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Evaluation of disinfection methods for autonomous mobile robots used in hospital logistics in emergency departments

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S U M M A R Y

Background: Autonomous mobile robots (AMRs) have been increasingly used in hospital logistics, particularly in high-risk areas, such as emergency departments (EDs), to streamline operations, reduce staff fatigue, and minimize infection risks. However, their effective disinfection remains a critical concern, especially when it comes to solutions aimed at preventing spread of multi-drug-resistant organisms.

Aim: This study evaluated the microbiological cleanliness and effectiveness of various disinfection methods for AMRs in real-life hospital logistics settings, with a particular focus on their application in EDs.

Methods: The HOSBOT, an AMR designed for hospital logistics, was deployed in a tertiary hospital for two weeks and validated for transport of biological samples. Microbiological contamination was assessed at multiple robot sites before and after disinfection, using two methods, i.e., manual wiping with a standard disinfectant and non-contact fumigation with low-temperature vaporized hydrogen peroxide. Contamination levels were evaluated using quantitative and qualitative microbiological techniques, and a threshold of <2.5 colony-forming units/cm^2 for critical environments, recommended by the Centers for Disease Control and Prevention (CDC), was considered as proof of success.

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Findings: Bacterial contamination exceeded thresholds at all sites. Both disinfection methods significantly decreased contamination. Manual wiping reduced bacterial counts below thresholds and eradicated fungal growth, while fumigation was effective for bacterial but not fungal contamination. Fumigation also failed to meet CDC cleanliness standards in hard-to-reach areas.
Conclusions: Both manual wiping and fumigation effectively reduced bacterial contamination, however, wiping showed better results in fungal eradication. Improvements to fumigation methods are necessary, such as application of higher disinfectant concentrations or alternative chemicals. The aforementioned findings not only support the use of AMRs in clinical settings but also emphasize the importance of effective disinfection for safety and efficacy.

Introduction

The adoption of robotic systems, particularly hospital robots, was significantly accelerated by the recent COVID-19 pandemic, largely due to their ability to reduce the risk of infection for medical personnel, particularly in high-exposure environments such as emergency departments (EDs) and intensive care units (ICUs) [1–3]. In consequence, a growing variety of robotic solutions have been increasingly utilized across diverse healthcare settings. Care homes use companion robots to enhance the well-being of older adults and patients with dementia [4]. In primary care, healthcare-assistive robots are deployed to support tasks such as sanitization, temperature monitoring, and mask-checking [5]. Meanwhile, hospitals employ a wide range of robots for various purposes, such as improving patient care, maintaining high hygiene standards, and optimizing logistics. In fact, a recent literature review identified as many as 10 distinct roles performed by robots across various clinical environments [6]. Even in ICUs, various robotic solutions are currently employed, such as therapeutic assistance robots, nursing assistance robots, rehabilitation assistance robots, telepresence robots, or logistics and disinfection robots [7].

Considering these diverse functions, it is crucial to integrate robots into logistics to provide streamlining hospital operations. Automated robotic systems can efficiently handle transportation of essential supplies, including sterile equipment, food trays, bedding, and diagnostic samples. By ensuring timely delivery of these materials from central warehouses to critical areas, such as patient care units and operating rooms, robots can contribute to a more effective functioning of healthcare services. Currently, logistics is often the second-largest cost in healthcare, and inefficiencies arise due to a lack of standardized processes. Additionally, these inefficiencies divert nurses and other medical staff from patient care, as shown by studies which prove that nurses spend up to 40% of their time on non-clinical tasks [8,9]. Automating logistics could free up this time, especially in EDs where staff shortages have been increasing [10].

In high-pressure environments such as EDs and ICUs, the transportation of goods and patients poses particularly significant challenges. Repetitive tasks can lead to both physical and mental fatigue in nurses, while prolonged patient handling frequently results in serious lumbar muscle injuries. Moreover, manual handling increases the risk of secondary injuries to patients. Therefore, various technologies have been proposed to respond to the challenges of hospital logistics, including autonomous mobile robots (AMRs). Automated transport vehicles address these issues by enhancing efficiency and reducing cross-infection risks, which is especially critical during emergencies such as the recent COVID-19 pandemic [11]. However, widespread adoption of AMRs in hospitals is limited by high upfront costs and a lack of modularity in commercial products, which often results in a failure to accommodate the diverse logistics needs across different hospital settings [12]. Furthermore, another concern that remains is the challenge of disinfecting AMRs to prevent the spread of infections within hospital environments. Given the high-risk nature of such settings, particularly in areas such as EDs or ICUs where multidrug-resistant bacteria and viruses are prevalent [13,14], it is essential to ensure safe disinfection of AMRs, without compromising their functionality.

Unfortunately, current literature provides limited practical guidance on disinfection protocols for robotic transportation systems. Even a recent review on advancements in the application of robots in critical care fails to address this crucial aspect [7]. Studies on cleaning of surgical robots highlight the importance of effective decontamination processes and may serve as an inspiration for other types of robots, including logistic robots [15,16]. However, even in this area, current disinfection standards are neither fully defined nor consistently applied [17].

To address this knowledge gap, this study evaluated various disinfection methods for AMRs in real-life settings of hospital logistics, with a particular focus on their use in EDs, i.e., high-risk areas with constant exposure to diverse pathogens. Stemming from a broader study on comprehensive validation of robotic transportation within clinical settings, this research aimed to offer guidance on safe integration of AMRs into hospital workflows, with the ultimate goal of enhancing the potential to streamline logistics, support patient care, and bolster preparedness for pandemics and other public health challenges [18].

Methods

Autonomous robotic transportation system

The HOSBOT (HOSpital roBOT), a modular, cost-effective system designed to enhance internal hospital logistics is one of the recent innovations in AMRs. It was created within the ODIN project [19], which was aimed at fulfilling specific demands of hospital operations, supporting disaster preparedness, and enhancing logistical efficiency. Validated in various clinical scenarios, the system was also tested in the ED.

A full description of the HOSBOT is available elsewhere [18]. Designed to streamline the transport of consumables and diagnostic samples from storage areas to patient care units or operating rooms, the HOSBOT combines robotics, Internet of Things (IoT), and artificial intelligence (AI) technologies. The system integrates a commercial AMR with a custom-built, passive cart, the SmartRack, capable of carrying boxes of different sizes. The key components of the HOSBOT include (see also Figure 1): (1) Autonomous Mobile Robot (AMR, Robotnik Automation S.L., Spain). Equipped with a laser scanner, the robot performs real-time collision avoidance with static and dynamic objects while planning an optimal trajectory, and communicates with other system components via the ODIN platform, a digital infrastructure enabling data communication, resource management, and task orchestration among hospital devices and systems [18]. (2) SmartRack, a customizable wheeled cart built with aluminium extruded profiles and PMMA (polymethyl methacrylate, a transparent thermoplastic material), that transports SmartBoxes. (3) SmartBox, a standalone storage unit within the SmartRack which can store essential items like blood samples, medications, surgical instruments, etc. (4) Human—Machine Interface (HMI), a web-based interface accessible on the SmartRack tablet that allows hospital staff to monitor and manage the system.

Overview of the AMR pilot in clinical settings

A pilot study was designed to evaluate the usability of HOSBOT for transporting biological samples in a hospital setting, i.e., the tertiary teaching hospital of the Medical University of Łódź. Conducted over a two-week period, the study tested the HOSBOT's ability to handle logistics tasks typically performed by hospital staff, specifically the delivery of blood samples from the ED to the central laboratory. This automation aimed to relieve staff of non-patient-facing tasks, reduce fatigue, and improve the speed and reliability of diagnostic sample transportation.

The pilot was conducted in a controlled 40-m-long space in a temporarily patient-free section of the ED, allowing for real-life testing within the hospital without disrupting daily operations. Working in four designated zones, the HOSBOT followed a structured protocol simulating the journey from the ED to the central laboratory. The pilot began in Room 1, designated as the home area, where the AMR recharged and underwent maintenance. Upon receiving a contactless request from a proximity capacitive sensor in Room 2 and exchanging such information through the ODIN platform, the HOSBOT autonomously navigated to the target location, retrieved the SmartRack, and collected the samples placed in a designated SmartBox. The AMR then proceeded to Room 3, simulating the central laboratory, where an operator retrieved the samples and instructed the HOSBOT to return to its base in Room 1. The entire pilot involved 17 protocol runs. During these operations, certain components of the HOSBOT, including the attached tablet and the SmartBoxes, were physically touched by the personnel.

Microbiological examination

The microbiological cleanliness of the AMR surface was tested using quantitative and qualitative methods. The methods were compliant with the procedures for controlling microbiological cleanliness in the hospital where the AMR tests were performed. The study was conducted from 12th-16th February 2024, following a one-week period of technical validation of the HOSBOT in a tertiary hospital ED, during which the system was exposed to the standard conditions of the venue.

The study employed conventional microbiological techniques, including contact plate imprinting for quantitative assessment and swabbing with culture-based identification for qualitative evaluation. These approaches remain the gold standard for environmental surface monitoring in healthcare settings, as they are widely validated and recommended by international guidelines such as the Centers for Disease Control and Prevention (CDC), for assessing microbiological cleanliness in hospital environments [20].

The contact plate method is a well-established technique for assessing microbial contamination on non-porous surfaces, particularly in healthcare settings. It is recommended for environmental monitoring due to its reproducibility, ease of use, and ability to provide quantitative data on bacterial and fungal contamination levels [21]. The swab method, conversely, is particularly useful for detecting a broader range of micro-organisms, including those present in biofilms and hard-to-reach areas [22]. These methods are commonly employed to assess bacterial presence on frequently touched surfaces in healthcare settings, as in the study by Muhammad *et al.* [23] discussing microbial contamination on hospital lift buttons.

Materials

The agar filled Rodac-type 25 cm^2 contact plates (Thermo Fisher Scientific, USA) were used for surface imprints, containing (1) tryptic soy agar (to test for the presence of bacteria) and (2) Sabouraud Agar (to test for the presence of fungi).

Sterile flocked dacron swabs (Medical Wire & Equipment, UK) were used for surface swabbing.

Tryptone Soy Broth, MacConkey Agar, Colistin and Nalidixic Acid Agar (Thermo Fisher Scientific, USA) media were used for culturing from swabs.

Procedures

Quantitative evaluation

Rodac-type plates with culture media were imprinted on the surface of the AMR in 10 selected places, often touched by the medical staff (as shown in Figure 2). The plates were then incubated at 35 $\pm$ 2 °C for 48 h. After this time, the grown colonies were manually counted. The microbiological cleanliness of the surface was presented in the form of total colony counts from a surface area of 25 cm^2. The procedure was performed before and after each disinfection method.

Qualitative evaluation

Samples were collected with flocked swabs moistened in a sterile 0.85% NaCl solution. Subsequently, the samples were manually agitated in Tryptic Soy Broth and incubated at 35 $\pm$ 2 °C for 48 h. Cultures showing growth were subsequently transferred to selective media for further bacterial identification, i.e.,

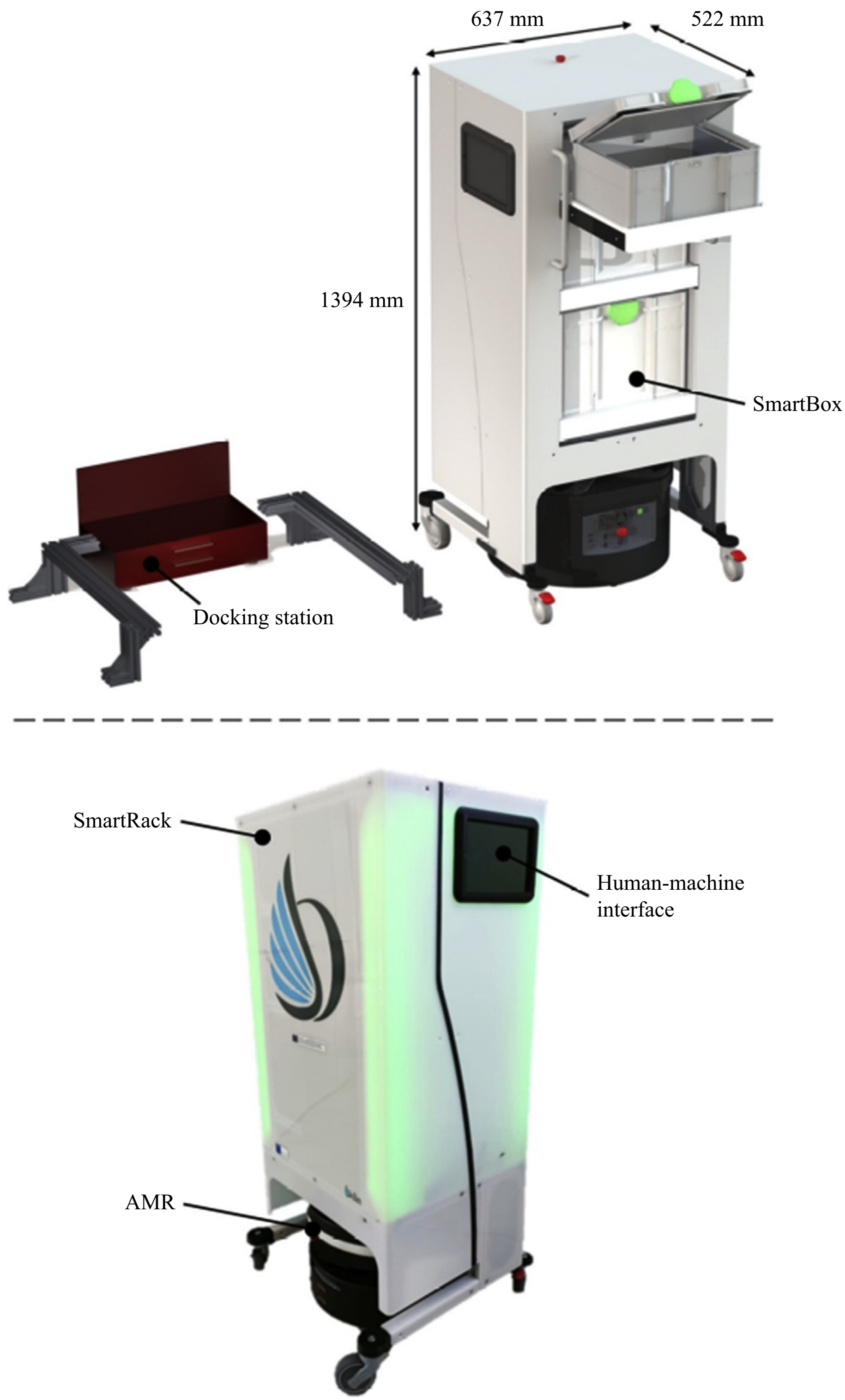

Figure 1. Design of the HOSBOT, an autonomous mobile robot system, utilized in this study for hospital logistics and disinfection evaluations. Top: Front view of the HOSBOT and its docking station. SmartBoxes can be retrieved from the SmartRack upon authorization. Bottom: Photograph of the HOSBOT navigating an obstacle-free environment, with green LEDs illuminated. The human—machine interface is accessible via a tablet located on one side of the SmartRack.

MacConkey Agar for Gram-negative bacilli, and Columbia Colistin and Nalidixic Acid Agar for Gram-positive cocci, with an additional 24-h incubation at 35 $\pm$ 2 °C. Bacterial identification was conducted using the matrix-assisted laser desorption/ionization time-of-flight (MALDI-TOF) mass spectrometry VITEK MS system (bioMérieux, France), while phenotypic tests were used to identify antimicrobial resistance mechanisms. In the case of Gram-negative bacilli, the tests included extended-spectrum β-

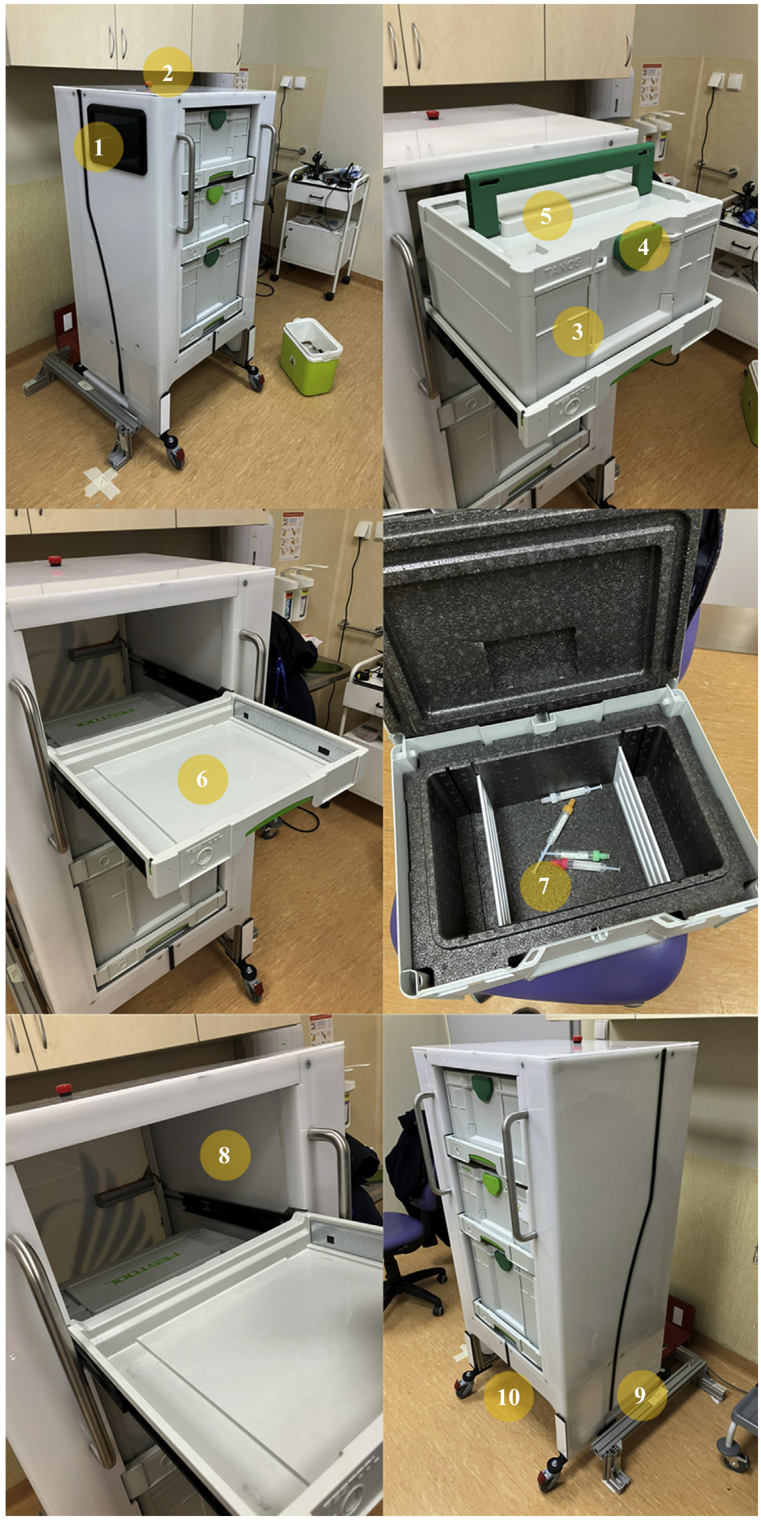

Figure 2. Locations on the autonomous mobile robot sampled using swabs and contact prints for microbiological analysis during the pilot implementation of the HOSBOT in emergency department settings.

lactamases (ESBLs), AmpC cephalosporinases, the Carbapenem Inactivation Method (CIM), and CARBA-5 immunoassays (NG Biotech, France). Whereas, in the case of Gram-positive cocci, the tests included resistance assessments for meticillin, vancomycin, linezolid, and the MLS (macrolides, lincosamides, streptogramins) resistance phenotype using the disc diffusion method.

Disinfection procedures

The study utilized two well-established methods of disinfecting surfaces and medical equipment, routinely applied in the hospital where the tests were conducted: (1) manual wiping with Meliseptol Wipes Sensitive (B. Braun, Germany), with active compounds of Propan-1-ol and didecyldimethylammonium chloride; and (2) non-contact fumigation using the Nocospray system (Oxy'Pharm, France) with Nocolyse neutral (Oxy'Pharm, France), which combines 6% hydrogen peroxide solution and silver cations.

All the procedures were performed according to the manufacturer's instructions. Supplementary material S1 compares the chemical composition and spectrum of activity of the disinfectants used in the experiment.

Microbiological outcome measures

In the absence of specific guidelines, this study adopted the general recommendation of the CDC, namely a threshold value of <2.5 colony-forming units (cfu)/cm^2 for high-touch areas in critical environments such as operating rooms and ICUs [19]. Values below this threshold were considered indicative of the success of the respective disinfection method.

Statistical analysis

The statistical analysis was performed with the use of the Statistica 13 software (TIBCO Software Inc., USA). The effectiveness of wiping and fumigation was compared based on paired *t*-tests for both bacterial and fungal colony counts, with Cohen's d applied for calculation of effect sizes. A *P*-value threshold of 0.05 was considered statistically significant.

Results

Swab cultures collected from various locations on the AMR showed no presence of alert pathogens or antimicrobial resistance mechanisms. However, all tested sites were found to be contaminated with bacteria, as indicated by colony counts ranging from 9 to 164 colonies per site. The highest colony count was observed on the top surface of the SmartRack, while the lowest was detected on its bottom surface. In as many as 5 of the 10 tested sites, the bacterial colony count exceeded the threshold value of <2.5 cfu/cm^2. In contrast, fungal contamination was minimal, with only two sites testing positive, i.e., the interior of the SmartRack drawer and the interior of the SmartBox.

The effectiveness of wiping and fumigation methods for AMR disinfection is compared in Table I. Wiping resulted in a significant overall reduction in colony counts (P=0.001). It completely eliminated bacteria in five of the 10 tested sites, and in the remaining cases, it effectively reduced the colony count to the level below the adopted threshold value. Additionally, wiping effectively eradicated fungal growth in all previously positive sites.

Fumigation also significantly reduced bacterial colonies (P=0.009), although it was less effective than wiping. Following the use of this method, residual colonies were detected in eight out of the 10 tested sites. While fumigation achieved the target threshold for bacterial counts (<2.5 cfu/cm^2) in most cases, it failed to meet the standard in 2 areas, namely the top surface of the SmartBox and the interior of the SmartRack drawer. Moreover, fumigation showed no statistically significant decrease in colony counts for fungal reduction.

Wiping and fumigation for AMR disinfection were compared using Cohen's d for effect size measure. Wiping demonstrated a large effect size for bacterial reduction, while only a small effect size for fungal reduction (2.08, and 0.45, respectively). In contrast, fumigation also exhibited a large effect size for bacterial reduction but showed a negligible effect on fungal reduction (1.24 and -0.001, respectively).

Discussion

Our study examined microbiological contamination of an autonomous mobile robotic system used in the hospital logistics of a tertiary hospital ED and tested the effectiveness of two disinfection methods applied to this type of equipment.

Table I
Comparison of wiping and fumigation for autonomous mobile robot disinfection

No.	Robot part	Before (total colony count)		After wiping (colony count)		After fumigation (colony count)	
		TSA	SDA	TSA	SDA	TSA	SDA
1	Tablet	22 (0.88)	0	0	0	0	0
2	Top surface of the SmartRack	164 (6.25) *	0	3 (0.12)	0	3 (0.12)	0
3	Front surface of the SmartBox	58 (2.32)	0	0	0	6 (0.24)	0
4	SmartBox opening button	94 (3.76) *	0	0	0	6 (0.24)	0
5	Top surface of the SmartBox	88 (3.52) *	0	2 (0.08)	0	65 (2.60) *	0
6	Interior of the SmartRack drawer	136 (5.44) *	mould over-growth	10 (0.40)	0	100 (4.00) *	Mould over-growth
7	Interior of the SmartBox	36 (1.44)	2 (0.08)	5 (0.20)	0	11 (0.44)	3 (0.12)
8	Inner wall of the SmartRack	56 (2.24)	0	1 (0.04)	0	48 (1.92)	0
9	Indentation above the wheel of the SmartRack	137 (5.48) *	0	0	0	10 (0.4)	0
10	Bottom surface of the SmartRack	9 (0.36)	0	0	0	0	0
Statistics							
Mean		80	30.2	2.1	0	24.9	30.3
Standard deviation		52.8	94.8	3.3	0	34.4	94.8
Mean reduction				77.9	30.2	55.1	-0.1
P				0.001	0.340	0.009	0.343

Values presented as total colony counts; in brackets – colony forming units (cfu) per surface (cfu/cm^2); asterisks mark the areas where the values exceed the limit of <2.5 cfu/cm^2. SDA, Sabouraud Dextrose Agar; TSA, Tryptic Soy Agar.

Notably, after a week in the ED, the AMR was found to be contaminated with bacteria at all the tested sites, highlighting the clear need for effective disinfection. The absence of alert pathogens or antimicrobial resistance mechanisms, along with limited fungal contamination, may result from the short time the robot stayed in the target area. Interestingly, surfaces most frequently touched by personnel, such as the tablet and the SmartBox opening button, were not among the most contaminated sites. This suggests that the primary source of bacterial contamination was rather the air in the ED, not the hands of the staff participating in the study.

Our results confirmed the effectiveness of both tested disinfection methods for AMR decontamination, i.e., manual wiping with a disinfectant and touchless fumigation using a low-temperature vaporized hydrogen peroxide. Of particular interest is our observation of the effectiveness of the non-contact method of disinfection. Both methods significantly reduced bacterial loads, with wiping achieving reductions to below the disinfection threshold for critical environments recommended by CDC, in all cases, and fumigation achieving the same result in most cases. While fumigation fell short of this criterion in some hard-to-reach areas, its overall effectiveness suggests that increasing the disinfectant concentration could improve its performance in these challenging locations.

Notably, none of the tested methods had a negative effect on the AMR's operation. On the contrary, after the completion of this study, the same HOSBOT was successfully deployed in two other clinical trials across different European locations, demonstrating that neither the mechanical, optical, nor electronic components were adversely affected by the employed disinfection methods [18]. This means that the HOSBOT in particular, and AMRs in general, may be adopted on a broader scale in hospital settings, including highly demanding environments such as EDs, where systematic disinfection of such devices is of paramount importance.

Under the current lack of dedicated guidance, the best approach to AMR disinfection may be adherence to general guidelines for hospital surfaces disinfection to minimize the risk of cross-contamination and nosocomial infections. According to the CDC, the choice of decontamination methods depends on the intended use of the device and the level of microbial contamination. High-touch surfaces of AMRs should be classified as non-critical items, requiring disinfection with scientifically validated and legally registered hospital disinfectants to eliminate potential pathogens, including multidrug-resistant organisms (MDROs) and other alert pathogens. Conversely, the CDC emphasizes that "devices entering sterile environments, such as operating rooms, may require higher levels of disinfection or sterilization, following protocols similar to those defined for semicritical or critical equipment", i.e., surface bacterial counts of <2.5 cfu/cm^2 for high-touch areas. To support a comprehensive strategy for infection prevention, routine cleanliness testing should be performed, including surface swabbing, air sampling, and surface prints to detect organic matter and microbial contamination. This testing is essential for identifying harmful pathogens such as *Clostridioides difficile*, meticillin-resistant *Staphylococcus aureus* (MRSA), carbapenem-resistant organisms (CRO), and vancomycin-resistant enterococci (VRE) [19].

Hence, depending on the situation, ensuring the safe and effective decontamination of robotic solutions may involve disinfection (process that reduces pathogens to safe levels, though it does not eliminate all micro-organisms, particularly spores, and is typically applied to non-critical surfaces), or sterilization (thorough process that eradicates all forms of microbial life, including spores). Various methods can be employed for this purpose with robotic solutions, as outlined in Table II. Our study focused on the disinfection process according to a recognized and universal definition [24], as a process that is readily feasible in the setting of the ED. Disinfection procedures, applicable to EDs, suggest integrating UV-C light and low-temperature vaporized hydrogen peroxide technologies into the robots' decontamination workflows to achieve consistent surface disinfection [20]. However, none of these methods has been extensively tested on robots, and their suitability for specific robotic systems remains uncertain. For example, UV-C light acts only on external surfaces, and might disintegrate certain plastics. Conversely, low-temperature vaporized hydrogen peroxide technologies may also be unsuitable, as the robots' electronic components, optics, and other hardware elements may not be resistant to this aggressive chemical compound. In this context, our positive assessment of the feasibility and effectiveness of fumigation with a low-temperature vaporized hydrogen peroxide is particularly significant, as this method can be easily automated.

Undoubtedly, adoption of effective disinfection methods opens up new opportunities for deploying AMRs in innovative and highly promising areas. One such application, particularly relevant from the perspective of infection prevention and control (IPC), is the transportation of medical waste, especially in operating rooms where strict sanitary and epidemiological standards must be maintained. Operating rooms generate substantial volumes of hazardous and infectious waste that require careful handling to prevent healthcare-associated infections. Autonomous robots could play a key role in minimizing staff exposure to medical waste, thus reducing the risk of contact with infectious substances and harmful micro-organisms, including MDROs and other critical pathogens [25,26]. However, a critical prerequisite for the successful implementation of this technology is the ability to perform rapid, safe, and effective disinfection.

A potential limitation of our study is that our qualitative analysis did not identify any alert pathogens on the AMR surfaces. This probably results from the fact that the robot was kept in the hospital ED environment for a short time only, which means that it was not sufficiently exposed to the hospital microbiota. Similarly, the limited contamination of the AMR surfaces with fungal pathogens could explain the lack of significant changes in their colony counts after applying both disinfection methods. To address these limitations, a long-term study should be conducted to evaluate how quickly AMR surfaces become carriers of alert pathogens and to further assess the effectiveness of the disinfection methods tested.

Moreover, the observed pattern of effectiveness for both disinfection methods may be influenced by the physical parameters of the robotic transportation system, as some areas were more difficult to access for both wiping and fumigation. To overcome this limitation, future studies could test a wider variety of robots. Notably, the robot tested in this study did not have special antimicrobial coatings, which can aid in eliminating micro-organisms on treated surfaces. Using robots made from such materials could enhance the generalizability of future studies [27]. Nevertheless, as one of the pioneering

Table II
Potential techniques of decontamination, disinfection, and sterilization for hospital robots

Name of the technique	Definition	Methods	Description
Decontamination	Removal of contaminants such as pathogens, toxins, and other harmful agents to specified levels; including cleaning/ sanitization, disinfection, or sterilization	Automated decontamination chambers/stations	Chambers using UV-C light and chemical sprays to clean robots before entering sterile areas
		Self-decontaminating surfaces	Coatings (e.g., antimicrobial copper, silver ions) inhibit bacterial growth on high-contact robot parts
		Ozone-based decontamination	Ozone gas inactivates micro-organisms in hard-to-reach areas but requires careful handling due to potential toxicity
Disinfection	Eliminates most pathogenic micro-organisms (excluding bacterial spores) to a level that does not pose a risk of infection	UV-C light disinfection	UV-C lamps inactivate pathogens on surfaces; effectiveness depends on calibration and avoidance of shadowed areas
	Removal of viable micro-organisms (excl. spores) to specified for a defined purpose level	Chemical disinfectant sprays and wipes	EPA-approved disinfectants (e.g., hydrogen peroxide, sodium hypochlorite) applied manually or via automated systems
		Electrostatic spraying	Charged particles evenly distribute disinfectants, enhancing coverage of hard-to-reach areas
Sterilization	Removal of all viable micro-organisms (incl. spores)	Low-temperature vaporized hydrogen peroxide	Effective for heat-sensitive materials; requires specialized chambers
		Ethylene oxide gas sterilization	Suitable for moisture/heat-sensitive materials but limited by toxicity and lengthy cycles
		Autoclaving (steam sterilization)	High-temperature-resistant detachable parts can be sterilized in autoclave chambers
Complementary techniques and protocols	Enhances existing decontamination and disinfection strategies	Regular maintenance and cleaning protocols	Standardized schedules ensure consistent robot cleaning
		Disposable covers for high-touch areas	Reduces contamination and simplifies cleaning of frequently touched parts
		Sensor-based contamination detection	Sensors detect contamination or residues and alert personnel when cleaning is required

EPA, US Environmental Protection Agency.

studies in this field, our research offers practical value. It demonstrates that both manual wiping and touchless fumigation effectively reduced bacterial contamination on AMR surfaces, although manual intervention was required for fungi. Fumigation in hard-to-reach areas did not meet CDC cleanliness standards; however, increasing the disinfectant concentration or exploring alternative chemicals could enhance its effectiveness. Importantly, none of the disinfection methods negatively affected AMR performance, and the HOSBOT successfully operated in subsequent clinical trials. These results support the potential for a broader adoption of AMRs in high-demand hospital environments. However, further research is necessary to optimize non-contact methods capable of achieving complete disinfection, with the goal of developing fully autonomous, human-free disinfection solutions for transportation robots. Additionally, creating alternative chemical agents for fumigation could be a valuable strategy to enhance its effectiveness.

Conflicts of interest

P.K. has received speaker honoraria from P&G; all other authors declare no conflicts of interest.

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Ethics statement

This study was part of a broader investigation carried out under the framework of the ODIN project, focused on validating the HOSBOT in clinical settings within the Emergency Department, approved by the Ethics Committee of the Medical University of Łódź (approval no. RNN/30/24IKE of 9th January 2024).

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT v2 for linguistic adjustment. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2025.05.006.

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