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QUALITY OF BAG-VALVE-MASK VENTILATION IN ADULTS: A COMPARISON OF PARAMEDIC AND NURSE PERFORMANCE

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ABSTRACT

INTRODUCTION: Oxygen delivery is an essential skill required for healthcare providers. The quality of ventilation affects patient survival. The purpose of this study was to analyze the quality of manual ventilation delivered with a bag-valve-mask (BVM) device by paramedics and nurses in relation to their clinical experience and self-assessment.

MATERIAL AND METHODS: A prospective experimental comparative simulation study was designed. Two hundred healthcare workers were invited (100 paramedics and 100 nurses) to manage an adult respiratory arrest scenario and perform a 4-minute manual ventilation cycle. Ventilation parameters were assessed with SimMan 3G human patient simulator. Data on demographics, occupation, clinical experience, and self-assessment of conducted ventilation were collected through a questionnaire.

RESULTS: Statistically significant differences in gender distribution across professions ($p < 0.001$), relationship between experience and occupation ($p = 0.018$), and frequency of ventilation within a year ($p < 0.001$) were observed. The median value for self-assessment in skills was 3 for nurses and 4 for paramedics. The average tidal volume in nurses was 394.6 mL and 390.1 mL in the paramedics group ($p = 0.674$). The mean ventilation rate was 10.4 bpm and 8.9 bpm respectively ($p = 0.013$). Only 4% of nurses and 1% of paramedics met the European Resuscitation Council (ERC) 2021 guidelines for manual ventilation. A statistically significant correlation was found between ventilation parameters and professional experience.

More experienced providers tended to ventilate faster (R = 0.158, $p = 0.025$) and with a higher volume (R = 0.265, $p < 0.001$).
CONCLUSIONS: Despite ventilations being performed by experienced personnel, ERC guidelines were met incidentally. It is recommended to pay more attention to BVM ventilation training even among experienced staff.
KEYWORDS: bag-valve mask; manual ventilation; BVM; performance; efficiency

INTRODUCTION

Oxygen delivery is a crucial skill required in the healthcare system. It depends on the clinical situation, the patient, and the skills of the healthcare provider [1]. In respiratory arrest situations, action is also required from personnel who are not trained in advanced airway management. Due to a lack of skills to perform endotracheal intubation or insert a laryngeal tube, manual ventilation with a bag-valve mask (BVM) is recommended to avoid critical complications or death [2].

The topic of manual ventilation has been discussed repeatedly in recent years, and the proficiency of hospital and prehospital staff in performing it varies. This can lead to challenges, such as the risk of hyperventilation [3, 4]. Ventilation performed with BVM is a mandatory method carried out by every healthcare provider regardless of level of training and personal experience. This crucial skill is a first-line treatment for patients with respiratory arrest in pre- and in-hospital environments [5–7].

The 2021 European Resuscitation Council (ERC) and 2020 American Heart Association (AHA) guidelines recommend delivering breaths at a rate of 10 breaths per minute in a respiratory arrest situation [8, 9]. Regarding tidal volume, ERC recommends 6–8 mL/kg. At the same time, AHA recommends 500–600 mL per one breath. There is a consensus that visible chest elevation serves as an indicator confirming proper ventilation.

High ventilation rates increase intrathoracic pressure, hindering right ventricle filling and output [10]. On the other hand, low rate and volume can result in hypoxemia, hypercapnia, and acidosis [11, 12]. Poor air delivery to the lungs leads to increased pulmonary vascular resistance and decreased blood flow through the lungs [13, 14]. Delivery of high tidal volume with high pressures or high rates can cause barotrauma and, therefore, pneumothorax, mediastinal emphysema, subcutaneous emphysema, and gastric distension with aspiration of gastrointestinal contents [15–18]. Minimizing these complications improves survival and oxygen delivery, underscoring the importance of precise ventilation guidelines.

In Polish ambulances and emergency departments, both paramedics and nurses work. The average age of a nurse in Poland is 54, making it one of the oldest professional groups in the healthcare system [19]. Paramedics are a younger professional group, and their pre-graduate and postgraduate training pathways are different.

Aim of study

This study aimed to analyze the quality of manual ventilation with BVM in paramedics and nurses as well as to determine its relationship with their clinical experience and self-assessment.

MATERIAL AND METHODS

Manikins

A SimMan 3G Human Patient Simulator (Laerdal Medical, Stavanger, Norway) was used to investigate the quality of manual ventilation. The manikin was operated by the Laerdal Education Application LLEAP (Laerdal Medical, Stavanger, Norway). To represent patients with healthy lungs, the parameters of the simulator were set as follows: Lung resistance: 0%, lung compliance: 100%. The maximum volume of the lungs was 1200 mL, and the maximum inspiration pressure was 80 cm H_2O.

Ventilation was performed with an Ambu Spur II BVM device (Ambu A/S, Ballerup, Denmark) with a reservoir capacity of 2600 mL and face mask no. 5 (Xiamen Composer Medical Tech. Co., Ltd, Xiamen, China). This device was standard equipment at the University Clinical Hospital in Poznan and the Provincial Ambulance Station in Poznan.

Protocol

The prospective experimental comparative simulation study was conducted in September 2024. Before the study, participants were briefed on the current ERC and guidelines for ventilation in adult respiratory arrest scenarios. Before the study commenced, participants were asked to complete a questionnaire including their age, gender, dominant hand, medical profession, and work experience. Additional questions addressed the annual frequency of performing ventilation with BVM. Participants were also asked to assess the quality of the ventilation they had performed so far and to report the average number of hours they worked per month (Supplementary material).

Next, participants were asked to perform 4 minutes of manual ventilation using a bag-valve-mask device. The manikin was placed on a hospital bed in a supine position, to simulate a healthy adult male of 80 kg weight and this information was also available for participants. Adjusting the bed's height to the individual's personal preferences before attempting ventilation was allowed. There was only one researcher in the simulation room. Time was measured using the LLEAP application. The researcher notified participants at the start of the study and upon the completion of the 4-minute cycle. Additionally, they were instructed to perform ventilation by ERC guidelines. Only manual airway maneuvers were allowed.

Participants

The study involved 200 volunteers (100 paramedics, 100 nurses) from the University Clinical Hospital and a Regional Ambulance Station in Poznan. Working as a paramedic or nurse in above mentioned facilities was the only criterion for inclusion in the study. Professional groups were informed of the planned study through mass media and internal hospital correspondence.

Variables

Ventilation outcomes

To assess the quality of ventilation, two parameters were selected: respiratory_rate (Vr, min^{-1}) and tidal volume (Vt, mL). Subsequently, the mean value for each participant was calculated over the entire ventilation cycle and compared with established guidelines. As the study was conducted in Poland, the authors referred to the guidelines of the ERC, which recommend a ventilation rate of 10 breaths per minute and a tidal volume of 6 to 8 mL/kg.

Self-assessment of ventilation skills

Self-assessment of conducted manual replacement ventilation was examined according to a five-point Likert scale, where 5 means very good, 4 — rather good, 3 — average, 2 — rather poor, and 1 is poor before the study.

Sample size estimation

Due to the lack of precise data on the number of paramedics working within the healthcare system in Poland, the study group size was estimated based on the number of participants in similar studies in European countries with comparable healthcare structures [20–22]. For this study, the size of the paramedic group was set at 100 participants. To ensure comparability of results, the nurse group was assigned the same size.

Statistical analysis

Qualitative variables such as gender, profession, and adequate ventilation were expressed as numbers and percentages (%). For quantitative variables, such as mean ventilation rate, mean respiratory volume, and age, the normality of data distributions was assessed using the Shapiro–Wilk test. Data were reported as mean ± SD for normal distributions and as median (IQR) for non-normal distributions. Differences were assessed using the Mann–Whitney U and chi-square tests. A simple linear regression was used to analyze the relationships between quantitative variables. P-values lower than 0.05 were considered statistically significant. Analysis was performed in STATISTICA v.13 (TIBCO Software Inc., USA). Regression was calculated with PQStat 1.8.6 (PQStat Software, Poland).

RESULTS

Study group

All included participants took part in the study and completed a 4-minute scenario. The median age was 32 years (IQR 26–42). The youngest participant was 21 and the oldest was 67 years old. Sixty-one percent of the participants were women. Among nurses, individuals without postgraduate training constituted the majority. Anesthetic nurses represented the second most numerous subgroup. As many as 40% of participants declared professional experience of more than 10 years. A low number of ventilations per year was reported by more than 57% of the respondents (detailed characteristics of the study group in Tab. 1).

Statistically significant differences in gender distribution across professions were observed ($p < 0.001$). Among nurses, the majority of respondents were women, in contrast to paramedics. The relationship between experience and occupation revealed a similar pattern, which was also significant ($p = 0.018$). For paramedics, the distribution of respondents across experience ranges was uniform. In contrast, the group of nurses displayed extreme results, with the highest numbers among the most experienced (n = 46) and the least experienced (n = 38). The frequency of ventilation within a year was the last confirmed significant difference ($p < 0.001$) between the professional groups. The largest subgroup among nurses reported the lowest annual ventilation frequency. In comparison, paramedics exhibited a similar distribution across the specified ranges.

Ventilation parameters

A statistically significant difference was found in ventilation rate (Vr) between the groups ($p = 0.013$). Nurses demonstrated a higher median ventilation rate. Median tidal volume (Vt) was similar and the difference was not significant ($p = 0.674$).

In both groups, the percentage of correct ventilation was very low (detailed results summarized in Tab. 2 and Fig. 1).

Self-assessment of ventilation

The median value of ventilation skills on the Likert scale for the paramedic group was 4 and for nurse group 3 and this was a statistically significant difference ($p = 0.036$).

Correlation between ventilation parameters and other variables

A statistically significant correlation was found between ventilation parameters and professional experience. More experienced providers tended to ventilate faster and with a higher volume (Vr/experience: $R = 0.158$, $p = 0.025$; Vt/experience: $R = 0.265$, $p < 0.001$; Fig. 2 and 3).

Other correlations were weakly positive and not statistically significant. The coefficients and p-values were calculated as follows: Vr/self-assessment: $R = 0.017$, $p = 0.801$; Vt/self-assessment: $R = 0.111$, $p = 0.115$; Vr/ventilations per year: $R = 0.035$, $p = 0.614$; Vt/ventilations per year: $R = 0.093$, $p = 0.187$.

DISCUSSION

ERC guidelines recommend monitoring both tidal volume and respiratory rate. Only by analyzing the quality of manual ventilation and relating these two parameters to each other can determine the degree of correct ventilation. Based on these two parameters, only a minor part of both groups (2.5 %) met the criteria of correct ventilation defined by ERC.

These results align with the observations from the study by Neth MR et al. [23], in which 2.8 % of participants met the AHA guidelines in out-of-hospital cardiac arrest. These results are surprising and confirm nurses' and paramedics' low level of ventilation skills despite its recognition as a core of their profession.

Most available studies have shown a tendency towards hyperventilation rather than hypoventilation, as observed in the present study [3, 24, 25]. In the referred results, the authors show differences between the studied medical professions. That observation appeared in the authors' investigation: paramedics in the study were hypoventilating, while the nurses were slightly hyperventilating.

The main difference between professions was gender, with the nursing profession being predominantly female worldwide. This is supported by data from Taylor C et al. [26] showing only 11.6% of men in nursing in England, consistent with findings in other countries.

According to Polish Law, paramedics and nurses are allowed to perform ventilation with BVM in a respiratory arrest situation. They acquire this competence during undergraduate training. Paramedics in Poland are also required to participate in ongoing professional development after graduation. As part of their mandatory training, they gain practical experience in managing respiratory arrest and performing ventilation using BVM devices. Nurses, unlike paramedics, are not obliged to undergo further training after graduation. Depending on their interests and further professional plans, nurses may begin specialty training in a specific field, during which the topic of respiratory arrest may be discussed and practiced.

The difference in nurses' experience and the low percentage of intermediate-experienced nurses may be linked to the generational change and the strategy implemented by the Supreme Chamber of Nurses and Midwives. They aimed to encourage young people to practice as nurses due to the aging population of this professional group. In the case of paramedics, no differences in experience can be observed as this is a professional group that has existed in the Polish healthcare system since 2006.

The frequency of procedures performed per year varied according to the profession. The higher frequency in paramedics may be attributed to an increased likelihood of encountering respiratory arrest, which is inherent to the nature of their work within EMS. Another factor is the lack of authorization for endotracheal intubation in a situation other than sudden cardiac arrest for non-physician staffed teams in Poland. In the in-hospital environment, there is easier access to rapid response teams. Transferring responsibilities to a team dedicated to this task reduces the exposure of other staff members to performing this procedure. Therefore, the vast majority of nurses ventilate very rarely.

Low ventilation volume may have been due to large leaks caused by inaccurate mask sealing. This is one of the basic skills that requires training. There are various mnemonics in common use to help with proper replacement ventilation. One of these is the acronym MOANS (mask seal, obstruction or obesity, advance age, no teeth, stiffness of the lungs) [27].

Also possible in use is the acronym BONES (beard, obesity, no teeth, elderly, snoring) [28]. Mastering mnemonic acronyms enhances preparation for ventilation, identifies patient issues, and guides management, especially in stressful respiratory arrest situations. Reducing ventilation errors should be a key focus of medical education at all levels. It is also recommended to take part in training courses on ventilation with BVM. To increase ventilation skills, it is potentially possible to volunteer in operating rooms under the supervision of experienced staff.

The study by Khoury et al. [20] showed that the leakage volume was 200 mL, representing 37% of the volume flowing out of the BVM. Even lower results were reported by Gruber E. et al. [29]. In their study mean tidal volume delivered by the nurses was 240 ± 210 mL. In another study by Khoury et al. [20] 333.94 mL, in the situations described, proper compression of the BVM device did not generate adequate ventilation, which may cause hypoxia. On the other hand, ERC strictly recommends observing visible chest rise as an indication of efficient ventilation [8]. In this study, this subjective feeling can be linked to an accurate measure of delivered tidal volume expressed in milliliters.

The difference between paramedics and nurses in respiratory rate may not be clinically relevant. However, paramedics did not follow the guidelines in the present study. Such a high level of non-compliance with the ERC recommendations must be highlighted. In addition, the authors were unable to demonstrate a clear reason for the differences in guided ventilation between nurses and paramedics. They suspect that the reason is the greater experience in years among nurses and the more frequent use of supraglottic devices in prehospital care by paramedics [30, 31]. In addition, it would be valuable to see if other methods of analyzing ventilation quality such as segmenting ventilation and evaluating each segment will yield different results in meeting the guidelines. In addition, it would be beneficial to see if devices that give real-time feedback can improve the quality of the ventilation being conducted. High-quality clinical trials to correlate physiological data with respiratory rate and volume would be necessary.

Limitation

The study has some limitations. Manikin tests do not fully replicate real-life scenarios, with clinical data being the most accurate performance indicator. While the sample size is larger than in similar studies, it may still not be representative. Studies on a larger study group are needed to strengthen the evidence.

While manikin-based simulations provide valuable opportunities to assess and standardize skills, some limitations must be recalled. Face masks are designed for humans, not manikins, and anatomical differences can affect mask sealing [32]. Hesselfeldt et al. [33] noted that even SimMan simulators, though widely accepted, have significant airway anatomy differences compared to humans. Despite these drawbacks, manikin testing remains popular due to its ethical simplicity, reproducibility, and ease of use [34].

CONCLUSIONS

During simulated respiratory arrest, ventilation with a BVM device with a face mask performed by paramedics and nurses incredibly rarely met the ERC recommendations. The authors also observed a lower rate of delivered breaths than demonstrated in the literature. More attention should be paid to training on the subject of manual ventilation for paramedics and nurses regardless of work experience.

Article information and declarations

Data availability statement

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

Ethics statement

Before attendance, all participants signed an informed consent. Study protocol was approved by the Bioethics Committee of Poznan University of Medical Sciences (KB-362/24).

Author contributions

Conceptualization, data curation, formal analysis, investigation, methodology, resources, visualization, writing: original draft, final approval, JL; formal analysis, methodology, validation, visualization, writing: original draft, final approval, TK; supervision, validation, writing: review & editing, final approval, MP.

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None.

Conflict of interest

The authors declare that they have no conflicts of interest.

Supplementary material

Questionnaire: quality of ventilation in adults carried out with a BVM by selected professional groups of the health care system.

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Table 1. Characteristics of the studied population in the professional category

	Paramedic	**Nurse**	**Total**	**p value**
Age (years)	32.0 (27.0–38.0)	32.5 (25.0–51.5)	32.0 (26–42)	
Sex				0.001
Female	34	88	122	
Male	66	12	78	
Professional experience (years)				0.018
< 5	33	38	71	
5–10	33	16	49	

➢ 10	34	46	80	
Average ventilation per year				0.001
0–5	40	73	113	
6–10	29	16	45	
> 10	31	11	42	
Handedness				0.205
Right-handed	94	89	183	
Left-handed	6	11	17	
Self-assessment of ventilation				0.036
5	7	9	16	
4	54	35	89	
3	36	49	85	
2	3	6	9	
1	0	1	1	
Average hours performed per month				0.209
< 160	24	28	52	
160–240	56	61	117	
> 240	20	11	31	

Data were presented as numbers or median (IQR)

Table 2. Ventilation parameters measured during a 4-minute ventilation cycle

	Nurse	**Paramedic**	**p value**
Ventilation rate (bpm)∗	10.4 (8.0–13.1)	8.9 (7.0–11.3)	0.013
Tidal volume (mL)∗	394.6 (349.4–448.7)	390.1 (345.4–441.6)	0.674
Tidal volume (mL/kg)∗	4.9 (4.3–5.6)	4.8 (4.3–5.5)	
Adequate ventilation (%)	4	1	N/A

∗Data were presented as median (IQR)

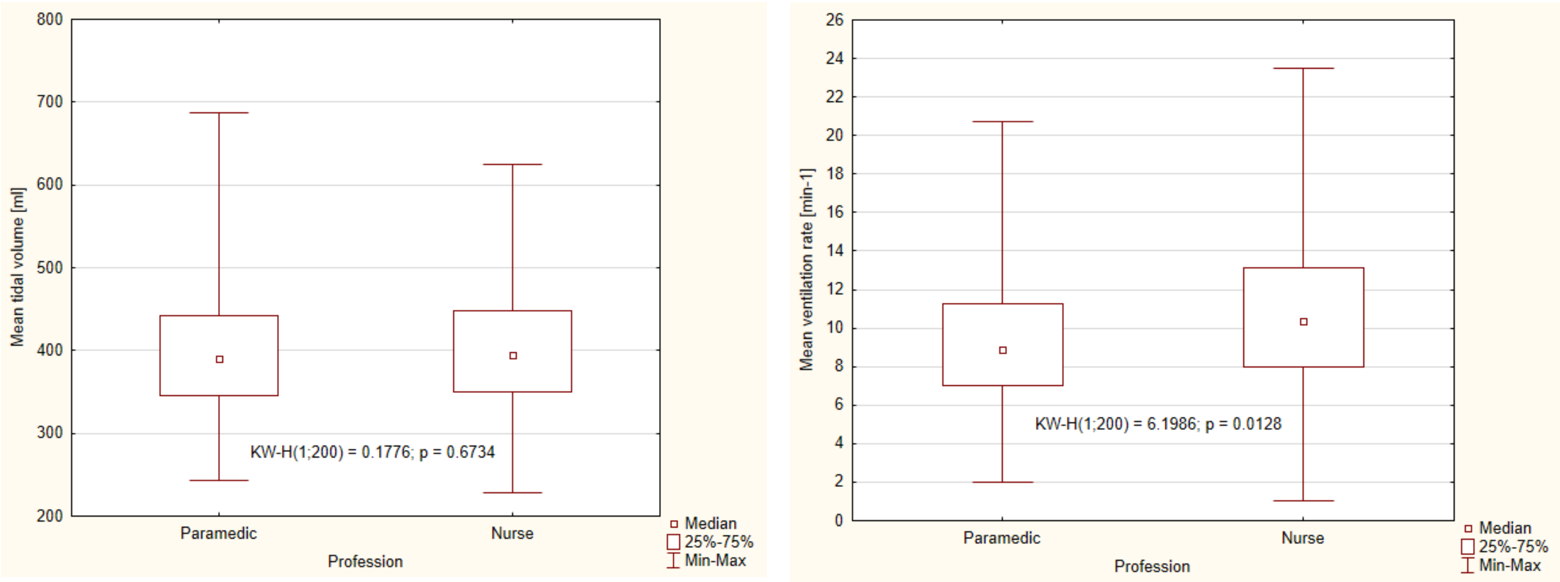

Figure 1. Ventilation rate and tidal volume among nurses and paramedics

Figure 2. Correlation between ventilation rate and professional experience

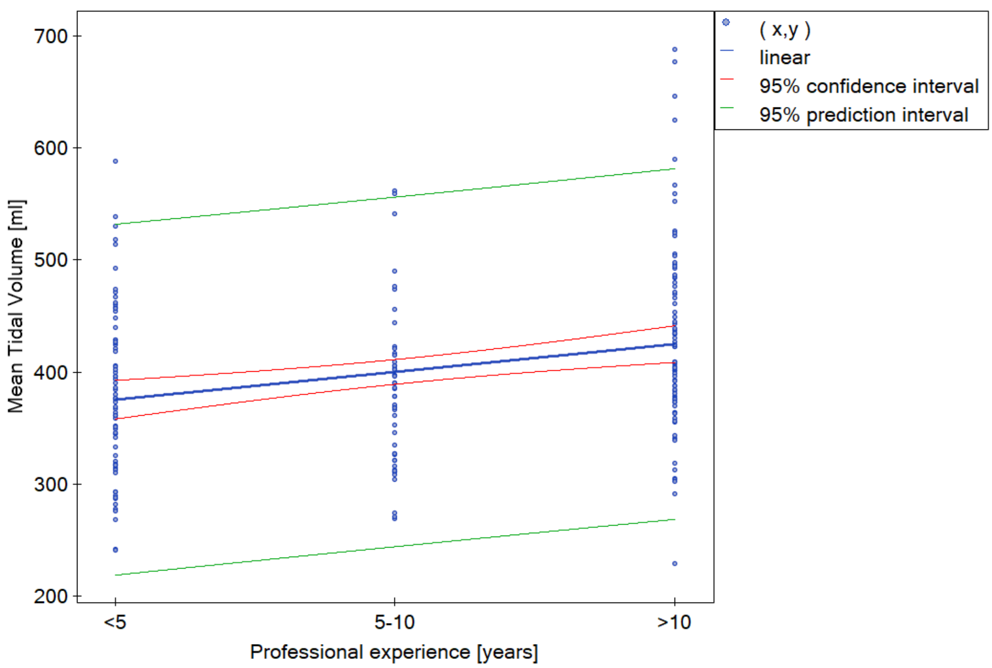

Figure 3. Correlation between tidal volume and professional experience