the patient.
3. Consider a fluid bolus to improve haemodynamics.

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