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Implementation of Robotic Hygiene System for Surveillance and Prevention of Hospital Infections in Non-Self-Sufficient Patients

Massimiliano Guastella[1], Linda Pasta[2], Andrea Cuvello[1], Mariano Frittitta[3]

[1]Information Technology Department, Prismed S.R.L., Palermo, Italy
[2]Casa di Cura Villa Serena, Palermo, Italy
[3]Management & Administration, Prismed S.R.L., Palermo, Italy
Email: m.guastella@prismed.it

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Abstract

Background: Personal hygiene in non-self-sufficient patients is essential to prevent the proliferation and spread of bacteria from one patient to another, both through inanimate objects (fomites) and directly through healthcare workers. The first 1000 bed hygiene treatments performed by the collaborative robot "COPERNICO Surveillance & Prevention" in 229 non-self-sufficient patients were analyzed. **Materials and Methods:** A total of 229 patients were included: 215 patients came from emergency contexts or home, and 14 from long-term care facilities; the presence of sepsis, venous or urinary catheters, non-invasive ventilation, bedsores, clinical condition at discharge, and treatment sessions performed were recorded. All patients were hospitalized in the Geriatrics, Medicine and Pneumology departments. The system is able to collect and process data in real time. **Results:** Seventy-one patients with community-acquired sepsis and fourteen with healthcare-associated infections were treated; sixty-two had pressure ulcers. The analysis of the first 1000 treatments shows the healing of almost all sepsis cases, positive evolution of pressure ulcers, and hospital stays comparable to those of the entire group of 1008 hospitalized in the same period. There was no onset of side effects or complications. **Conclusions:** Although the healthcare setting is not among those at greatest risk of infections, the clinical efficacy, along with excellent evaluations from patients, family members, and healthcare personnel and the absence of side effects and complications, makes the system exceptionally manageable and user-friendly for non-self-sufficient patients.

Keywords

Infection Prevention, Healthcare-Associated Infections, Collaborative Robot, Geriatric Nursing, Personal Hygiene, Missed Nursing Care

1. Introduction

Maintaining personal hygiene in non-self-sufficient patients is critical to prevent the spread of bacteria, whether through inanimate objects known as fomites or directly via healthcare workers. Proper hygiene is essential not only for controlling and preventing infections among hospitalized patients but also for supporting the physical and psychological well-being of these individuals. Respecting patients' dignity and establishing rapport are paramount in clinical practice [1]. Innovative systems designed to minimize the discomfort experienced by patients can significantly impact their quality of care [2]. Additionally, they can help alleviate major challenges faced by nurses, such as the difficulties involved in assisting elderly patients in and out of the tub [3]. To ensure that bed bathing practices are as safe as possible, it is recommended to adhere strictly to an established procedure using a checklist. This approach ensures that staff execute these tasks systematically and use the prescribed tools correctly, as has been proven effective in intensive care settings [4]. The present study was therefore conducted with the aim of controlling and preventing hospital infections, following these simple rules: respect for the dignity of the patient, the safety of the operators, and finally, as a predominant value, patient safety, using a collaborative robotic system that acts in compliance with a predefined checklist, simultaneously recording and monitoring the clinical conditions of the individual and of the other hospitalized patients; it was conducted in a Clinic, authorized by the National Health Service for inpatient care. The system was developed, implemented, and tested on a preliminary sample of 300 interventions before January 15, 2024, during a period of approximately two and a half months. This is the report of the prospective study that analyzes the first 1000 consecutive interventions performed starting from January 15, 2024.

2. Materials and Methods

To obtain a rapid evaluation of the efficacy of the treatment and the appearance of any side effects, avoiding any recruitment bias, with the aim of completing the observation within a few months from the start, this prospective study was designed to analyze all patients, without any exclusion, consecutively hospitalized, who would have undergone the first consecutive 1000 treatments, with the "COPERNICO Surveillance & Prevention" system, scheduled every other day, starting from January 15, 2024. The inclusion criteria were as follows: non-self-sufficient patients, without age or pathology limits, hospitalized in the three departments: Geriatrics, Medicine and Pneumology. No surgical or intensive care units were involved. No exclusion criteria were predefined, excluding refusal to treatment. Possible side effects during treatment were recorded: appearance of skin erythema, falls during treatment, appearance of bedsores, intolerance or refusal to treatment, and others. To evaluate the satisfaction of patients, familiar with and health workers, we used a number scale from 1 to 5, with 1 indicating strong discordance or disturbance and 5 indicating strong accord: 1—Strongly Disagree; 2—Disagree; 3—Neutral or Neither Agree nor Disagree; 4—Agree; 5—Strongly Agree.

The system, designed to perform bed bathing in non-self-sufficient patients, consists of a collaborative robot (**Figure 1**), managed by two specially trained healthcare assistants, consisting of:

- an operational system dedicated to hygiene interventions, equipped with: soap wipes, ozone sterilized water effective for Legionella sterilization, tools for oral cleaning, management of bedsores and drying;
- a computer system, connectable to medical records, collecting data on the patient and procedures: sex, age, department, admission-discharge day registration, COVID-19 infection, presence of urinary, pulmonary or systemic sepsis, acquired in the community (CAI), or developed during hospitalization, *i.e.*, healthcare-associated infection (HCAI). Other data include urinary, peripheral, or central venous catheters, non-invasive ventilation (NIV), bedsores (staging and evolution), side effects, and clinical course with three possible outcomes: "Improved", "Transferred" and "Discharged in preterminal condition/Deceased", degree of satisfaction of patients and/or their caregiver.

The medical director or the ward nurse coordinator, who oversee the "COPERNICO Surveillance & Prevention" system, are tasked with remotely programming the daily sequence of patient interventions each morning. Once they confirm the schedule, it is automatically uploaded to the collaborative robot responsible for executing the hygiene, surveillance, and prevention tasks within the hospital ward. This robot, equipped with IoT (Internet of Things) technology, navigates autonomously to the designated patient's bed according to the schedule. It is possible to monitor activities live through a digital replica of the actual department, which enables real-time observation and management of various operations. This virtual model, depicted in **Figure 2**, reflects the physical layout and dynamic functions of the department, providing staff with up-to-the-minute data and interactions as they occur.

Figure 1. "COPERNICO Surveillance & Prevention" robotic system with integrated display to monitor the hygiene robotic intervention and collect data.

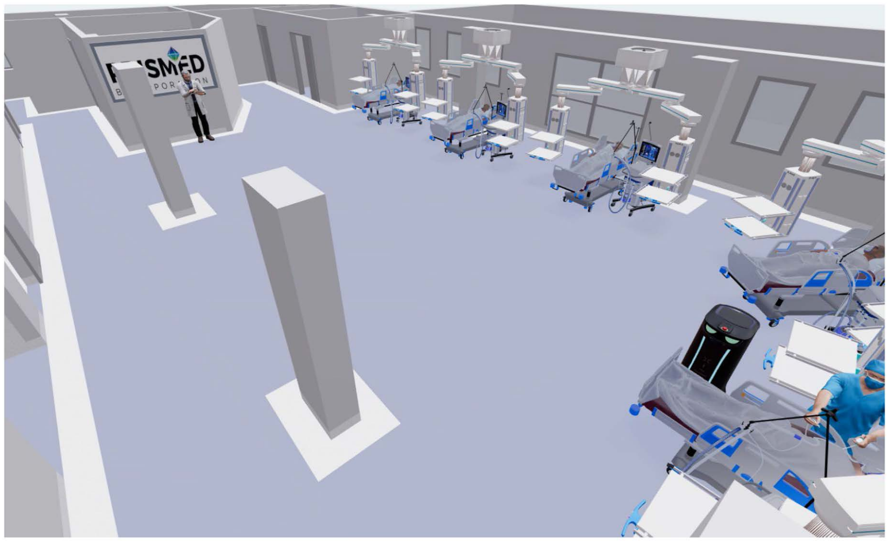

Figure 2. Digital twin visualization of hospital layout: this model represents a digital simulation of a hospital environment, showcasing various medical equipment and robotic systems in operation to enhance hospital management and patient care.

Robot Procedure Data

The robotic hygiene intervention follows a sequence of well-defined phases. The procedure consists of three main phases: preparation, intervention, and closure. The preparation and closure phases include all operations such as management of personal protective equipment (PPE), sanitizing accessories, elimination of all waste materials, and changing the bed linens. The intervention phase begins after preparation and involves cleaning specific body areas in a predefined sequence, from cleanest to dirtiest, from top to bottom, with the perineal-pubic area treated last. For each body area, both operators registered their hand washing, glove changes, sanitization of locally used accessories, and PPE. Data is collected daily, recording the completion of each phase mentioned above. A daily compliance analysis of the operators with the procedure is planned, with a scale from 0% to 100%, where 0% indicates no compliance and 100% indicates full compliance with the procedure. A color gradient from white (0%) to green (100%) facilitates immediate visualization of daily performance (**Figure 3**). Sex, mean age, medium hospital stay, and outcome indicators of all hospitalized patients are provided by the Medical Direction for comparison with treated patients. For each intervention performed, a certificate is produced to be included in the patient's medical record (**Figure 4**).

The system can provide real-time answers to queries about collected indicators, such as if and where there is an infected patient with CAI or HCAI or with pressure ulcers. At the end of each intervention, a form is regularly filled out to measure the degree of satisfaction of patients and/or their caregivers, which provides a rating from 0 to 5 on indicators of the level of comfort, general well-being, discomfort, cold, dyspnea and objective data in the monitored patients: HR and O2 saturation, as reported in an observational study after bed bathing in the critically ill patient [5]. In addition to individual patient analysis, the collected information can be used to calculate weekly or monthly trends of various events, such as sepsis, bedsores (staging and evolution), type and site of infection, CAI or HCAI. The following report is automatically generated from the data collected by the system. It should be noted that the analysis depends on the variables entered, which may change over time, depending on the healthcare team's information requests.

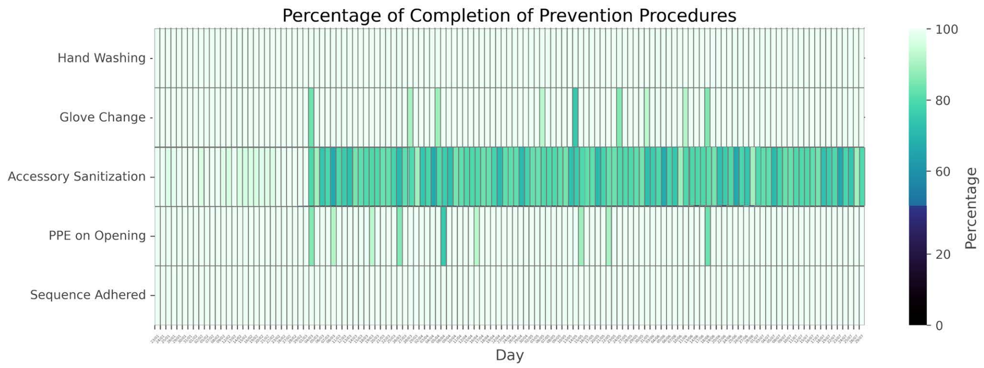

Figure 3. Percentage of completion for all hygiene procedures for each day in the entire study period.

COPERNICO
Surveillance & Prevention System

DATE	ENTE APALTANTE	HOSPITAL	OPERATING UNIT	BED	SCORE
May 8, 2024	Villa Serena S.P.A.	Casa di Cura "Serena"	Pneumology	111 - 01	55%

ID TRATAMENT	DATE OF TRATAMENT	TRATAMENT TYPE
363	March 1, 2024	Partial Care

Initiation	Change of sheets	12:29:14 pm	Yes	Yes	Positive
	Change of DPI	12:30:09 pm	Yes	Yes	Positive
	Duration	12:31:06 pm	min 60 sec - max 180 sec	114 sec	Positive
Face	Sanitizing of accessories	12:29:32 pm	Yes	Yes	Positive
	Sanitizing of hands	12:30:25 pm	Yes	Yes	Positive
	Change of gloves	12:30:26 pm	Yes	Yes	Positive
	Temperature	12:40:59 pm	Min 40°C - Max 42°C	42.3°C	Negative
	H_2O	12:40:59 pm	Min 0.01 l - Max 0.02 l	0.240 l	Negative
	Duration	12:41:02 pm	Min 30 sec - Max 45 sec	595 sec	Negative
Oral hygiene	Sanitizing of accessories	12:41:05 pm	Yes	Yes	Positive
	Sanitizing of hands	12:41:07 pm	Yes	Yes	Positive
	Change of gloves	12:41:08 pm	Yes	Yes	Positive
	Temperature	12:41:11 pm	Min 40°C - Max 42°C	42.3°C	Negative
	H_2O	12:41:11 pm	Min 0.001 l - Max 0.012 l	0.0 l	Negative
	Duration	12:41:15 pm	Min 45 sec - Max 75 sec	13 sec	Negative
Hands and breech hygiene	Sanitizing of accessories	12:41:16 pm	Yes	Yes	Positive
	Sanitizing of hands	12:41:18 pm	Yes	Yes	Positive
	Change of gloves	12:41:19 pm	Yes	Yes	Positive
	Temperature	12:41:22 pm	Min 40°C - Max 42°C	42.2°C	Negative
	H_2O	12:41:22 pm	Min 0.01 l - Max .05 l	0.0 l	Negative
	Duration	12:41:24 pm	Min 30 sec - Max 45 sec	8 sec	Negative
Intimate hygiene	Sanitizing of accessories	12:41:24 pm	Yes	Yes	Positive
	Sanitizing of hands	12:41:25 pm	Yes	Yes	Positive
	Change of gloves	12:41:26 pm	Yes	Yes	Positive
	Temperature	12:41:30 pm	Min 40°C - Max 42°C	42.1°C	Negative
	H_2O	12:41:30 pm	Min 0.2 l - Max 0.4 l	0.0 l	Negative
	Duration	12:41:34 pm	Min 60 sec - Max 120 sec	25 sec	Negative
Closing	Sanitizing of sheets	12:41:35 pm	Yes	Yes	Positive
	Sequence	12:41:35 pm	Yes	Yes	Positive
	Duration	12:42:06 pm	min 60 sec - max 120 sec	25 sec	Negative

Treatment	O_3 sanitizing range on bed place	12:28:00 pm	min 1 mg/l - max 2 mg/l	Yes	Positive
	O_3 sanitizing duration on bed place	12:28:00 pm	30 sec	30 sec	Positive
	H_2O	12:42:00 pm	Min 0.221 l - Max 0.482 l	0.240 l	Positive
	Duration	12:42:00 pm	min 375 sec - max 645 sec	767 sec	Negative

Sede legale: Via marchese di Villabianca 101, 90143, Palermo, Italia

Figure 4. A detailed certification is produced at the end of each hygiene intervention, including information such as times, types of care, and staff involved.

3. Results

A total of 229 consecutive patients were included: 135 men and 94 women (mean age 77 years) underwent 5 interventions ± 1 intervention per 10 days. No patient refused treatment. The study ended on July 29, 2024. In Geriatrics and Medicine (basic intensive care unit), 127 patients were observed with 564 interventions; in addition, 102 patients were admitted to Pneumology (medium intensive care unit) with 436 robotic hygiene interventions. No side effects were recorded during the observational period. A total of 215 patients came from emergency contexts (Emergency Department ED) or home, classified under the category "ED/Home". A smaller number of 14 patients came from long-term care facilities, such as Assisted Living Facilities or Nursing Homes, classified as "ALF/Nursing Homes". This data aligns with the origin of all 1008 patients admitted to the same departments during the same period: 583 men and 425 women, with an average age of 73 years; the sample of 229 patients treated with COPERNICO is part of this entire group. These patients required complete bed hygiene at least five times over a ten-day hospital stay. All evaluations on the satisfaction level of patients, familiar with and health workers, overtreatment with the COPERNICO system, were over 4: Agree and Strongly Agree.

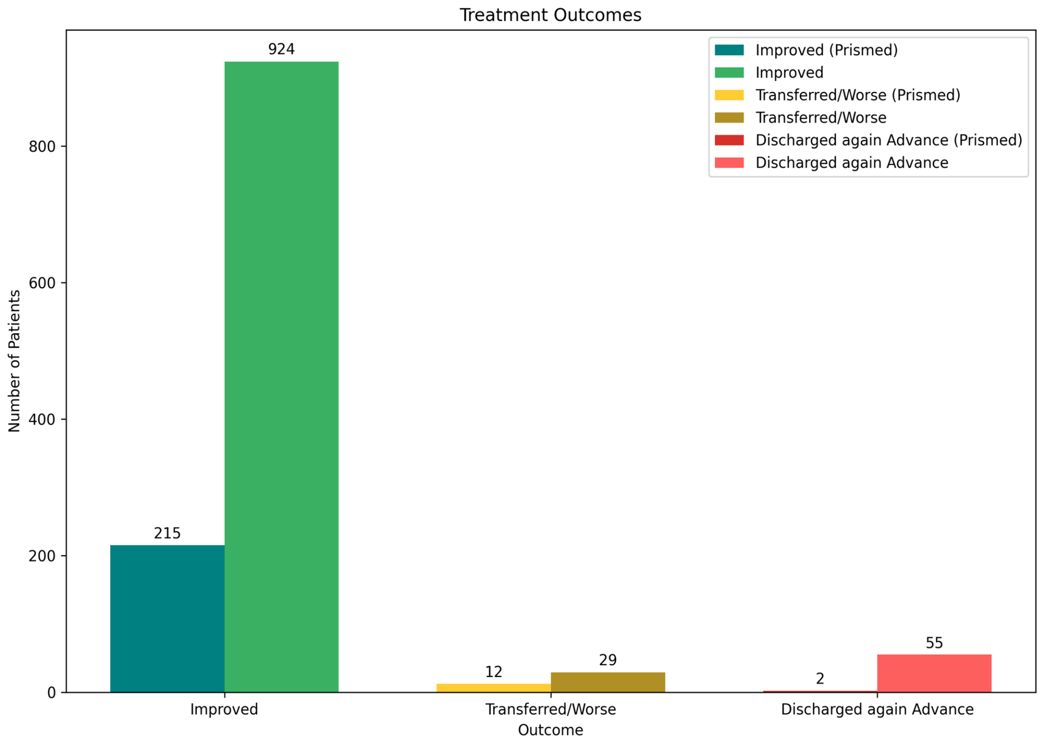

Figure 5. Treatment outcomes: distribution of patient improvements and deteriorations post-treatment.

The outcome indicators, depicted in **Figure 5**, showed that 215 patients (93.9%) were classified as "Improved", 12 patients (5.2%) were "Transferred" to tertiary care due to severe clinical deterioration (only one case related to sepsis), and 2 patients (0.9%) were "Discharged in preterminal condition or Deceased". Notably, all sepsis cases present at admission, including the 14 patients with healthcare-associated infections (HAI), were resolved at discharge. In comparison, 1008 patients were admitted to Geriatrics during the same period. Of these, 924 patients (91.4%) were discharged with "Improved" outcomes, 29 patients (3.2%) were transferred to tertiary care, and 55 patients (5.4%) were "Discharged in preterminal condition" or "Deceased".

4. Discussion

Hygienic patient care is of enormous importance in the treatment of community-acquired infections and in preventing HCAI. In support of this, bedside hygiene is classified as basic nursing care and not subjecting patients to this procedure can be considered an error of omission with the possibility of producing health problems for patients and costs for hospitals. In recent years, a movement has developed to study nursing care practices that, although considered absolutely indicated, are not performed on hospitalized patients, called Missed Nursing Care. The Missed Nursing Care survey [6] investigated which nursing care activities are not completed and how many. The study results show that a large percentage (nearly 70%) of all patients admitted to hospitals are put at risk due to omitted nursing care. Specifically, just over 60% of patient bed baths are omitted care. These omission errors can have serious implications on the costs associated with the clinical management of patients and/or the possible compensation claims for hospitals. Bed bathing is certainly the best system at the moment to take care of non-self-sufficient hygiene, treat bedsores, contain the spread of germs that they carry, and finally give a moment of comfort to the patient. In the present study, the inclusion of both patients admitted from emergency contexts and long-term care facilities ensured that the sample covered a diverse group, allowing for a more comprehensive analysis of the system's efficacy across different patient origins. This selection process ensures the reproducibility of the study by outlining clear criteria for patient inclusion based on their nursing or clinical needs. From the comparison of outcome indicators, it emerges that the COPERNICO group had a slightly higher rate of improvement, a lower rate of severe clinical worsening and preterminal discharge. The result that the patients treated with Copernicus had a better prognosis than the entire group of patients could be explained by a possible positive effect on the prognosis of the patients, or alternatively, it cannot be excluded that the self-sufficient patients were affected by diseases with poor prognosis worse. The bed bathing service does not seem very important what is used, whether chlorhexidine [7], ozone, proven effective in healing skin lesions [8], in aqueous solution (as in the present study) or oily or soap and water or disposable wet wipes [9]. Much more needs to be developed to define the economic analysis and costs of bed bathing, as reported in an excellent report on the subject [10]. It would also be interesting to evaluate patients' preferences [9]. It would be impossible to design a comparison study, due to the unattainable number of patients needed to treat (NNT), to validate a possible outcome indicator to be identified. At the beginning of the 2000s, robotic surgery was met with skepticism. Today, thanks to the Da Vinci Robot, a surgeon can perform a procedure remotely thousands of kilometers away. Similarly, the "COPERNICO Surveillance & Prevention" collaborative robots enable a medical director and their team to deliver robotic hygiene, surveillance and prevention services to hundreds of patients. They can remotely schedule hygiene interventions and set protocols based on continuous real-time data monitoring and analysis. Unlike traditional methods, which often use the same water for multiple areas of the body, the "COPERNICO Surveillance & Prevention" system ensures that fresh, sterilized water is used for each intervention in different areas of the body, minimizing the risk of cross-contamination, which is one of the key factors in infection control. The design of the robotic system allows for consistent and repeatable hygiene procedures that are superior to manual methods, reducing human error and ensuring thorough cleaning. It is well demonstrated [4] that to carry out a quality procedure, it is necessary to follow a predefined program checklist for body hygiene, such as the one reported in the certificate used in the COPERNICO system in **Figure 4**. Furthermore, the system is not intended to replace healthcare workers, but rather to assist them, improving their ability to maintain adequate hygiene standards without adding physical effort. This capability is especially critical in an era where increasing life expectancy makes patients more fragile, vulnerable, and susceptible to infections and pandemic events. Considering the aging population and the shortage of staff available for care, it is important to ask how we will respond to the following questions:

- Safety in hospital environments with increasing patient numbers and a reduction in staff, who are themselves aging and burdened by the strain of handling heavy workloads?
- Are necessary care practices guaranteed to all in an equitable, standardized, and certified manner?

"COPERNICO Surveillance & Prevention", covered by World Intellectual Property (WIPO) patent, can be considered a valid response for the intervention and prevention of infections in non-self-sufficient and/or non-self-sufficient patients, essential to prevent the proliferation and spread of bacteria from one patient to another, through fomites and/or through healthcare workers; this, whether it is the spread of germs causing CAI generally with a low level of antibiotic resistance, even if many reports document their increase, or whether it is an HCAI, characterized by high levels of antibiotic resistance. The system has proven to be suitable for solving the problem of personal hygiene in non-self-sufficient and/or non-self-sufficient patients and for preventing the spread of bacteria from one patient to another, through fomites and/or directly through healthcare workers, improving the control and prevention of infections, both in the same patient and in other hospitalized patients. "COPERNICO Surveillance & Prevention" system respects a predefined checklist in line with what Silva indicated [4] and demonstrates, through the collection of satisfaction sheets, that patients receive physical and psychological well-being; this is in line with what many authors invited to develop on the subject: respect for the patient's body and dignity [1], minimization of his possible perceived discomfort [2], reduction of the main causes of disability for nurses, due to difficulties in caring for elderly patients [3]. This initial report, focused on low-to-medium care hospital settings, shows encouraging results: discharge outcome indicators, despite the non-self-sufficient nature of the patients and, therefore, their severe prognosis, showed a clinical course that was overall similar compared to the entire patient group. This suggests that the interventions provided may have played a positive role in the overall care of these patients. Patients admitted for HCAIs did not pose a risk to other patients, confirming the effectiveness of the hygiene intervention system used to prevent the germ spread. The systematic recording of information related to the patients' clinical course, carried out during the robotic hygiene intervention, forms the basis for the continuous improvement of intervention methodologies, ensuring ongoing control over the ability to meet patients' care needs. This type of analysis is crucial for maintaining high standards of care, ultimately translating into a higher level of well-being for patients. Regarding pressure ulcers, if untreated, can progress to more severe stages, causing significant damage to the skin and underlying tissues, potentially involving muscles and bones. The results indicate that monitoring pressure ulcers is effective in detecting and treating them early, preventing their progression or occurrence. In addition to the data included in this study, the system can collect other data that the Medical Director or Risk Manager may consider useful for infection control, such as the types of bacterial isolations, sensitivity, and potential antibiotic resistance. This could allow for the analysis of sepsis flows in departments or suggest additional containment measures for patients with infections from highly resistant germs, such as individual isolation. "COPERNICO Surveillance & Prevention" can integrate functions deemed suitable for infection control monitoring, helping to identify risk patterns and develop effective preventive strategies. In synthesis, the COPERNICO System allows for real-time monitoring of the clinical situation and any sepsis present in a single patient or in all non-self-sufficient patients hospitalized at the same time, in the various rooms of the hospital, offering the possibility of evaluating any bacterial diffusion flows in the healthcare context analyzed. In recent years, there have been significant advancements in the field of robot-assisted bed washing systems, which integrate a range of capabilities to safely and effectively perform hygiene tasks. For instance, experimental systems such as RABBIT have been developed, featuring mannequin arms and leveraging multimodal perception technologies [11]. These systems, while innovative, primarily serve as proofs of concept or developmental models and have not yet been widely implemented in real-world healthcare settings. Unlike these experimental systems, the "COPERNICO Surveillance & Prevention" system has been fully implemented and is actively used in clinical environments. The practical application in these settings demonstrates its reliability and effectiveness, going beyond the theoretical or prototype stages often seen in newer technologies. Notably, throughout its deployment, it has maintained a flawless safety record; no side effects have been reported, and the robot has never crashed or caused any damage. This underscores the system's advanced design and operational stability, which ensure that high hygiene standards are consistently met without compromising patient safety. By integrating real-time data collection with standardized procedural checklists, "COPERNICO Surveillance & Prevention" ensures that the risk of infections is significantly reduced, enhancing patient care and providing tangible benefits to patients and staff alike. However, in accordance with Thomas Bock, many open questions remain: what degree of automation is suitable for which type of person? Can safety concerns, especially in the bathroom, be met by an automated bathroom? Can the system be modularized to meet the requirements of different room layouts? [12]. Future studies will use Robot-Assisted Patient Hygiene to answer these questions.

5. Conclusion

"COPERNICO Surveillance & Prevention" is able to collect and process patient data in real time. The analysis of the first 1000 interventions performed shows encouraging results from a clinical point of view and satisfaction from patients, their families and the healthcare personnel involved, who deserve to be reconfirmed in environments with a higher risk of infections, where any limitations can be more easily highlighted. For a better objective evaluation, it will be necessary to compare with other automated systems dedicated to patient hygiene or with more complex systems such as the multifunctional intelligent bed proposed by Zhao, which integrates multiple modes of interaction to improve the well-being of users with reduced mobility and reduce the workload of medical personnel [13]. However, the current lack of real-world applications of such sophisticated robotic systems in hospital settings makes direct comparisons challenging. Most available systems, including those recently developed, have not progressed beyond the prototype or trial phase in clinical environments. This gap in deployment limits the opportunity to perform exhaustive side-by-side evaluations under similar operational conditions. At the moment, it can be said that there is a great movement for the automation of hygiene systems for non-self-patients, which is dictated by the aging population and the need to contain the development and spread of multi-resistant germs. At the same time, the development of assistive robotics will have to be associated with a thorough ethical evaluation during its design, production and use [14], in order to fully respect the patient's dignity, developing innovative systems that also aim to minimize the possible discomfort perceived by patients [2]. As the adoption of robotic hygiene systems becomes more widespread, future studies should aim to gather comparative data to more definitively assess the relative performance and safety profiles of these innovative technologies. Notably, during the course of this study, no limitations were observed from a technical standpoint, as the robot operated without any mechanical failures or issues with movement or navigation. From a clinical perspective, there were no recorded adverse effects or complications, such as skin irritations, infections, or other unexpected reactions. The system demonstrated both operational stability and patient safety, reinforcing its potential for broader application in healthcare settings.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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