Development and validation of a course concept for Tactical Medical Mining Rescue. Standardized training curriculum for mine rescue teams

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Translation of the original research publication in Med Klin Intensivmed Notfmed
https://doi.org/10.1007/s00063-021-00861-w

Funding. Creative Commons Open Access funding enabled and organized by Projekt DEAL.

Abstract

Background: Structural changes in modern mining industry increase the potential for medical emergencies. Furthermore, rescue times in mining are prolonged and public medical resources are not consistently available.
Objectives: We sought to train mine rescue brigade lay people to cover medical emergencies in mining.

Materials and methods: A standardized tactical–medical approach including specific equipment was developed and taught in a didactically optimized way in 16 lessons. Objective Structured Practical Examinations (OSPE) were conducted in 3 groups of 4 mine rescue personnel and compared to the identical exam of the reference group (17 paramedics of different educational and experience levels).

Results: The tactical–medical scheme includes vital functions and body checks, advanced life support, nasal and intraosseous drug administration, airway management, thoracocentesis, bleeding control, tourniquet, fracture repositioning, splinting and transport bedding. In OSPE evaluation, the scores of the trained mine rescue personnel (mean [M] = 3.42, 95% confidence interval [$CI_{95\%}$] = [3.24; 3.60]) were statistically equal to those of advanced paramedics (M = 3.28, $CI_{95\%}$ = [3.09; 3.46]), but much better than basic German paramedic level (M = 2.43, $CI_{95\%}$ = [2.10; 2.77]). Competency retention of mine rescue personnel remained on the same level after

a period of 6 months without further training (M = 3.54, $CI_{95\%}$ = [3.31; 3.73]). Conclusion: The competency level after the Tactical Mining Rescue Course is comparable to the advanced paramedics level in the spectrum of competencies addressed. Medical lay people can be trained to deliver an acceptable treatment level within a clearly defined treatment algorithm, and thus potentially close the gap towards professional medical emergency rescue in mining.

Keywords

Emergency rescue · Mining · Course development · Effect quantification · Practical competency

Background

The development of German mining, from formerly a few large production facilities to small companies with a broad spectrum novel raw material mining, research, recultivation, landfilling and final storage, lead to structural changes in mine rescue work. As a result of currently 500 annual accidents, which are associated with more than 3 days inability to work, the demand for comprehensive primary medical care in underground mining operation is growing – in contrast to often lacking medical resources available for underground first aid response. Based on risk analysis from past mine rescue operations, it is known that the lay medical rescue time (until the patient is handed over to an emergency physician) is usually much longer than the statutory response time of typically 12 minutes [20]. Furthermore, when considering the operational spectrum, there are significant differences between civilian and mining sectors with predominantly traumatologic emergencies [18, 22]. The currently required level of qualification according to the guideline for the German mine rescue system as company first aider is therefore no longer sufficient for the emergency forces of mine rescue services due to the expected severity of injuries [12]. In addition, public emergency rescue availability is not assured: Fire departments mainly lack long-term respiratory protection technology and communication equipment. Apart from equipmental challenges, the regulations of professional paramedic associations typically exclude operations in hazardous areas. Therefore, underground operations of public emergency services are available only to a very limited extent and on a voluntary basis in particular cases. Hence, the transformation process of modern mining in Europe requires new concepts to ensure adequate emergency rescue services.

As a basis for concept development, tactical medical approaches in military (Tactical Combat Casualty Care, TCCC; [6]) or police (Tactical Emergency Medical Support, TEMS; [3, 6, 10, 15]) forces were evaluated due to similar conditions in high-risk areas with limited resources of equipment and personnel, complex trauma, long transport distances, and lack of initial medical review by a physician. However, only few strategies and procedures were suitable for adoption due to deviating challenges such as lacking space, darkness, wetness and dirt, vertical rescue and non-breathable atmosphere, which are much more relevant than the tactical situation itself. For this reason, existing models from civilian fields with elements of tactical medicine were evaluated and incorporated into the development of a fully new rescue scheme, equipment and course concept. Further elements were adopted from the recommendation for First Aid in Offshore Wind Farms of the German Social Accident Insurance [23] and the concepts of tactical alpine medicine of the Austrian Mountain Rescue Service [1, 15]. The training guidelines of the Medical Services of the German Armed Forces with a comparable level of qualification were evaluated as well [7, 10, 11]. Nevertheless, the operational concept, treatment spectrum, equipment and training curriculum had to be completely redeveloped in order to address the specific requirements in underground mining and remote areas.

Research Question

Can members of the mine rescue team without prior emergency medical training achieve a practical level and range of competence in emergency rescue underground with a 2-day standardized curriculum that is comparable to the real preclinical patient care standard of public rescue service?

Study design and research methods

For the definition of the necessary treatment spectrum, the operational spectrum of mine rescue services in recent years was used, which were regularly deployed for emergency rescue in addition to firefighting and technical assistance. **Table 1** shows examples of injury types and deployment times for mine rescue operations in Saxony and Saxony-Anhalt in 2018-2019.

Date	**Mine**	**Cause of Accident**	**Injury**	**Time of Rescue** (Time of emergency until handover to public emergency ambulance services)
03/2019	1	Fall	Multiple trauma	11 h
04/2019	2	Suicide	Strangulation	2,5 h
11/2019	3	Explosion	Burn, inhalation trauma	1 h
06/2018	4	Transportation injury	Multiple trauma	1,5 h
07/2018	5	Entrapment	Multiple trauma	3 h
08/2018	4	Fire	Inhalation trauma	1,5 h

Tab. 1: Examples of medical dispositions of mine rescue teams in mid-Germany 2018 and 2019 including net time of rescue before handover to public emergency services, mines anonymized for confidentiality.

The current development in mining is also visible in the Austrian mining industry, where an increase in accidents has already been registered in the last 5 years [5]. Of around 150 accidents per year, almost 30% are serious and almost 1% are fatal. Typical causes of accidents are attributable to work equipment and -materials, extraction and transport, falling rocks, electric current and blasting operations. The majority of injuries are hand and foot injuries (around 45%), followed by head- and trunk injuries.

In order to direct this pattern of injury and potential illness to initial treatment with the primary goals of preventing further deterioration, stabilizing vital signs, and efficient casualty salvage, the following priorities were established to develop a condensed treatment algorithm:

1. Assessment of vital signs and identification of acute life-threatening conditions;
2. Bleeding control;
3. Cardiorespiratory stabilization;
4. Pain Management;
5. ventilatory support and artificial respiration, if necessary; both independent of ambient athmosphere
6. body temperatore preservation;
7. Transport positioning with fixed equipment;
8. Possibility of ground dragging and vertical rescue.

In addition to the development of the treatment algorithm, material and equipment tailored to the range of operations and the aforementioned special features had to be assembled and integrated into the algorithm.

Thereby the following requirements were prioritized:

1. Small size and weight;
2. Resistance to moisture, dirt, and mechanical stress;
3. Operability under limited visibility conditions;
4. Ability to be integrated into transportation requirements;
5. Operability during transportation.

Furthermore, once the treatment algorithm and adjusted equipment had been developed, a didactically optimized teaching concept [16] had to be created to meet the following requirements:

1. Standardized identical training procedure;
2. Clearly definable didactic units for sequential teaching of practical skills;
3. Transparently conveyed and measurable learning objectives tailored for the medical laypersons;
4. Development and training of a logical medical causal chain while avoiding overload with medical background knowledge.

After participants informed consent and positive ethical and legal statement of the Technical University Bergakademie Freiberg, 3 squads of mining rescue services, each with 4 men from different mining companies were recruited. These teams completed the developed training curriculum, which is presented in the results section. Immediately afterwards, the participants underwent a standardized Objective Structured Practical Examination (OSPE), on both simulator and standardized patient.

In order to compare the OSPE results in relation to the actual standard of patient care in public paramedic rescue service, randomly selected paramedics with different levels of experience and training (“Rettungssanitäter”, “Rettungsassistenten”, and “Notfallsanitäter”) underwent the identical OSPE test as reference group while using their own equipment.

The individual OSPE stations were rated by different examiners, but each individual OSPE station performance was rated for mine rescue participants and rescue service reference group by the identical examiner. The examination checklists contained several items for each practical skill, the items were rated on a 4-point scale (poor, satisfactory, good, very good). Zero points were given if a sub-aspect was not performed at all.

The statistical analysis and the graphical representation were conducted by using R v4.0.3 [19]. The respective total scores of the 7 OSPE-stations were calculated from the average of the single marks for each exam item with equal weighing. The total scores of the OSPE-stations 1-6 were compared through using variance analysis with repeated measurements, whereby the participant or reference group and the respective OSPE station were defined as fixed factors [24]. Post hoc, the Tukey test was used [9].

Station No. 7 as station for patient positioning in the drag-stretcher does not occur in the public paramedic rescue service and is therefore excluded from the comparison. Different material from the mine rescue brigade and public rescue service test groups was modified for the OSPE to the extent that only known material was used in each group (e.g. replacement of the sternal intraosseous access set of mining rescue brigade by the standard intraosseous drilling machine in public rescue service).

Finally, a subgroup analysis differentiating the level of training and experience of the public rescue service was calcutated using the described method.

Results

The standardized medical-tactical rescue scheme developed for underground operations is shown in **Fig. 1**, the principal approach according to the cABCDE-algorithm was modified.

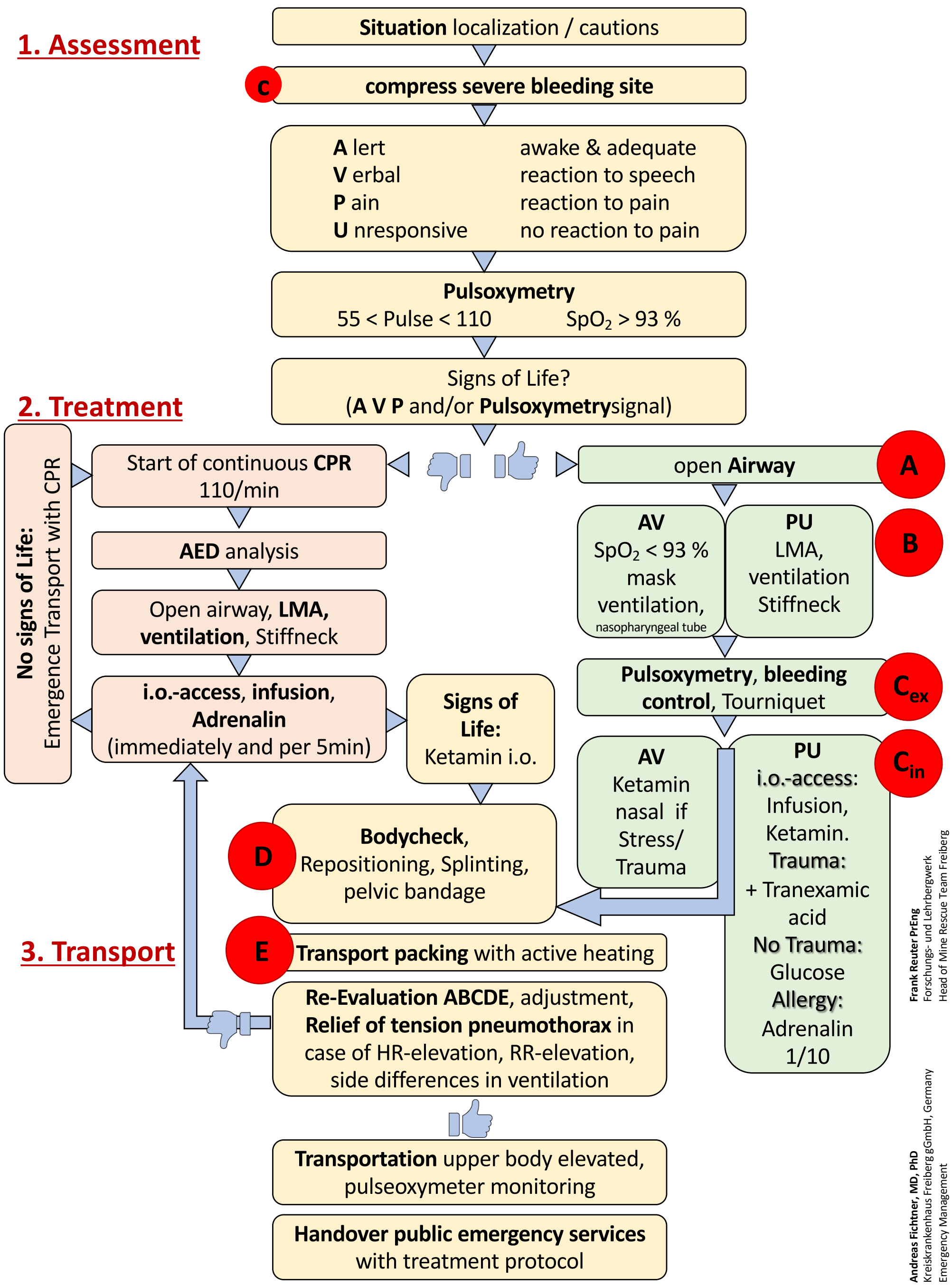


Fig. 1: Tactical Medical Rescue scheme with modified cABCDE-algorithm for mining rescue. This flowchart is part of the equipment as laminated guideline through the treatment process.

The matching modified equipment meeting the requirements outlined in the methods section is shown in **Fig. 2.** All equipment except for the rolled drag-stretcher cocoon is stowed in the pictured backpack in a process-oriented manner and has the external dimensions of 47 × 36 × 26 centimetres and a total weight of 12.5 kilograms. A rescue foil for passive heat preservation was glued into the stretcher cocoon and a modified Hibler-heat-pack was integrated into the rescue system as an active heat pad.

Fig.2: Standardised tactical medical equipment during patient rescue – left: stored in the 47cm-backbag, right: in use at a patient simulator with semi-closed drag-stretcher: **1.** Backbag front with examination gloves, universal rescue cutting tool (Leatherman Raptor), permanent marker and documentation card. **2.** Side bag with 5cm silk plaster tape, compresses and disinfection; **3.** Side bag with Celox and Z-Gauze and material for temperature preservation (Silber-Gold-Foil, active chemical warming pad), inner bag with pelvic bandage, 2x tourniquet, 2x SAM-splint **4.** Outer bag with mask and silicon head belt for non-invasive ventilation; **5.** LMA Supreme sizes 4 + 5 incl. accessories; **6.** I.O.-access, infusion system incl. accessories, Gelatine-4%-solution; **7.** Nasopharyngeal tube size 24Ch, thoracic decompression needle 14G; **8.** AED (Schiller Easyport), Adrenaline; **9.** Ampoule case with tranexamic acid, Ketamine S, Glucose and second Gelatine-4%-solution; **10.** Ventilator (Oxylator FR 300 B), oxygen tank 2L, manual suction, Stifneck, ventilation bag (Pocket BVM) and Pulseoxymeter with cable and circular finger sensor.

In consideration of maximizing user safety and reducing training requirements, difficult, time-consuming and exercise-intensive tasks were substituted, e.g. intravenous access was omitted and sternal intraosseous access (EZ-IO T.A.L.O.N.) was used instead. Further advantages of a sternal intraosseous access are easy securing and accessibility during transport.

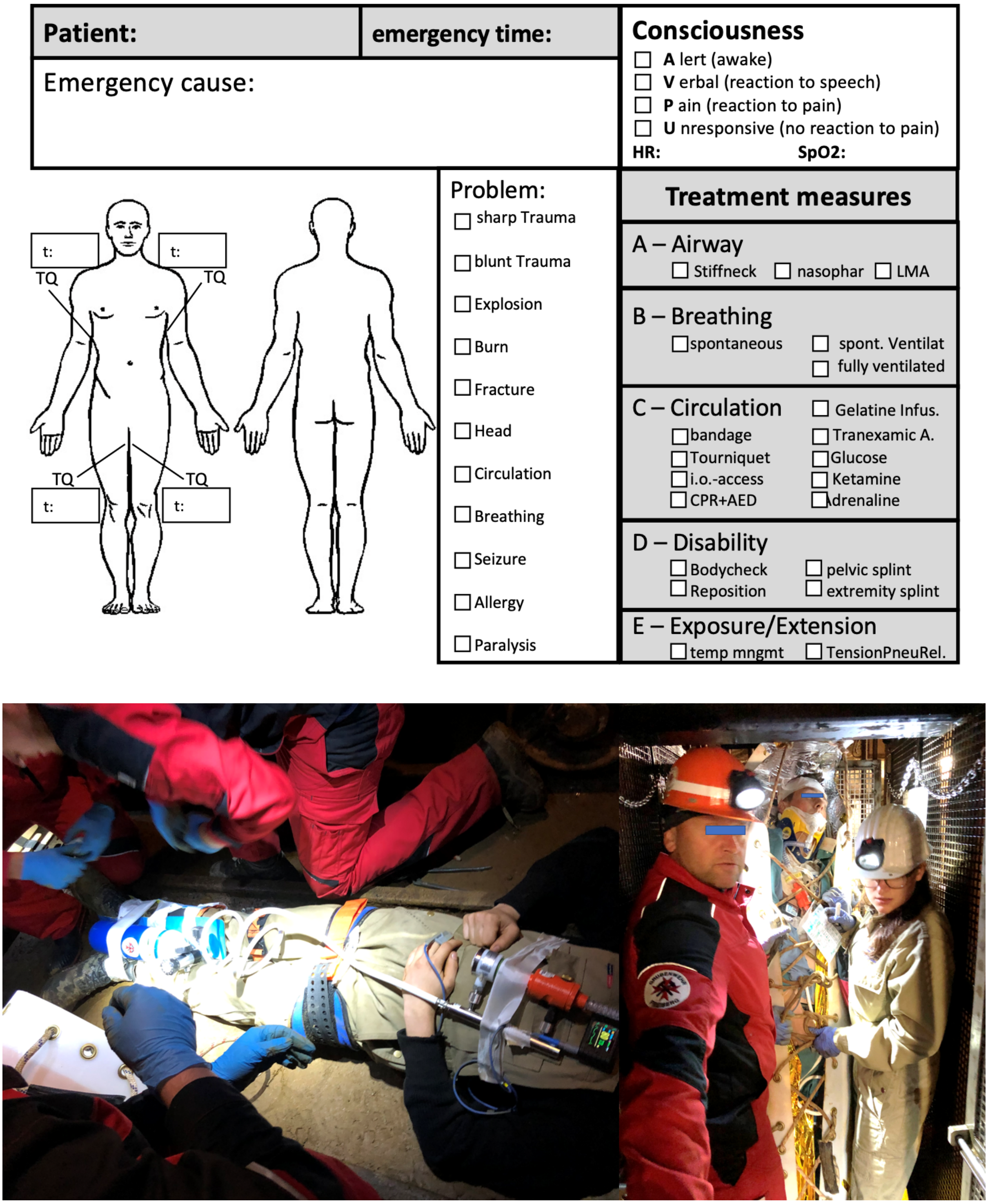
A fully deaerated colloid infusion was placed under the buttock, avoiding gravity installation and increasing flow rate by the patient's own weight.

An OXYLATOR FR 300B with the corresponding demand valve (CPR Medical Inc., Canada) was used for pressure-controlled ventilation or rather ambient-air-independent pressure-supported spontaneous breathing. At patient side, a stable inflatable rubber mask was used noninvasively, and a laryngeal mask (LMA) Supreme (sizes 4 and 5) was used invasively because it has a more robust cuff and superior placement and sealing properties compared to other supraglottic airways [21].

For transportation, all relevant medical equipment (defibrillator, pulse oximeter, ventilator and injection port of the i.o. access) was fixed in the sternal area, so that the operability and the overview of the vital functions is guaranteed at any time. For the fixation of all equipment, only 5 centimetres wide silk-plaster strip was available for reasons of resistance to moisture and dirt.

The choice of medications was limited to 4% Gelatine solution (2 bags of 500 ml), Tranexamic Acid (2 vials of 500 mg), Ketamine S (3 vials of 50 mg), Epinephrine (3 vials of 1 mg), and glucose 40% (3 vial of 10 ml). In this context, to avoid errors due to stress and limited expertise, the drug vial sizes were selected in such a way that always a complete ampoule is administered at a time for the adult patient.

A laminated patient attachment card in A5 format was developed to document any provided treatment measures in the most easiest way (**Fig. 3**).


Patient: | emergency time:

Emergency cause:

Consciousness
- ☐ A lert (awake)
- ☐ V erbal (reaction to speech)
- ☐ P ain (reaction to pain)
- ☐ U nresponsive (no reaction to pain)

HR: SpO2:

t: TQ | t: TQ | TQ t: | TQ t:

Problem:
- ☐ sharp Trauma
- ☐ blunt Trauma
- ☐ Explosion
- ☐ Burn
- ☐ Fracture
- ☐ Head
- ☐ Circulation
- ☐ Breathing
- ☐ Seizure
- ☐ Allergy
- ☐ Paralysis

Treatment measures

A – Airway
☐ Stiffneck ☐ nasophar ☐ LMA

B – Breathing
☐ spontaneous ☐ spont. Ventilat ☐ fully ventilated

C – Circulation
☐ bandage ☐ Tourniquet ☐ i.o.-access ☐ CPR+AED ☐ Gelatine Infus. ☐ Tranexamic A. ☐ Glucose ☐ Ketamine ☐ Adrenaline

D – Disability
☐ Bodycheck ☐ Reposition ☐ pelvic splint ☐ extremity splint

E – Exposure/Extension
☐ temp mngmt ☐ TensionPneuRel.

Fig. 3: Laminated documentation card for fast summary of the emergency situation and relevant treatment measures. This card is for handover to the public emergency rescue services. Down: Ventilated patient with monitoring, intraosseous access, pelvic bandage and plaster-tape-fixed equipment just before transfer to the drag-stretcher (left) and later in vertical ventilated transport in a narrow mine lift (right).

The training curriculum, developed for the training of the treatment scheme as well as the use of the corresponding equipment was optimized in terms of medical didactics and was subdivided into 7 areas of competence, which were taught sequentially using a modified Peyton method [16] (**Tab. 2**). Training and scenarios took place entirely underground in realistic conditions of the working environment.

Areas of Competence	Content
Initial Assessment	c-AVPU-ABCDE process chain, Pulseoxymetry, provisional bleeding control
BLS with AED	CPR-algorithm, AED-usage without ventilation
A,B	Ventilation with mask / head belt and ventilator, nasopharyngeal airway, Laryngeal mask insertion
C-out	Bodycheck, definitive bleeding control, Tourniquet
C-in	Mucosal Atomization Device, sternal intraosseous-access, Gelatine-Infusion, drugs (Tranexamic Acid, Adrenaline, Ketamine S, Glucose)
D	Repositioning, Splinting, pelciv bandage, relief of tension pneumothorax
E	Reevaluation-ABCDE, Transport bedding and strategic equipment fixation, body temperature preservation

Tab. 2: en-bloc skills training units following the cABCDE-principle for teaching the practical competencies of the developed treatment algorithm.

Comparison of the test results of the practical skills between intervention group mine rescue brigade and reference group public rescue service

The comparison revealed clear subgroup differences within the reference group paramedic. The reference participants with the qualification level “Rettungssanitäter” (lowest training level) performed worse ($p< 0.001$) than the remaining participant groups with the qualification levels “Notfallsanitäter”, “Notfallsanitäter”- in training, and “Rettungsassistenten”, especially in the skills stations 1,4, 5, and 6 (**Fig. 4**). No difference was found between “Notfallsanitäter”, “Rettungsassistenten” and “Notfallsanitäter”- in training ($p> 0.05$; **Fig. 4**).

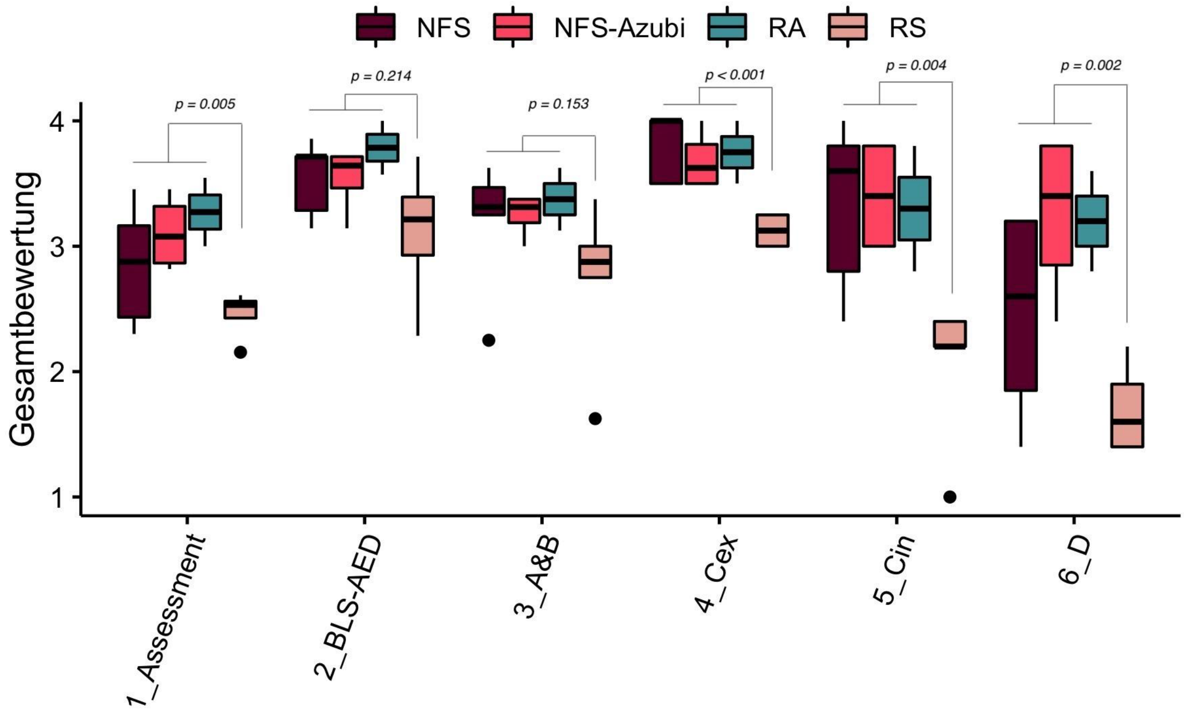


Fig. 4: Comparison of OSCE results within the control group with median (bold line), upper and lower quartiles (box) as well as maximal and minimal scores (whiskers).

Therefore, for further evaluation, an overall reference group of “Notfallsanitäter”, “Notfallsanitäter”- in training and “Rettungsassistenten” was formed, hereinafter to be referred to as group of paramedics - while the “Rettungssanitäter” were considered as a separate group.

Comparing all test items across OSPE Stations 1-6, the mine rescue intervention group (M = 3.42; CI95% = [3.24; 3.60]) scored the same as the paramedic group (M = 3.28; CI95% = [3.09; 3.46]) but significantly better than the „Rettungssanitäter”-group (M = 2.43; CI95% = [2.10; 2.77]).

In the individual analysis of the OSPE stations (**Tab. 2**), the two groups mine rescue team and „Rettungssanitäter” differed in stations 3, 4, 5, and 6, and the groups mine rescue team and paramedics only in station 6 (**Fig. 5**; **Tab. A1** to **A3** in the online supplementary material).

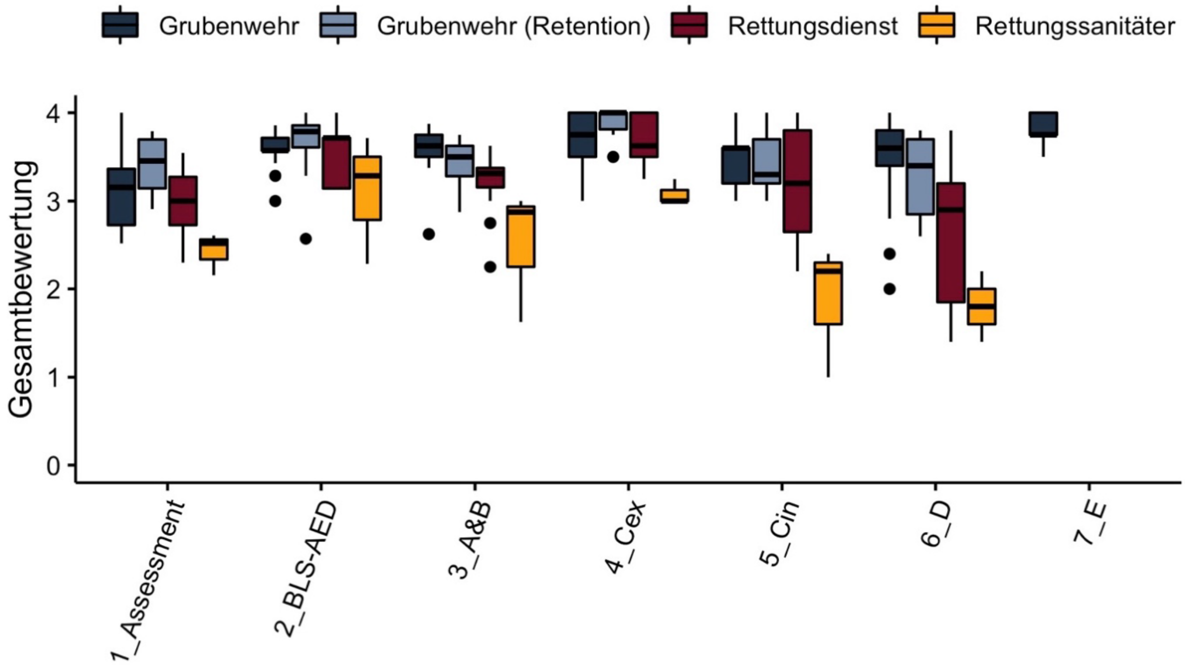


Fig. 5: Comparison of OSCE results between mine rescue teams (Grubenwehr), their skill retention level 6 months after the course without further training and their reference groups advanced public emergency rescue servicesw (Rettungsdienst) and lowest public emergency rescue level (Rettungssanitäter), each for the average scores of a complete OSPE-station (A-D of the cABCDE-algorithm). Boild line = median score, upper and lower quartile = box, minimal and maximal scores = whiskers.

After a 6-month interval without any training, the trained mine rescue team members underwent again the identical OSPE examination. The final results (M = 3.54; CI95% = [3.31; 3.73]) showed neither a difference to the results of the mine rescue team immediately after training nor to the reference group paramedic rescue service.

Discussion

During the development of this treatment, equipment and training concept, procedures were adopted from the military and civilian sectors and adapted to the needs and requirements of the mine rescue service in regards to special conditions underground. We were able to show that it is possible with a one-time, standardized, medically didactically optimized practical, two-days training duration to achieve a level of competence that is comparable to the standard of patient care in the public paramedic ambulance service. Retention measurements by means of follow-up tests after 6 months without intermittent training showed a stable level of competence.

Our training concept for the qualification of medical laypersons in mining rescue consists of teaching a relatively simple treatment algorithm under combination of the AVPU and c(x)ABCDE scheme [14]. Within this scheme, especially developed practical skills are specifically assembled for complexity reduction. Comparable studies for effect quantification of one-time teaching of less complex medical-practical skills using a didactically optimized curriculum achieve similar results [8], whereby complex acute medical skills require a significantly higher amount of practice [13]. In the final scenarios of the developed trainings, very realistic simulations were performed using standardized patients, which some participants did not recognize as exercises.

The limiting factor is that the clinical performance in the interaction of the practical learned skills was only tested qualitatively in the final scenarios. In the process, all mine rescue teams were able to independently, fluently, and correctly apply their practical skills within the described tactical medical rescue scheme so that the standardized patient was sufficiently treated and ready for transport within 15 minutes. The oxygen supply (2 l; 200 bar; 3.5 kg steel) was just sufficient and could be optimized by a 300 bar composite cylinder. Quantitatively, only the competence level of the individual practical skills could be tested. However, this was also the case in the examination of the reference group public rescue service. Therefore, experiences with the use of the learned course content in clinical reality is still pending.

However, medical-tactical rescue by the mine rescue team is to be performed only as an emergency competency until handover to public emergency medical services and within the frame of the mediated treatment algorithm. Based on the results to date, compared to the alternative - salvage only without medical intervention - the risk of poor patient outcome after use of acquired medical skills by mine rescue personnel should be significantly minimized.

Approval procedure

The obligation of employers to ensure emergency medical care results from law section 11 (1) Nos. 4 to 7 ABBergV, Germany [17]. The type and scope of the measures are to be determined within the framework of the company-related hazard analysis and included in the company emergency plan in accordance with Section 11 (1) No. 6 ABBergV [17]. The approval of the planned measures is granted by the responsible approval authority, in Saxony, for example, by the Saxon Upper Mining Authority. This can be done in the form of a special operating plan (SBP), which is submitted by the respective contractor or in case of common mine rescue service on a cross-company basis. If there is no independent SBP, the operational regulation for medical first aid is the subject of the main operating plan according to Section 55 (1) No. 3 BBergG [4]. The content is a detailed description of the possible scope and utilization of the mine rescue team, which also includes the personal qualification for first aid measures. To assess these requirements, reference can be made here to a standardized education and training concept for precisely defined measures of medical first aid, as developed in this paper.

The extended operational capability of the mine rescue team for emergency measures, that is otherwise reserved for emergency paramedics and doctors, remains, however, subordinately with respect to the latter, as it is only justified in an emergency situation.

In the event of an emergency, it must always be weighed up whether the indicated measures can be carried out by an emergency physician, whether a consultation or instruction by a physician can be made available via suitable communication channels or whether, in order to avert an immediate danger to the life and health of an accident victim, the qualified mine rescue team must act within the scope of its acquired emergency competence.

Conclusion

This validated training concept can serve as a basis for the submission of the special operating plan and as a template for accident insurance institutions to close the gap of extended first aid in mining, that was not existing up to date, and to define a current validated and standardized definition and level of the generally accepted rules of medical aid, training and rescue techniques in mining. It also meets the basic requirements for comparable environments with difficult access to personnel and materials, e.g. in forestry, mountain rescue, power line- and wind turbine construction.

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