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ORIGINAL PAPER

Evaluation of ventilation quality conducted by firefighters during simulated cardiopulmonary resuscitation

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ABSTRACT

INTRODUCTION: High-quality ventilation in unconscious victims is a priority action for first responders at the scene. Firefighters often arrive first at the scene, providing medical assistance at the level of qualified first aid (QFA). This research aimed to evaluate the quality of ventilation using supraglottic methods with and without visual feedback and self-inflating bags during simulated cardiopulmonary resuscitation (CPR) performed by members of the State Fire Service (SFS).

MATERIAL AND METHODS: A cross-sectional study was conducted in organizational units of the State Fire Service (SFS) in the Lubelskie and Warmińsko-Mazurskie voivodeships (24-hour duty officers). 112 firefighters aged 26–48 years (Mean 33.1; SD 6.7), with service duration of 1-20 years (Mean 7.3; SD 4.7) participated in the study. The study involved a 2-

minute supraglottic ventilation (self-expanding bag + I-gel mask, size 4: 50–90 kg). Subsequently, 2-minute ventilation was conducted with the effectiveness visible on the monitor in real-time. The following ventilation variables were recorded: frequency (per minute), the volume of each inhalation (mL), and the ratio of correct to incorrect single inhalations (%).

RESULTS: It was shown that in stage 1, firefighters more often ($P < 0.001$) performed ventilation at an excessively high frequency (max rate = 14 ± 4) compared to stage 2 (max rate = 11 ± 1). A statistically significant influence of the possibility of assessment and correction of rescue actions in real-time on the correct frequency (% correct – rate = 52.3 ± 30.1 vs 91.4 ± 12.1; $P < 0.001$) and ventilation volume (% correct — V = 40.6 ± 28.2 vs 85.3 ± 15.0; $P < 0.001$) was demonstrated. No statistically significant impact of service duration and age on evaluating parameters in stages 1 and 2 was shown.

CONCLUSIONS: Software assistance and the possibility of real-time feedback significantly improve the quality of ventilation conducted by firefighters using SAD. More training using elements of medical simulation with visual feedback should be introduced so that firefighters improve ventilation quality under realistic conditions. Consideration should be given to including tools for assessing CPR quality in CPR rescue kits, especially in units that, according to statistics, handle a larger number of EMS interventions.

KEYWORDS: airway patency; emergency medical rescue; ventilation; SAD; firefighting and rescue operations

INTRODUCTION

High-quality ventilation in unconscious victims is a priority action for first responders at the scene. Firefighters often arrive first at the scene, providing medical assistance at the level of qualified first aid (QFA). These entities rely on rescue procedures to assist both trauma and non-trauma victims. For QFA procedures, firefighters utilize rescue kits described in the "Principles of medical rescue organization in the National Fire and Rescue System" [1].

Medical kits for firefighters allow for cardiopulmonary resuscitation (CPR) and maintaining open airways in unconscious victims using supraglottic methods (SAD) [2]. This ensures a higher quality of ventilation for the victim while waiting for the State Medical Rescue (SMR) units, which are equipped with superior equipment as the leading service in medical rescue and stocked with resuscitation drugs. Firefighters cooperate with SMR without having statutorily equipped drugs [3].

Interventions where firefighters conduct medical operations independently before the SMR arrives are classified as isolated medical rescue events (IMRE). This includes situations when dispatching a SMR ambulance is not feasible, or when the expected ambulance arrival time is considerably longer than the time of arrival for a Fire Protection Unit (FPU). The deployment of firefighters then occurs upon request of a medical dispatcher (MD) via a command post (CP), which is equivalent to MD in the SMR system. IMRE criteria also encompass firefighter interventions when, upon returning from their operations or exercises, they notice or witness situations requiring QFA procedures implementation [4].

Properly securing the airway patency of a victim in sudden cardiac arrest (SCA) is a priority action in pre-hospital rescue due to the short time reserves of progressing hypoxia [5]. SAD methods offer an effective alternative to airway clearance and ventilation to intubation, which is considered the "gold standard" and provides the highest level of airway security [6]. Firefighters do not perform intubation procedures due to the limited number of firefighters with medical training, resulting in a lack of systematic training and the absence of this method in equipment sets.

The number of medics in the State Fire Service (SFS) is about 2,200 firefighters [7], accounting for approximately 7% of the 32,000-strong population of professional firefighters [8].

This research aimed to assess the quality of ventilation using supraglottic methods with and without visual feedback and self-inflating bags during simulated cardiopulmonary resuscitation carried out by SFS officers.

MATERIAL AND METHODS

Research design

A cross-sectional study was conducted in organizational units of the SFS in the Lubelskie and Warmińsko-Mazurskie provinces (Poland) among officers serving in combat divisions. The study population consisted of 112 firefighters aged 26–48 (Mean 33.1; SD 6.7), with a service length of 1–20 years (Mean 7.3; SD 4.7) who take direct part in firefighting and rescue operations. The largest group consisted of firefighters with 1–5 years of service (n = 42). Daily service officers (i.e., 8-hour shifts) and civilian employees were excluded from the group. The study was conducted from 1.12.2022 to 25.04.2023.

Research setting

The study was dedicated to firefighters who do not simultaneously practice medicine and who do not have daily experience with rescue kits, including supraglottic methods for airway clearance and ventilation with a self-inflating bag.

Study procedure

The research was conducted using a training station (adult mannequin Rescue Anne QCPR Airway Head + cardiomonitor Zoll X Series Advanced with a ventilation quality measurement sensor Accu Vent). Each officer underwent preliminary instruction to fully understand the study scenario. Each firefighter participating in the study had to conduct victim ventilation (simulation-mannequin) in two stages (each lasting 2 minutes). For research and statistical calculations, the study time was expressed in seconds:

— stage 1: T1 measured in seconds (T1 max = 120 seconds), parameter abbreviations used in tables and figures in the Results chapter: volume V1, frequency R1;

— stage 2: T2 measured in seconds (T2 max = 120 seconds), parameter abbreviations used in tables and figures in the Results chapter: volume V2, frequency R2.

In both stages, the effectiveness of the conducted ventilation was assessed using two parameters determining ventilation quality:

— ventilation volume,

— ventilation frequency asynchronously to chest compressions, taking into account supraglottic methods.

Additionally, the software (Real Bag Valve Mask (BMV) Help in Zoll X Series Advanced) allowed the calculation of the ratio of correct breaths to all performed during the two-minute stage. The study assumed asynchronous CPR ventilation for an adult weighing around 65 kg. The correct values based on guidelines calculated 6–8 mL per kilogram of body weight [9]:

— volume: standard 500 mL (tolerance: –10%; +10%) — breaths within 450–550 mL were recognised as correct by the algorithm,

— frequency: standard 10/min (tolerance: –10%; +10%) — frequency 9–11/min. was recognised as correct by the algorithm.

Differences between stage I and II:

— stage 1: ventilation without the possibility of real-time rescue operation assessment,

— stage 2: ventilation with real-time assessment and correction capability, thanks to the use of a monitor/defibrillator equipped with a ventilation measurement module for BVM.

Measurements cover two values showing the correctness of the conducted ventilation: the volume administered to the patient and the frequency of administered substitute/supplementary breaths. Data recording and storage were ensured by a flow sensor located at the exit of the breathing mixture from the self-inflating bag before the patient's mouth, regardless of the method of ventilation (face mask, laryngeal tube, laryngeal mask, tracheal tube).

Each participant in the study went through stage 1, then stage 2, in which the defibrillator was turned with its screen facing the subject so that they could correct its operation in real-time (real-time visual feedback described in Fig. 1). The results and quality after stage 1 obtained were not discussed to avoid a false positive effect in terms of improving quality in stage 2.

Chest compressions were not considered in the study, and they were not performed. The anticipated break between stages 1 and 2 was 2 minutes, related to saving activity in the cardiometer memory activating the data collection module and connecting the sensor to the ventilation set. The study was conducted in normothermia (room temperature) and standard air humidity conditions. These conditions were achieved in a heated medical training room at the Training Center of the SFS Provincial Headquarters.

Ethical considerations

The study was conducted in accordance with the Helsinki Declaration, and the protocol was approved by the Ethics Committee No. 16/2022 ABNS. Firefighters participating in the study remained anonymous. The study was voluntary, and participants were informed about this. In September 2022, permission was obtained from the Voivodeship Commander of the SFS in Lublin and Olsztyn to conduct the study in the regions.

Intervention records

For the purpose of the study, a database was created in which the following sociodemographic data of the participants were collected: age, gender, and length of service. The results were interpreted based on an automatically created database of each activity at the workstation. The pattern for interpreting the results is shown in Table 1.

Statistical analysis

Results concerning quantitative variables were presented as average values ± standard deviation. Qualitative variables were presented as quantity (n) and percentage values of the whole group (%). The normality of the distributions was tested with the Kolmogorov-Smirnov test. As the parametric tests did not meet the criteria, nonparametric tests were used in the study. A Wilcoxon matched-pairs test (non-parametric test) was used in the comparative characteristics (stage 1 vs stage 2). In the comparative analysis of length of service and age and ventilation efficiency, Spearman's rho correlation coefficient was applied to detect and describe the strength and direction of correlations. Statistica 13 software (StatSoft Inc., Tulsa, OK) was used in the statistical analysis. $P < 0.05$ was adopted as the significance level.

RESULTS

112 firefighters aged 26–48 (Mean 33.1; SD 6.7), with a service length of 1–20 years (Mean 7.3; SD 4.7) participated in the study. The largest group consisted of firefighters with 1–5 years of service (n = 42). Statistically significant differences were demonstrated between the effectiveness of the ventilation performed in stage 1 and stage 2. It was shown that in stage 1, firefighters statistically more often ($P < 0.001$) ventilated with too high frequency (max rate = 14 ± 4) compared to stage 2 (max rate = 11 ± 1). The analysis of the correct frequency showed a statistically significant effect of real-time assessment and correction on the correct frequency (% correct — rate = 52.3 ± 30.1 vs 91.4 ± 12.1; $P < 0.001$) and volume of ventilation (% correct — V = 40.6 ± 28.2 vs 85.3 ± 15.0; $P < 0.001$) — Table 2.

In the analysis, no statistically significant impact of subjects' service length and age on assessing the parameters of ventilation effectiveness was demonstrated, both in stages 1 and 2.

DISCUSSION

The presented study with an element of medical simulation allowed us to evaluate how modern medical equipment and new technologies can influence the quality of rescue operations, in this case, Basic Life Support (BLS) executed by firefighters. A cardiac monitor with ventilation or chest compression assessment (assistant) is not commonly used among firefighters. Participation in the study was also a good opportunity for the officers to recall more challenging BLS procedures, which are rarely used in their practice.

A crucial aspect of firefighter skills is the training system, obtaining certifications, and maintaining BLS qualifications. BLS recertification is conducted every three years for every firefighter, excluding those with a medical background, who undergo professional medical improvement in accordance with the SMR Act. The present study did not consider whether the officer has a medical education in the achieved quality of ventilation [10].

Several factors influence the quality of pre-hospital ventilation: maintaining open airways, selecting the appropriate method and size of the device, atmospheric conditions, and the skills and experience of the rescuer. This study evaluated the baseline skills of a rescuer vs the skills of an assistant in the cardiac monitor. Several other studies describe supraglottic methods as alternatives to tracheal intubation, e.g., Soar et al. [11] in the European Resuscitation Council (ERC) guidelines review describes the sequence of advanced activities

(ALS) during CPR: defibrillation, airway clearance, oxygenation and ventilation, circulatory support, monitoring, drugs.

Länkimäki et al. [12] define activities related to ventilation as airway management to ensure sufficient gas exchange which is of paramount importance. This includes intubation and SAD methods, including laryngeal mask airways (LMA). The described techniques fit the criteria of the present study, i.e., using SAD when intubation is not possible in firefighters' practice.

Enterlein et al. [13] emphasize the time of effective airway clearance and maintaining their patency, as well as the role played by the knowledge and experience of rescuers. Effectively clearing the airways requires knowledge of respiratory anatomy, equipment familiarity, and manual dexterity from rescuers, and achieving open airways should take up to 30 seconds. The present study did not consider such criteria, although it is essential to assess airway clearance by firefighters in relation to time criteria in the future.

Improper ventilation is associated with impaired haemodynamics and leads to increased morbidity and ultimately, mortality. Hyperventilation results in decreased PaCO2, leading to the constriction of central nervous system vessels and reduced brain blood flow, which causes brain tissue damage. Research results from O'Neill et al. show that hyperventilation is mainly the consequence of excessive ventilation frequency rather than excessive volume [14].

To understand factors that might affect the efficacy of manual ventilation, one should fully investigate operator characteristics, including hand size and grip strength. Studies by Sall et al. indicate that the size of the hand gripping the bag is particularly important, especially for novice medical staff, firefighters, and first aid volunteers. Individuals with larger hands tend to hyperventilate, while those with smaller hands tend to hyperventilate more often. This factor was not considered in the aforementioned studies, but it is worth noting in the future [15].

American firefighters also possess medical equipment and victim care procedures. Bolland et al. [16] describe firefighters' independent interventions before medical teams arrive and the use of procedures, including the use of SAD (325 cases of cardiac arrest), ventilation, defibrillation, and resuscitative pharmacotherapy. Polish firefighters' medical rescue kits are not equipped with pharmacology, yet they complement the SMR system, implementing ALS-level procedures while waiting for medical teams, which can improve prognosis in many cases.

Tymiński points out the competency gap of BLS rescuers that could enhance the quality of firefighters' medical interventions, indicating, for instance, the inability to monitor victims, and access intravenous therapy, intravenous, intramuscular, and inhalation pharmacotherapy. Higher standards are achievable with an increasing number of firefighters with medical education in service. Additionally, as the authors suggest, supplementary training for BLS rescuers should focus on practical exercises, using high-fidelity medical simulation [17].

The increasing number of medical interventions, including assistance to SMR entities and IMRE as independent interventions, means that medical rescue within the structures of SFS should develop with new equipment, procedures, and qualified staff to implement BLS procedures and experienced instructors for training [18].

Madziała [19] highlights that firefighters are the leading rescue service in Poland, often being the first to undertake BLS actions and importantly, operate in danger zones, implementing medical care during the evacuation of victims from hazardous areas where medical teams lack access due to security measures.

Activities beyond BLS can be performed by firefighters with medical rescuer qualifications, as noted by Krzyżanowski [20]. This is enabled by the amendment to the SMR Act [21]. According to the amendment, a medical rescuer can work professionally in entities other than SMR e.g., fire protection units. Among the 2015 changes, the range of activities and equipment was expanded, including instrumental airway clearance techniques, which are consistent with the methodology of the present study. 2015 can be seen as the beginning of the use of SAD in the fire brigade in Poland.

The use of SAD in the Polish police is described by Bielecka in the context of BLS training in police schools, with particular emphasis on supraglottic methods. The author lists BLS course participants, which can include firefighters, police officers, and specific civilian groups. Internal regulations obligate police officers to provide BLS, training, and recertification of qualifications, similar to professional and volunteer Polish firefighters [22, 23].

Limitations

The study has limitations related to the small population that participated in it. It would be interesting to compare firefighters after the CPR course versus firefighters with medical education. This could be a future study concept using this methodology. The quality of other key elements of resuscitation was not assessed:

— the effective time of establishing the supraglottic method (I-gel mask, size No. 4 — for an adult weighing 50–90 kg),

— chest compressions.

The order of study stages was intentional (stage 1 vs stage 2). The aim of the study was not to assess the effectiveness of ventilation itself, but mainly the impact of monitoring equipment on ventilation results. To achieve this, a study was performed using two series of results as related (dependent) variables. This pairing and calculation of differences gives us information about the difference in the results of the examined people than the information which would be obtained using two separate groups (student t-test for unrelated variables). Undoubtedly, the use of randomization would have a beneficial effect on minimizing the effect of familiarization with the mannequin. Due to the fact that stages I and II were not randomized, which would improve the quality of the study (minimizing the familiarity effect), this concept may be used in the future in studies on a larger population of firefighters (in other regions of Poland).

CONCLUSIONS

The practical utilization of medical equipment should be regular to maintain the initial skills at a high level before facing more challenging real-life operations where stress, difficult terrain and weather conditions, as well as time pressure, are encountered. It is necessary to introduce more training and practical exercises utilizing elements of medical simulation so that firefighters can practice the most difficult CPR procedures in conditions that are as realistic as possible. Software assistance and the possibility of real-time feedback significantly improve the quality of ventilation conducted by firefighters using SAD in terms of observed parameters. It is worth considering including in the composition of CPR rescue kits tools (devices) for assessing the quality of CPR, primarily in units that, according to statistics, carry out a larger number of independent medical rescue interventions.

Article information and declarations

Data availability statement

Original contributions presented in the study are included in the article — section 'Results'. The data that support the findings of this study are available from the corresponding author, L.Cz, upon reasonable request.

Ethics statement

The study was conducted in accordance with the Helsinki Declaration, and the protocol was approved by the Ethics Committee No. 16/2022 ABNS. Firefighters participating in the study remained anonymous. The study was voluntary, and participants were informed about this.

Author contributions

Work concept and design, L.D.; data collection and analysis, L.D, M.K., T.K., K.M.; responsibility for statistical analysis, L.C.; writing the article, L.D., M.K.; critical review, L.D., R.K.; final approval of the article, L.C.

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Conflict of interest

The authors declare no conflicts of interest.

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Table 1. Method of result interpretation — data presented by the software, an example of 1 minute of study implementation for a randomly selected firefighter

Activity time**	Interval in seconds	Calculated frequency	Rating	Calculated volume	Rating
xx.xx.2023 11:47:**59**	6	10	T	429	F
xx.xx.2023 11:48:**05**	6	10	T	470	T
xx.xx.2023 11:48:**11**	5	11	T	458	T
xx.xx.2023 11:48:**16**	5	11	T	480	T
xx.xx.2023 11:48:**21**	5	12	F	407	F
xx.xx.2023 11:48:**25**	4	13	F	468	T
xx.xx.2023 11:48:**31**	6	10	T	475	T

F —false: a single breath counted as incorrect; T — true: single breath counted as correct; xx — full date not given, protection of group personal data. On the basis of the ratio of ventilation marked T to all attempts in the 2-minute stage, the percentage of correct breaths was calculated

**Seconds are described in a bold font to draw attention to the essence of the record. The exact time of subsequent activities was automatically converted into frequency by the software. The algorithm of the program took into account the frequency of the commenced activity and the time of execution of each ventilation, therefore, comparing the same interval values (seconds), it calculated a different minute frequency

Table 2. Univariate comparison of ventilation frequency and volume

Parameter	Stage 1	Stage 2	Z-value	Effect size-r_C	P
Rate	11 ± 3	10 ± 1	4.217	0.404	< 0.001
Min rate	8 ± 3	9 ± 1	3.532	0.368	< 0.001
Max rate	14 ± 4	11 ± 1	7.535	0.781	< 0.001
% correct – rate	52.3 ± 30.1	91.4 ± 12.1	8.741	0.861	< 0.001
Volume	520.6 ± 85.4	520.9 ± 31.0	0.294	0.028	0.769
Min V	412.7 ± 115.2	462.8 ± 47.2	4.371	0.415	< 0.001

Max V	626.2 ± 118.3	570.5 ± 37.0	4.919	0.471	< 0.001
% correct V	40.6 ± 28.2	85.3 ± 15.0	8.572	0.814	< 0.001

Max — maximum; Min — minimum; V — volume

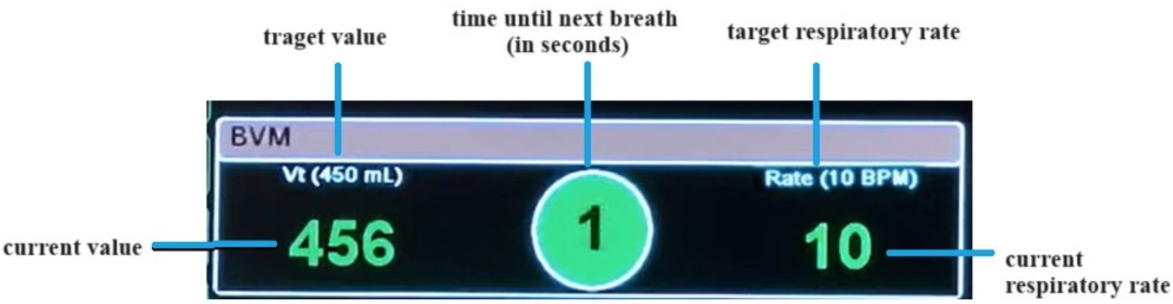

FIGURE 1. Visualization of the feedback in real time — stage 2 (visible on the cardiomonitor screen)