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## Effectiveness of the MILGEOMED system in supporting medical activities in a hospital emergency department: an experimental evaluation

Ocena efektywności systemu MILGEOMED wspomagającego działania medyczne w warunkach szpitalnego oddziału ratunkowego – analiza eksperymentalna

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### Abstract

**Introduction and objective:** Modern combat medicine is developing innovative solutions aimed at saving lives in extreme conditions with limited resources. These experiences are increasingly being transferred to civilian settings, particularly emergency medicine. Solutions such as advanced triage systems, mass-casualty incident procedures, and haemostatic technologies have already been successfully adapted for use in hospitals and emergency medical services. The MILGEOMED system, developed under a national defence and health innovation programme, is designed to support emergency response through real-time biomedical monitoring, unmanned aerial vehicle deployment, and geoinformation processing. This study evaluated the system's effectiveness in a hospital environment, specifically within the emergency department. **Materials and methods:** The study included 100 randomly selected patients from the Emergency Department of the Military Institute of Medicine – National Research Institute. All patients underwent standard diagnostics (TOPSOR, NEWS2) and vital-sign measurements using Mindray/ZOLL devices and the MILGEOMED system (noise radar, capnometer). The collected data were subsequently subjected to statistical analysis. **Results:** The radar sensors used in the study showed greater measurement variability than the reference clinical devices Mindray and ZOLL; however, their accuracy remained within clinically acceptable limits for diagnostic-support applications. Compared to standard triage performed by emergency department staff, the MILGEOMED system was associated with a reduction in triage time and an improvement in the quality of patient assessment. Additionally, fewer procedural errors and better team communication were noted. **Conclusions:** The implementation of the MILGEOMED system could be a significant step towards developing automated methods for assessing patient condition and supporting clinical decision-making in Poland, by integrating medical, geoinformation, and artificial intelligence technologies.

**Keywords:** MILGEOMED, medical triage, hospital emergency, biomedical sensors, system evaluation

### Streszczenie

**Wprowadzenie i cel:** Współczesna medycyna pola walki opracowuje innowacyjne rozwiązania mające na celu ratowanie życia w ekstremalnych warunkach i przy ograniczonych zasobach. Doświadczenia te są coraz częściej stosowane w środowisku cywilnym, szczególnie w medycynie ratunkowej. Rozwiązania, takie jak zaawansowane systemy triage'u, procedury postępowania w przypadku zdarzeń masowych i technologie hemostatyczne, zostały już z powodzeniem zaadaptowane do potrzeb szpitali i pogotowia ratunkowego. System MILGEOMED, opracowany w ramach programu innowacji w dziedzinie obronności i zdrowia, ma na celu wsparcie reagowania kryzysowego poprzez monitoring biomedyczny w czasie rzeczywistym,

wykorzystanie bezzałogowych statków powietrznych i przetwarzanie geoinformacji. W badaniu oceniono skuteczność systemu w środowisku szpitalnym na szpitalnym oddziale ratunkowym. **Materiał i metody:** Badaniem objęto 100 losowo dobranych pacjentów Szpitalnego Oddziału Ratunkowego Wojskowego Instytutu Medycznego – Państwowego Instytutu Badawczego, u których przeprowadzono standardową diagnostykę (TOPSOR, NEWS2) oraz pomiary parametrów życiowych urządzeniami Mindray/ZOLL i systemem MILGEOMED (radar szumowy, kapnometr). Zebrane dane poddano analizie statystycznej. **Wyniki:** Automatyczna segregacja medyczna pacjentów realizowana przez system MILGEOMED stanowiła efektywne wsparcie dla procedur medycznych prowadzonych w warunkach szpitalnego oddziału ratunkowego. Zaobserwowano skrócenie czasu triage'u i poprawę jakości oceny stanu pacjentów w porównaniu z segregacją przeprowadzaną przez personel medyczny. Dodatkowo odnotowano zmniejszenie liczby błędów proceduralnych i usprawnienie komunikacji w zespole medycznym. **Wnioski:** Uzyskane wyniki wskazują na zasadność dalszego rozwoju i wdrażania systemów wspomagających pracę personelu medycznego. Implementacja systemu MILGEOMED może stanowić istotny krok w kierunku rozwoju zautomatyzowanych metod oceny stanu pacjenta i wspierania decyzji klinicznych w Polsce, integrując technologie medyczne i geoinformacyjne oraz rozwiązania z zakresu sztucznej inteligencji.

**Słowa kluczowe:** MILGEOMED, triage medyczny, szpitalny system ratunkowy, czujniki biomedyczne, ewaluacja systemu

## INTRODUCTION

The growing number of health- and life-threatening emergencies, in both peacetime and crisis conditions, necessitates the implementation of modern technologies to support rescue operations. According to a report by the Statistics Poland (GUS), in 2024, nearly 4.1 million individuals utilised outpatient emergency medical assistance at hospital emergency departments (EDs) or admission rooms (a 2.9% increase compared to 2023). More than 2.3 million individuals were treated as inpatients in EDs (a 13.1% increase over the previous year)<sup>(1)</sup>.

In a hospital emergency department, care is provided to patients with an exceptionally wide spectrum of health issues: from minor injuries and ailments, through exacerbations of chronic diseases, to immediate life-threatening conditions such as cardiac arrest or severe multi-organ trauma. This diversity of cases requires medical staff to possess broad interdisciplinary knowledge and the ability to adapt rapidly to patients' dynamically changing clinical states. Unlike many other hospital departments, the ED demands that diagnostic and therapeutic decisions be made quickly, often with limited access to the patient's complete medical history. As a result, clinicians must act efficiently, relying on the information obtained from the medical interview, presenting symptoms, initial laboratory and imaging tests, as well as their own clinical experience. The prolonged duration of medical service provision during the patient triage stage results from limited staff availability, an insufficient number of diagnostic rooms, and the necessity of performing – and often repeating – basic diagnostic procedures, such as measuring body temperature, assessing heart and respiratory rates, determining blood pressure and oxygen saturation levels, as well as conducting and interpreting electrocardiographic examinations<sup>(2)</sup>.

Combat medicine currently represents a field of innovation aimed at effective life-saving in extreme conditions with limited access to diagnostics. In recent decades, there has been a growing interest in adapting these experiences

and tools to the civilian environment, particularly in the field of emergency medicine. The MILGEOMED project focuses on the development of an integrated medical system that enables early assessment of casualty status and supports triage and medical evacuation processes through the use of geoinformation data and biomedical sensors. In recent years, attention has been drawn to the fact that radar technologies can precisely measure vital parameters, such as respiratory rate and heart rhythm, while integrated classification systems enable the early identification of life-threatening conditions<sup>(3–5)</sup>. This study evaluates the effectiveness of the MILGEOMED system within the ED, which plays a pivotal role in providing immediate care despite resource constraints and the variability of patient priorities. The functional assessment of the MILGEOMED system specifically considers its capability for automated physiological data collection using non-contact sensors (noise radar and capnometer), the assignment of triage classifications based on a simplified NEWS2 (National Early Warning Score 2) and its mapping to the NATO-TRIAGE system, the comparison of system results with reference measurements [ZOLL X-series, Mindray, and the Patient Service Mode Management System in Hospital Emergency Departments (Tryby Obsługi Pacjentów w Szpitalnym Oddziale Ratunkowym, TOPSOR)], and the validation of classification algorithm compliance with medical decisions made by ED staff. The devices used in the study serve to assess the level of consciousness, respiratory rate, heart rate, and to analyse lactate levels. Additionally, image analysis systems were utilised, enabling rapid detection of injuries invisible to macroscopic assessment, such as external bleeding from difficult-to-access areas (junctional haemorrhage) or the absence of eyeball movement in critical states. The study also evaluated the feasibility of using the MILGEOMED system as a real-time clinical decision-support tool, as well as its impact on the quality of the medical triage process and early patient assessment under real-world ED workload conditions. Furthermore, integrating the system with existing HIS (Hospital Information System)



Fig. 1. Unmanned Aerial Vehicle of the MILGEOMED system during field trials

solutions can allow for the continuous verification of patients' clinical status and dynamic adjustment of the order in which medical services are provided. Beyond utilising unmanned aerial platforms equipped with biomedical sensors, the MILGEOMED system supports the Mobile Management and Analysis Centre, which collects and analyses data in real time (Fig. 1). A key element of the system is the Intelligent Life Map (ILM), which enables the visualisation of patients' health status, their location, and the assignment of medical priorities.

The objective of this study was to evaluate the accuracy and repeatability of vital sign measurements (heart rate and blood pressure) obtained using the MILGEOMED system sensors in comparison with clinical reference devices (Mindray, ZOLL) in a real-world ED setting, and to compare the medical accuracy of patient triage performed by ED staff with the automated classification of the same patients conducted by the MILGEOMED triage system. The analysis examined the agreement in patient assignment to priority categories within the NATO TRIAGE and TOPSOR systems, as well as differences in clinical risk assessment using the NEWS2 and ACVPU scales.

## MATERIALS AND METHODS

### Participants and study conditions

The study involved experienced members of the ED team of the Military Institute of Medicine – National Research Institute (Wojskowy Instytut Medyczny – Państwowy Instytut Badawczy, WIM-PIB), instructors from the WIM-PIB Medical Simulation Department (responsible for the registration and technical supervision of the MILGEOMED system), and 100 patients admitted during that time to the WIM-PIB ED in Warsaw. The sample selection was randomized from the general population of ED patients, who were recruited based on their written informed consent. Individuals unable to provide consent or those in an immediate life-threatening condition were excluded from the study.

The study was conducted in two phases, maintaining the patient's full diagnostic pathway. In the first stage, each patient was assessed by the ED medical team in accordance with established clinical procedures. Standard procedures included, among others, the classification of the patient's condition within the TOPSOR system and the measurement of vital signs using standard clinical devices. In the second stage, patients were invited to participate in the verification using the MILGEOMED system, where identical measurements were performed using a noise radar and a capnometer mounted on an Unmanned Aerial Vehicle (UAV) positioned in a designated ED zone at a distance of 2 metres from the participants. All measurements were conducted in a non-invasive and passive manner, without affecting the ongoing clinical decisions of the ED team. In a subgroup of study participants ( $n = 33$ ), capillary or venous blood samples were additionally collected to determine lactate concentrations as a metabolic indicator of tissue hypoxia. Measurements were performed using an i-STAT portable point-of-care analyser, in accordance with the manufacturer's instructions. In addition, the collected data were used in the context of the future development of the MILGEOMED system, in which the extension of the NEWS2 algorithm with a biochemical component – lactate measurement – is anticipated for subsequent phases of medical evacuation. The study was approved by the WIM-PIB Bioethics Committee (ref. no. WIM/KB/2025/04/01), and patient participation was preceded by obtaining their voluntary and written informed consent. Data were collected anonymously.

### Measurement tools

To ensure study standardisation, the duration of individual procedures was measured (from patient admission to triage completion), procedural errors were recorded (including omission of vital signs measurement), and team communication quality was assessed (e.g. number of command repetitions, synchronisation of actions). Medical staff evaluated the system's usability, intuitiveness, and ergonomics using a 5-point Likert scale (1–5). The study utilised non-contact sensors (noise radar and capnometer) mounted on UAVs and standard devices (Mindray and ZOLL X-series) used to assess vital signs (heart rate, respiratory rate, and end-tidal carbon dioxide (EtCO<sub>2</sub>) concentration in exhaled air were measured). All patients were triaged according to the TOPSOR and NEWS2 systems and their mapping within the NATO TRIAGE system; the level of consciousness was assessed using the ACVPU scale [A (alert), C (confusion) – disoriented; V (verbal) – responds to verbal commands; P (pain) – responds to painful stimuli; U (unresponsive) – unconscious, unresponsive to any stimuli].

The TOPSOR system assigns an urgency category (colour-coded) to patients, which determines the priority of medical intervention. The interpretation of the results is as follows: red (category 1) indicates the highest priority and the

need for immediate medical assistance; orange (category 2) denotes high priority and the necessity for rapid medical contact; yellow (category 3) represents assistance with a potentially shorter waiting time; green (category 4) indicates that the waiting time may be up to 4 hours; and blue (category 5) includes stable patients whose assistance will be provided within 6 hours.

The NEWS2 scale is designed to assess the severity of a patient's condition and to detect clinical deterioration. The scale excludes the assessment of children under 16 years of age, pregnant women, and patients in intensive care units. Interpretation is based on the aggregate score obtained from the assessment of six vital signs (respiratory rate, oxygen saturation, heart rate, systolic blood pressure, level of consciousness, and body temperature). A score of 0–4 points indicates low risk, meaning the patient does not require an immediate clinical assessment. A score of 5–6 points represents medium risk – the patient requires an urgent clinical assessment within 60 minutes. A score of  $\geq 7$  points (high risk) requires an immediate, emergency clinical response.

The NATO TRIAGE system, in turn, is a standardised triage system used in the member states of the North Atlantic Alliance, assigning a casualty to one of four groups:

- T1 (Immediate Treatment Group) – casualties in a state of immediate life threat;
- T2 (Delayed Treatment Group) – casualties requiring life-saving interventions or surgery, where a delay will not lead to a deterioration of their health status;
- T3 (Minimal Treatment Group) – casualties in a stable condition, not requiring immediate intervention;
- T4 (Expectant Treatment Group) – casualties in critical condition with minimal chances of survival, or the deceased.

The assessment of differences in the obtained vital-sign measurements was carried out using three monitoring systems: the standardized clinical systems Mindray and ZOLL, and the non-contact Radar system.

To better illustrate the operation of the MILGEOMED system and the measurement conditions, photographic documentation of the measurement station is presented (Fig. 2). The measurement system consisted of a non-contact noise radar and a capnometer integrated with a measurement platform, which, under the study conditions, was placed in a designated zone of the ED. During the measurement, the patient was in a standing or sitting position at a distance of approximately 2 metres from the sensor module. Noise radar enabled the recording of chest wall micromovements resulting from respiratory activity and haemodynamic changes associated with cardiac function. These data were subsequently processed by the MILGEOMED analytical algorithms, which calculated the respiratory rate and heart rate (HR).

Concurrently, reference measurements were performed using certified Mindray and ZOLL X-Series clinical devices, which served as the benchmark for evaluating the accuracy of the non-contact measurements. The acquired data were automatically transmitted to the MILGEOMED analytical



Fig. 2. MILGEOMED system measurement station in the ED settings at WIM-PIB



Fig. 3. Performing non-contact vital signs measurement using noise radar

system, where they were visualised and integrated with the triage classification module.

To enhance the transparency of the study methodology, sample images illustrating the vital signs measurement process using the MILGEOMED system are also presented (Figs. 3–5).

This study was conducted as part of the research and development project entitled “MILGEOMED – Intelligent geoinformatic systems supporting medical operations in hazardous conditions”, funded by the National Centre for Research and Development (NCBR) under the SZAFIR program (agreement no. SZAFIR/0248/2020).

The project was implemented by a consortium comprising the Military University of Technology (WAT), the Air Force Institute of Technology (Instytut Techniczny Wojsk Lotniczych, ITWL), INVESTCORE, and the WIM-PIB.

## Statistical methods

The results were subjected to statistical analysis using SPSS Statistics for Windows, version 29.0.0.0 (IBM Corp,

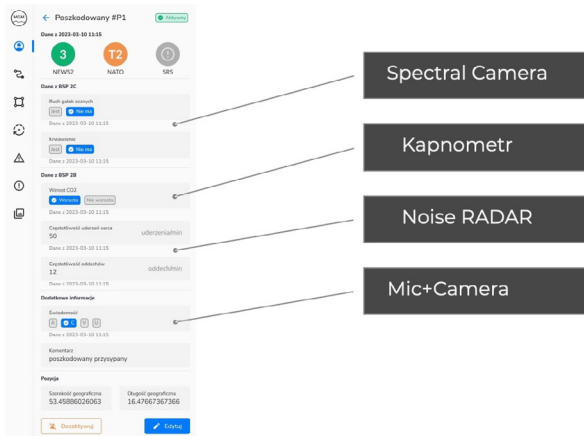


Fig. 4. Measurement data visualisation in the MILGEOMED system



Fig. 5. i-STAT critical care analyser used during measurements

New York, USA). Prior to the analysis, the data were pre-screened using normality plots and ultimately verified using the Kolmogorov–Smirnov and Lilliefors tests for normality. Given the lack of normal distribution for selected variables, non-parametric tests that do not require normality were utilised for statistical evaluation in these cases. Student’s *t*-test was applied to evaluate variables with a normal distribution. For correlation analysis, Pearson’s linear correlation coefficient was calculated. The level of statistical significance was set at  $p < 0.05$ .

## RESULTS

In the assessment of the participants’ level of consciousness, level A (alert) predominated, observed in 99 subjects (99%), while level C (confusion) was recorded in one individual (1%). No cases of loss of consciousness or unresponsiveness to stimuli were observed. In the NEWS2 scale, values ranged from 1 to 7 points, with a median of 3.0 (interquartile range, IQR: 2.0–4.0). The largest group consisted of patients with a score of 3 points (37 out of 83; 44.6%), indicating moderate clinical risk. High NEWS2 scores ( $\geq 5$  points) were obtained in 12% (10 out of 83) of the participants. According to the NATO TRIAGE classification, the majority of patients were assigned to category T3 (72%, 72 out of 100), corresponding

to stable conditions that do not require immediate intervention. Categories T1 (immediate life-threatening condition) and T4 (deceased) occurred marginally, each representing 1% of cases. In the TOPSOR system, category 4 predominated (51.5%, 50 out of 97), representing cases of moderate urgency. This was followed by category 5 (41.2%, 40 out of 97), which included stable patients, while categories 2 and 3, requiring more urgent intervention, accounted for a total of 7.2% of cases. A comparison of the MILGEOMED system’s classification results with the medical personnel’s assessment demonstrated a high level of agreement, ranging from 82% to 89% depending on the scale applied. The most frequent discrepancies concerned borderline cases between categories T2 (urgent) and T3 (stable). Importantly, no cases of misclassification were identified for patients requiring immediate intervention (T1).

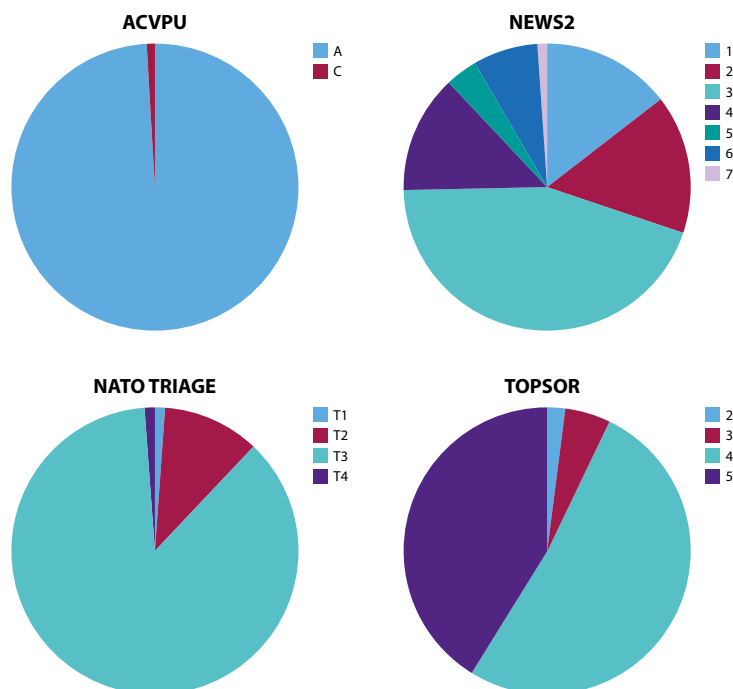
Data regarding the distribution of patient scores according to the ACVPU, NEWS2, NATO TRIAGE, and TOPSOR scales are presented in Fig. 6.

Lactate measurements were performed in 33 patients. The median lactate concentration in the study group was 0.89 mmol/L (IQR: 0.76–1.29 mmol/L). The values ranged from 0.47 to 2.98 mmol/L. An evaluation survey was conducted among the medical staff, the results of which indicate a positive assessment of the MILGEOMED system’s ergonomics and intuitiveness (mean scores of 4.1–4.3 on a Likert scale). Respondents rated the clarity of operation and the possibility of simultaneous viewing of measurement data and classification results particularly highly.

The objective of the comparative analysis was to determine the degree of agreement between vital sign measurements obtained using the MILGEOMED non-contact radar system and measurements performed with clinical reference devices. The Mindray and ZOLL systems served as the clinical standard routinely used in the ED and were treated as the benchmark for assessing the accuracy of measurements performed using the radar method. The statistical analysis aimed to determine whether the measurements obtained by the radar system could be considered sufficiently reliable for applications supporting diagnostics and the medical triage process.

## Heart rate assessment

The Kruskal–Wallis test for independent samples was used to evaluate differences in heart rate (HR) values obtained from three measurement systems: Mindray, ZOLL, and Radar. The differences in measured HR values were analysed between the Mindray and Radar systems (Group 1) and between the ZOLL and Radar systems (Group 2). Group 3 consisted of the differences in measured HR values between the two standardised measurement systems: Mindray and ZOLL. The values between measurements were presented as the percentage difference in the obtained HR values. The distribution of the percentage analysis of the HR difference is shown in Tab. 1.



**ACVPU** – consciousness assessment scale: A – alert, C – confusion, V – voice, P – pain, U – unresponsive. The chart shows only categories A and C, meaning the vast majority of patients were alert (A), while a small percentage exhibited confusion (C).  
**NEWS2** – National Early Warning Score 2 (range 0–20 points; the higher the score, the greater the clinical risk). Categories 1–7 on the chart represent the NEWS2 point values obtained by patients. The most frequent values are low scores (1–3), indicating a low clinical risk for most subjects, although a group with higher values (5–7) is also visible.  
**NATO TRIAGE** – NATO medical triage system: T1 – immediate (immediate aid, life-threatening), T2 – delayed (delayed aid, serious injuries but stable), T3 – minimal (minimal injuries, walking wounded), T4 – expectant (poor prognosis/deceased). T3 predominates on the chart, meaning that the majority of patients had minor injuries.  
**TOPSOR** – an urgency scale in the patient triage system at the emergency department. Categories 2–5 correspond to the following urgency levels: 2 – urgent (very urgent/life-threatening), 3 – urgent (requires rapid intervention), 4 – standard (less urgent), and 5 – non-urgent. Categories 4 and 5 predominate in the chart, indicating a prevalence of lower-priority patients.

Fig. 6. Clinical characteristics of the study group – distribution of consciousness assessments (ACVPU) and urgency levels according to NEWS2, NATO TRIAGE, and TOPSOR scales

The analysis revealed statistically significant differences between the groups ( $p = 0.004$ ), indicating that the values of the analysed variable differed depending on the measurement system used. To identify the source of the differences, a post hoc analysis with Bonferroni correction was performed. Statistically significant differences were found between the Mindray and Radar systems when compared with the differences observed between the standardised Mindray and ZOLL systems ( $p = 0.003$ ) (Fig. 7). In the subsequent stage, an analysis of the relationships between HR values obtained using the Mindray, ZOLL, and Radar systems was conducted using Pearson’s correlation coefficient. The analysis demonstrated a strong positive correlation between the HR values obtained from the Mindray and ZOLL systems ( $r = 0.789$ ;  $p < 0.001$ ), confirming the high level of agreement

between these two clinical reference systems. However, no statistically significant correlations were found between the HR values obtained from the Radar system and those from the Mindray system ( $r = -0.033$ ;  $p = 0.753$ ) or the ZOLL system ( $r = 0.071$ ;  $p = 0.497$ ). These results indicate that HR measurements performed by the non-contact Radar system do not exhibit a linear relationship with measurements obtained using standard clinical devices, which may suggest limited accuracy or greater measurement variability in clinical settings.

### Assessment of blood pressure values

Analysis of the percentage difference in blood pressure (BP) values revealed the largest measurement deviation between the Mindray system and the non-contact Radar system, where the median difference was 44.44% (IQR: 11.56–64.29%). A similar level of discrepancy was observed in the ZOLL vs. Radar comparison, with a median of 41.67% (IQR: 0.00–64.29%). The highest measurement agreement was achieved between the clinical Mindray and ZOLL systems, for which the median difference was 0.00% (IQR: 0.00–11.11%) (Tab. 2). Statistically significant differences were observed between the compared systems ( $p < 0.001$ ), confirming the variability in

Variable	Group 1	Group 2	Group 3
HR difference [%], median (IQR)	14.94 (0.25–31.28)	7.24 (–4.36–25.27)	5.71 (0.00–12.70)

**Group 1** – difference between values measured by the Mindray and Radar systems; **Group 2** – difference between values measured by the ZOLL and Radar systems; **Group 3** – difference between values measured by the Mindray and ZOLL systems; **HR** – heart rate; **IQR** – interquartile range.

Tab. 1. Distribution of heart rate differences between groups

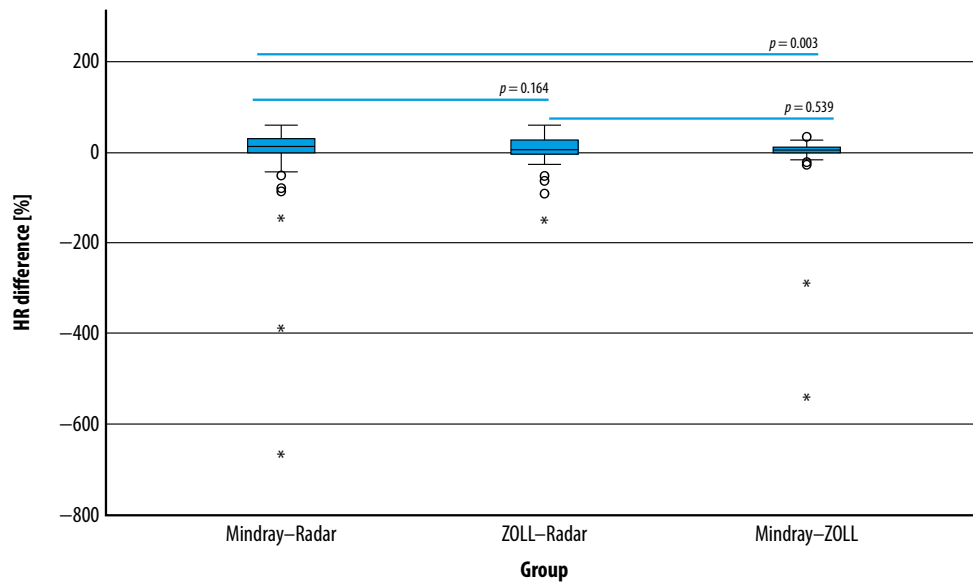


Fig. 7. Results of the Kruskal–Wallis test and post hoc analyses (with Bonferroni correction) for comparing differences in heart rate (HR) measurements between the Mindray, ZOLL, and Radar systems

the percentage discrepancy of BP measurements depending on the technology used. Post-hoc analysis with Bonferroni correction revealed that significant differences occurred in the Mindray–ZOLL and ZOLL–Radar pairs ( $p < 0.001$ ), as well as in the Mindray–ZOLL and Mindray–Radar pairs ( $p < 0.001$ ). The difference between the ZOLL–Radar and Mindray–Radar systems was not statistically significant ( $p = 1.000$ ). These results indicate that the largest percentage differences in BP measurements occurred in comparisons involving the non-contact Radar system, whereas the highest consistency was recorded between the standardised clinical Mindray and ZOLL systems (Fig. 8).

The correlation between blood pressure (BP) values obtained from the Mindray, ZOLL, and Radar systems was analysed using Pearson’s correlation coefficient. No significant correlation was found between BP values measured by the Mindray and ZOLL systems ( $r = 0.141$ ;  $p = 0.163$ ) or between the Mindray and Radar systems ( $r = -0.079$ ;  $p = 0.449$ ). A significant, though weak, correlation was observed only between the ZOLL and Radar systems ( $r = 0.312$ ;  $p = 0.002$ ).

## DISCUSSION

The obtained results confirmed that the radar and capnometric sensors used in the MILGEOMED system enable effective – though still limited – monitoring of vital signs

in a clinical environment. Despite significant differences in HR and BP values compared with the reference devices, the direction and nature of the changes remained consistent with clinical data. The agreement between automatic classifications and staff decisions indicates a high diagnostic accuracy of the MILGEOMED algorithm. Similar results were presented by Karpel et al., who confirmed that automated vital sign analysis systems can achieve a level of agreement exceeding 80% with clinical assessment, particularly in a controlled environment<sup>(6)</sup>.

The obtained results indicate that the measurements performed by the radar system exhibit greater variability compared with those obtained using standard clinical devices. At the same time, it should be emphasised that the primary objective of the MILGEOMED system is not to replace certified monitoring devices used in clinical practice, but rather to provide rapid, non-contact assessment of vital signs in situations requiring patient pre-selection or in environments with limited access to medical personnel. In this context, the radar system can serve as a tool supporting the initial patient assessment process, particularly in mass casualty incidents or during periods of increased emergency department workload.

The highest measurement agreement was demonstrated between the Mindray and ZOLL reference systems, whereas the measurement discrepancies with the radar system resulted primarily from the influence of environmental conditions and patient positioning. Similar observations have been reported in international studies. Dong et al. found that radar systems in hospital settings demonstrate an accuracy of 10–20% in heart rate and respiratory rate measurements, with measurement errors increasing in the presence of patient movement and electromagnetic interference<sup>(7)</sup>. It is worth emphasising that in the studied MILGEOMED system, the primary measurement method is radar

Variable	Group 1	Group 2	Group 3
BP difference [%], median (IQR)	44.44 (11.56–64.29)	41.67 (0.00–64.29)	0.00 (0.00–11.11)

BP – blood pressure; **Group 1** – difference between values measured by the Mindray and Radar systems; **Group 2** – difference between values measured by the ZOLL and Radar systems; **Group 3** – difference between values measured by the Mindray and ZOLL systems; **IQR** – interquartile range.

32 Tab. 2. Distribution of blood pressure differences between groups

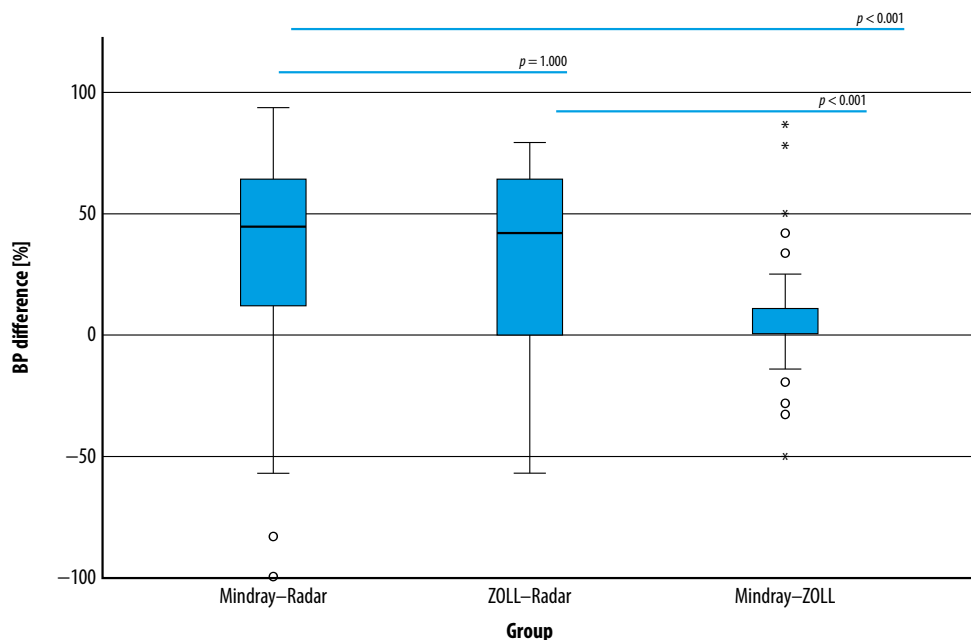


Fig. 8. Results of the Kruskal–Wallis test and post hoc analyses (with Bonferroni correction) for comparing differences in blood pressure (BP) measurements between the Mindray, ZOLL, and Radar systems

technology, whereas the Mindray and ZOLL devices were used exclusively as clinical reference systems to validate measurement accuracy. The triage classification agreement between the MILGEOMED system and medical personnel remained at a high level (82–89%), confirming the utility of the automated clinical assessment algorithm. The study results provide a basis for further optimisation of data analysis algorithms and the integration of the system into emergency environments. The high ratings from participants and the successful adaptation of the system to ED working conditions suggest the possibility of integrating it into standard hospital equipment for both daily operations and crisis management scenarios.

Preliminary automatic triage based on integrated biological data (e.g. assessment of consciousness level, respiratory rate, or HR) could shorten the time needed to determine the priority of intervention. The application of sensor data may contribute to accelerating diagnostics in crowded patient environments and facilitate the supervision of patients during mass influx situations (e.g. during a pandemic or disaster), when personnel-intensive techniques are not feasible. It is worth noting that despite statistically significant measurement differences, the values obtained from the MILGEOMED system remained within a clinically acceptable range for screening and monitoring applications. This supports the conclusion of Choo et al. that non-invasive systems can serve as a complementary tool to traditional measurements, particularly in the context of patient pre-selection or mass monitoring<sup>(5)</sup>.

Experiences gained during the COVID-19 pandemic, caused by the influx of a large number of patients in a short period, indicate the necessity for rapid prioritisation and the allocation of limited medical resources. During that

time, simple algorithms for patient admission and guidelines for ventilator allocation were being developed. White et al. developed a method for prioritising those who would derive the greatest potential health benefits. Patients were assessed based on clinical parameters described by the SOFA (Sequential Organ Failure Assessment) score and the presence of severe chronic diseases affecting long-term prognosis<sup>(8)</sup>. During the COVID-19 pandemic in the United States and Canada, between 19 and 30 March 2020, a triage procedure either did not exist or was still being developed in 50% of the surveyed institutions. The values most frequently mentioned in the description of the procedure were honesty, transparency, the provision of care, the prevention of unnecessary loss of life, and appropriate management of work organisation in the ward. The SOFA score was also cited as the primary algorithm used in the majority of centres (80.8%)<sup>(9)</sup>.

The development of artificial intelligence (AI) technologies opens new possibilities for emergency departments, where AI algorithms can support the triage process by analysing large datasets that include vital signs, symptoms, medical history, and demographic information, enabling a more objective and faster assessment of a patient's condition<sup>(10)</sup>. A benefit of the MILGEOMED system is the ability to manage medical teams and equipment more effectively, thanks to the development of the ILM as a decision-support system for on-duty physicians regarding resource allocation, including the number and placement of available beds and the assignment of tasks to personnel. This is a technology used on the battlefield that reduces risks for medical rescuers during the provision of care and facilitates the location and assessment of the condition of casualties. Effective resource optimisation plays a key role – not only in improving

therapeutic outcomes for patients, but also in ensuring continuity and efficiency of work in the emergency department and in reducing the physical and psychological burden on medical personnel<sup>(11,12)</sup>.

The reduction in procedure times – from medical triage to preliminary diagnostics and the identification of potential health threats – combined with a lower error rate and improved communication within the medical team confirms the validity of implementing the proposed solution into the hospital system. It must be emphasised, however, that the application of such a system entails the necessity of obtaining appropriate certifications. Furthermore, integration with HIS-type platforms raises ethical and legal challenges related to the security of personal data collection and processing. Nevertheless, the application of modern information protection technologies, based on multi-layered security mechanisms, can contribute to increased confidentiality and a reduced risk of unauthorised access to medical data.

Ultimately, the effective operation of the system depends on proper preparation and the continuous professional development of medical personnel. This entails the necessity of time and financial investment, which in the long term translates into both clinical and organisational benefits. Additionally, merging technologies in civilian and military environments results in comprehensive preparation of the civilian sector for armed conflicts, disasters, terrorist attacks, or mass casualty incidents. As noted by the Director of the WIM-PIB, Lieutenant General Professor Grzegorz Gielerak, MD, PhD, the current geopolitical situation necessitates the organisational and functional integration of both components of the healthcare system, as well as defining the scope of needs and the conditions for cooperation between civilian and medical sectors<sup>(13)</sup>.

Given the promising prospects for the implementation of the MILGEOMED system, further clinical trials and the

initiation of pilot projects within healthcare facilities are well justified.

## CONCLUSIONS

The radar sensors used in the study demonstrated greater measurement variability than the Mindray and ZOLL clinical reference devices; however, their accuracy remained within clinically acceptable limits for diagnostic support applications. Automated medical triage conducted by the MILGEOMED system provided effective support for medical procedures in the ED environment. A reduction in triage time and an improvement in the quality of patient assessment were recorded compared to triage performed manually by ED personnel. Furthermore, a lower number of procedural errors and enhanced team communication were observed.

In conclusion, the conducted research indicates the necessity for further actions regarding the implementation and refinement of medical personnel support systems. The introduction of the MILGEOMED system may represent a significant step toward the development of automated patient assessment and clinical decision support methods in Poland, integrating medical, geoinformation, and AI technologies.

### Conflict of interest

*The authors do not report any financial or personal connections with other persons or organisations which might negatively affect the content of this publication and/or claim authorship rights to this publication.*

### Author contribution

*Original concept of study; collection, recording and/or compilation of data; analysis and interpretation of data; writing of manuscript: PW, AR, AT, BR, AG. Critical review of manuscript; final approval of manuscript: AR.*

## References

1. Główny Urząd Statystyczny: Pomoc doraźna i ratownictwo medyczne w 2024 r. Główny Urząd Statystyczny, Warszawa 2025. Available from: <https://stat.gov.pl/obszary-tematyczne/zdrowie/zdrowie/pomoc-dorazna-i-ratownictwo-medyczne-w-2024-r-,14,9.html>.
2. Yuzeng S, Hui LL: Improving the wait time to triage at the emergency department. *BMJ Open Qual* 2020; 9: e000708.
3. Wollner EA, Nourian MM, Bertille KK et al.: Capnography – an essential monitor, everywhere: a narrative review. *Anesth Analg* 2023; 137: 934–942.
4. Ali M, Elsayed A, Mendez A et al.: Contact and remote breathing rate monitoring techniques: a review. *IEEE Sens J* 2021; 21: 14569–14586.
5. Choo YJ, Lee GW, Moon JS, et al. Application of non-contact sensors for health monitoring in hospitals: a narrative review. *Front Med (Lausanne)* 2024; 11: 1421901.
6. Karpel I, Mysiński M, Olesz K et al.: Overview of respiratory sensor solutions to support patient diagnosis and monitoring. *Sensors (Basel)* 2025; 25: 1078.
7. Dong S, Wen L, Ye Y et al.: A review on recent advancements of biomedical radar for clinical applications. *IEEE Open J Eng Med Biol* 2024; 5: 707–724.
8. White DB, Lo B: A framework for rationing ventilators and critical care beds during the COVID-19 pandemic. *JAMA* 2020; 323: 1773–1774. doi: 10.1001/jama.2020.5046. PMID: 32219367.
9. Antommaria AHM, Gibb TS, McGuire AL et al.; Task Force of the Association of Bioethics Program Directors: Ventilator triage policies during the COVID-19 pandemic at U.S. hospitals associated with members of the Association of Bioethics Program Directors. *Ann Intern Med* 2020; 173: 188–194.
10. Tahernejad A, Sahebi A, Abadi ASS et al.: Application of artificial intelligence in triage in emergencies and disasters: a systematic review. *BMC Public Health* 2024; 24: 3203.
11. Singla B, Shalender K, Stamer K et al. (eds.): *Revolutionizing the Healthcare Sector with AI*. IGI Global, 2024.
12. Khang A (ed.): *AI-Driven Innovations in Digital Healthcare: Emerging Trends, Challenges, and Applications*. IGI Global, 2024.
13. Gielerak GG, Murawski P: A model of dynamic planning of medical support for combat troops. A new perspective on the requirements and capabilities of the medical component. *Lek Wojsk* 2024; 102: 56–67.