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Enhancing bedding hygiene in long-term care facilities: investigating the impact of multilevel antimicrobial polymers (MAP-1) on bacterial and MDRO reduction

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Abstract

Objective This study aims to assess the bactericidal efficacy of Multilevel Antimicrobial Polymer (MAP-1) on standard bedsheets in Long-term care facility (LTCF). The research quantifies total viable bacteria and MRSA counts and evaluates the percentage difference between treated and control bedding material over a one-week period. Design: A double-blind interventional, double cross-over study. Setting: Haven of Hope Woo Ping Care and Attention Home in Sai Kung, Hong Kong.

Methods Over an 8-week period, bedding materials from residents' rooms were sampled, totalling 288 samples from 96 bedsheets, with half treated with MAP-1 and the remaining serving as controls. MAP-1, developed at The Hong Kong University of Science and Technology, incorporates USFDA and USEPA-approved polymers. Sampling procedures adhered to standardized protocols, and bacterial counts were determined using culture methods. Data analysis employed *t*-tests and ANOVA to compare microbial loads between the control and treatment groups, with statistical significance set at $p < 0.05$.

Results The study revealed a significant reduction in total viable bacteria and MRSA counts on bedsheets treated with MAP-1. Noteworthy reductions of 80.37% for total bacteria and 87.31% for MRSA at the end of seven-day use, in the intervention group compared to the control. These reductions were statistically significant across all four observation periods and among both male and female residents.

Conclusion The study establishes the bactericidal efficacy of MAP-1 on standard bedsheets, showcasing its potential in diminishing total bacterial counts and MRSA contamination. These results hold promise for enhancing infection control practices and promoting improved sanitary conditions within healthcare settings.

Keywords MDROs contamination, Multilevel antimicrobial polymer (MAP-1) coating, Healthcare-associated infections, Bacterial reduction, Bactericidal efficacy, Long-term caring facility (LTCF)

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Introduction

The global population aged 60 and above is projected to increase dramatically, from 901 million in 2015 to an estimated 2.1 billion by 2050 [1, 2]. In Hong Kong, where life expectancy averages 87.09 years for women and 81.05 years for men, the elderly population is becoming increasingly significant [3, 4]. Approximately 15% of Hong Kong's population is currently aged over 65, a figure projected to exceed 30%, or 2.4 million people, in the next three decades [5].

Nearly 7% of Hong Kong residents aged over 65 reside in long-term care facilities (LTCFs), a rate significantly higher than China, Taiwan, Singapore, and Japan, where institutionalization remains below 3%. As the aging population continues to grow, the number of elderly individuals requiring care in LTCFs is expected to rise significantly [6]. Many residents in these facilities face reduced functional capacity, often compounded by conditions such as dementia, which presents substantial challenges to self-care and overall quality of life.

LTCF have been identified as critical reservoirs for multidrug-resistant organisms (MDROs), posing a significant health threat [7–9]. Studies show that these facilities play a crucial role in the dissemination of MDROs within the healthcare system. The prevalence of Methicillin-resistant Staphylococcus aureus (MRSA) among LTCF residents has increased from 2.8% in 2005 to 32.2% in 2015 [10, 11], with MRSA acquisition rates among residents approximately 3.4 times higher than those of non-residents [12, 13]. Additionally, outbreaks of vancomycin-resistant Enterococci (VRE) have occurred in both hospitals and elderly care homes, prompting urgent calls for improved infection control measures [14].

Residents with advanced dementia are particularly vulnerable to MDRO colonization [15, 16], with studies indicating a 48% acquisition rate within 12 months [17–19]. This heightened risk leads to more frequent hospitalizations, extended stays, and increased healthcare costs, negatively impacting residents' quality of life due to invasive isolation practices [20–22]. Furthermore, inappropriate antibiotic prescriptions in LTCFs contribute to elevated rates of multidrug-resistant organisms [23, 24].

Given the rising prevalence of MDRO infections in Hong Kong [25], there is an urgent need for innovative interventions to curb their transmission [26], particularly within LTCFs. This study aims to evaluate the bactericidal effectiveness of Multilevel Antimicrobial Polymer (MAP-1) coating on standard bedsheets, quantifying total bacterial counts and determining the reduction in MDRO contamination. By addressing the intersection of elderly health and infection control, this research seeks to enhance the well-being of elderly residents in LTCFs.

Methods

Study design and setting

A double-blind, double cross-over study was conducted at Haven of Hope (HOHCS) Woo Ping Care and Attention Home in Sai Kung, Hong Kong. Formal ethical approval was not required for this environmental sampling of residents' bedsheets; however, the study protocol and sampling plan were approved by HOHCS management. Sampling took place in the absence of residents, who were informed of the procedures. Bedsheets were collected from rooms on the third and fourth floors over an eight-week period from January to February 2019. A total of 288 samples were gathered from 96 bedsheets across four observation periods. To maintain blinding, matched-pair randomization was used, with two beds in each room serving as controls and the other two treated with MAP-1.

MAP-1 coating and bedding material Preparation

MAP-1 coating was developed in the laboratory at HKUST, comprising a combination of three polymeric materials: polyhexamethylene biguanide (PHMB), polyethyleneimine (PEI), and polyvinyl alcohol (PVA). All active ingredients were approved for use by the US Food and Drug Administration (USFDA) and the US Environmental Protection Agency (USEPA). The liquid MAP-1 formulation met safety requirements for human use. A 180-liter 1:16 dilution MAP-1 coating was prepared to treat 100 bedsheets. Clean bedding materials were immersed in the MAP-1 solution and gently agitated for 30 min before drying in the HOHCS laundry facility, coded, and placed on the designated beds.

Sample size and sampling frequency

The sample size for the main study was determined based on a laboratory-controlled test analyzing 80 samples over three weeks to compare viable microbial loads on control and treated bedsheets. The analysis revealed a significant reduction in total bacterial counts, with log 4.68 ± 0.05 CFU·m^{-2} for the control group ($n = 40$) and log 4.41 ± 0.05 CFU·m^{-2} for the treated group, confirming a 0.258 log reduction as per t-test results. To achieve 95% power with an alpha error probability of 0.05, a minimum of 185 specimens was required. Considering ward capacities and sampling logistics, a sample size of 288 was chosen for the interventional double crossover study.

In the 8-week study at LTCF, an initial phase involved collecting 108 samples from 36 bedsheets over four weeks to establish a baseline environmental bacterial load. Subsequently, a total of 288 samples were systematically collected from 96 bedsheets across four observation periods. Half of these samples ($n = 144$) were from control bedsheets subject to regular washing. Each week, the infection control team collected 72 samples from 24 bedsheets.

Environmental sampling method

Environmental samples were taken from the upper, middle, and lower sections of the bedsheets, representing the head, body, and leg areas, respectively, after 7 days of use in the LTCF resident's bed. Each sampling area, measuring 50 × 50 square cm, was swabbed using a sterilized sponge (POLYWIPE™, Medical Wire & Equipment, Corsham, UK), as illustrated in Fig. 1–(1). To ensure accuracy and minimize contamination risks, each sample was collected using a new sterile glove. The swabbed sponge was then promptly placed in a sterile, labeled bag (Fig. 1–(2)) containing 10 ml of a neutralizing solution composed of 30 g/L Polysorbate 80 (Tween 80), 30 g/L Saponin, and 3 g/L Lecithin. To maintain sample integrity during transportation, the bagged sponges were stored in a cold box before being transported to the laboratory.

Microbiological methods

The environmental samples were processed within 2 h of collection. Microorganisms were extracted by resuspending the sponge samples in the elution solution using a Vortex mixer (Thermolyne, Type 37600 Mixer, Maxi Mix II) set at maximum speed for 30 s (Fig. 1–(3)). Subsequently, as illustrated in Fig. 1–(4), 100 µl of the suspension were transferred onto 90 mm tryptone soya agar (TSA) culture plates to quantify total viable bacterial counts, with each sample plated in duplicate. Additionally, 100 µl of the suspension were plated on 90 mm CHROMagar™ MRSA agar plates, also in duplicate, to identify and confirm the presence of MRSA.

Following a 48-hour incubation at 35 °C to assess the bacterial load of the samples (Fig. 1–(5)), colony-forming units (CFUs), as shown in Fig. 1–(6), were enumerated. Colonies were counted based on distinct margins and colors, treating spreading colonies as single units. Optimal counts for accurate calculations ranged from 30 to 300 CFUs per plate. MRSA colonies, appearing pink mauve on CHROMagar™ MRSA agar, were differentiated from yellow, round-shaped colonies observed on TSA plates for total viable counts. Confirmatory testing for MRSA, including Gram staining, tube coagulase, and Staphaurex tests, all yielded positive results for Gram-positive cocci, confirming the presence of MRSA.

Data collection and statistical analysis

The use of duplicate plating was crucial for ensuring the validity of sample data, allowing for the identification and elimination of outliers. An average CFU count from the duplicate plates was calculated and reported. The total bacterial count provided an overall assessment of cleanliness, while the presence of MRSA indicates contamination by multidrug-resistant organism. Microbial loads were expressed in $\log_{10}$ CFU·m^{-2}, and plates with no growth were assigned a value of 0.5 CFU, based on the minimum detection limit determined in the dilution study.

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) for Windows, version 21.0 (SPSS, Inc., Chicago, IL, USA). The total bacterial counts from the bedsheets of the control and

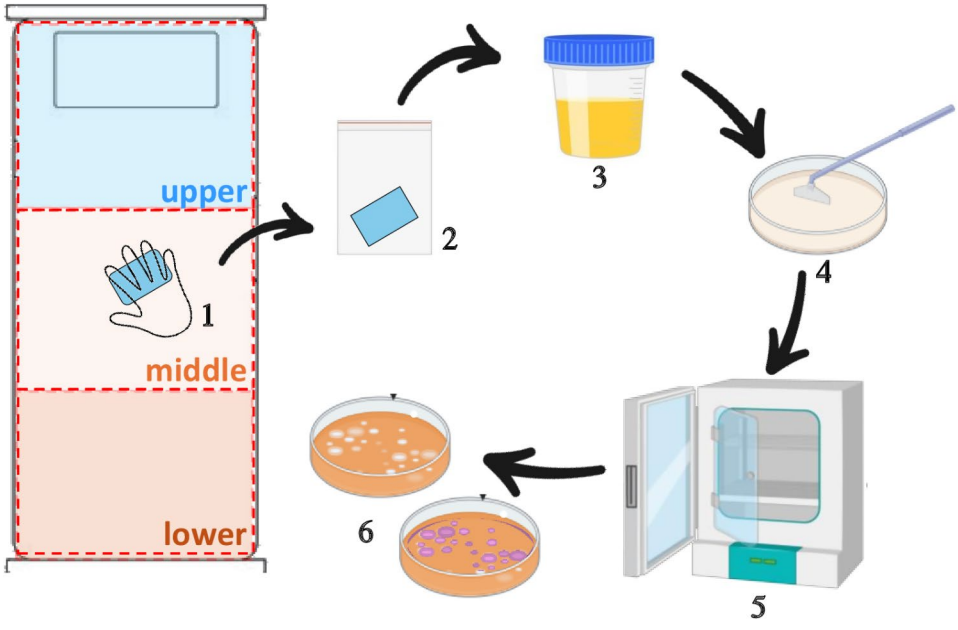

Fig. 1 Schematic drawing of the environmental sampling procedure (**1**), sample preservation (**2**), microbial extraction (**3**), bacterial plating (**4**), incubation (**5**), and enumeration (**6**)

treatment groups were compared using a *t*-test. Categorical variables, such as the percentage of MRSA presence, were assessed using the Chi-square test. Parametric tests were employed to evaluate the baseline cleanliness of each bed before and after treatment. Furthermore, ANOVA was employed to compare microbial loads across different periods of the study, as well as variations across different sections of a bedsheet and among bedsheets within the same resident area. Statistical significance was established at a *p*-value of less than 0.05.

Results

Figure 2 presents the baseline environmental bacterial load of 36 randomly selected bedsheets from the LTCF during the initial phase of the study. The total recovered culturable bacteria amount to 10^6 CFU· m^{-2} (Fig. 2a), with approximately 70% identified as Gram-positive bacteria (Fig. 2b). Among the recovered bacteria were antibiotic-resistant strains such as MRSA, Vancomycin-resistant Enterococci (VRE), multidrug-resistant *Acinetobacter* (MDRA), as well as opportunistic pathogens like *E. coli*, *P. aeruginosa*, *Acinetobacter* spp., *Klebsiella* spp. and other Enterobacteriaceae. MDROs accounted for 43.7% of the culturable bacteria, with MRSA being the most prevalent at 41%. Consequently, MRSA was selected as the marker species for MDRO in the trial study.

Figure 2c compares the total viable bacteria and MRSA detected on bedsheets belonging to male and female residents. The results reveal a higher bacterial contamination level on the bedsheets of male residents compared

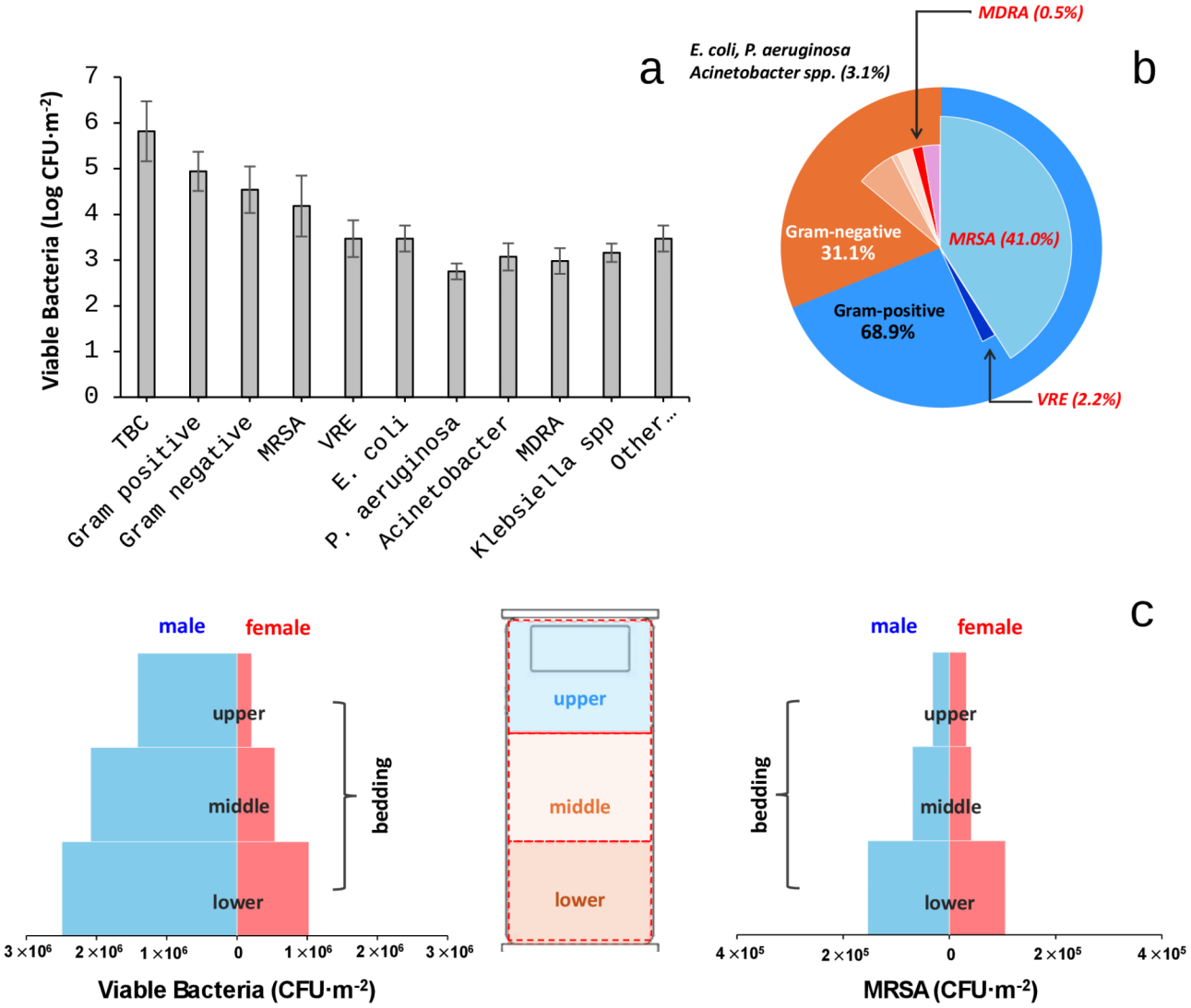

Fig. 2 (**a**) Logarithmic plots of viable bacterial counts (log CFU·m^{-2}) of drug-sensitive strains (*E. coli*, *P. aeruginosa*, *Acinetobacter spp.*, *Klebsiella spp.*, and *other Enterobacteriaceae*) alongside drug-resistant strains (MRSA, MDRA, and VRE) recovered from LTCF bedsheets during the initial phase of the study. (**b**) Percent distribution of Gram-positive, Gram-negative, drug-sensitive, and drug-resistant bacteria. (**c**) Comparisons of total viable bacteria (*left*) and MRSA (*right*) in CFU·m^{-2} found on the upper, middle, and lower sections of bedsheet (*middle*) from male and female LTCF residents

to those of female residents ($p < 0.0001$). Contamination on both male and female bedsheets was predominantly concentrated at the lower end, near the leg and feet areas. MRSA was detected on all bedsheets, indicating its widespread prevalence in the LTCF. Furthermore, a greater presence of MRSA was observed on male bedsheets primarily concentrated near the feet area. This discrepancy may be attributed to variations in hygiene practices between genders. Implementing policies emphasizing proper foot cleaning could potentially reduce MRSA loads. Additionally, establishing protocols for handling bedsheets contaminated with MDROs is crucial to prevent cross-infection within the LTCF.

Table 1 presents the results of the double-blind, double cross-over study conducted over four 7-day observational periods, showcasing total viable bacteria and MRSA counts in both the control group (clean untreated bedsheets) and the intervention group (clean MAP-1 treated bedsheets). The microbial counts were quantified in log (CFU· m^{-2}), with reductions documented in both log and percentage values. Statistical significance was established with a *p*-value below 0.05.

The results indicate a significant decrease in microbes on the intervention group bedsheets after seven days of use compared to the control group. Specifically, there was a 79.28% reduction in total viable bacteria ($p < 0.0001$). MRSA counts also exhibited a notable decline, with an 87.31% reduction ($p < 0.0001$). These trends were consistent across the four observational periods, as outlined in Table 1. The difference in total bacterial load between control and treatment groups differed by at least 69% or more in bedsheets treated with MAP-1 after seven days of use. Notably, the MRSA count decreased below a mean value of 3.40 log CFU·m^{-2}. In essence, the intervention with MAP-1 significantly enhanced the microbial cleanliness of the bedding, resulting in substantial reduction in both total bacterial and MRSA contaminants.

The total bacterial counts exhibited significant variations over the four-week study period, with the control bedsheets exhibiting 6.44, 5.59, 4.21, and 5.43 log CFU·m^{-2} for weeks 1 to 4, respectively. In contrast, the MAP-1 treated bedsheets displayed lower bacterial loads of 5.93, 4.93, 3.39, and 4.59 log CFU·m^{-2} for the corresponding weeks. These findings highlight the consistent efficacy of MAP-1 in reducing bacterial viability on bedsheets. Regarding MRSA, weekly reductions of 94.03%, 84.82%, 86.62%, and 78.58% were recorded (Table 1).

The lower sections of the bedsheets, where the legs and feet typically rest, exhibited higher contamination levels ($p < 0.0001$) than other areas. Additionally, there was a significant difference in bacterial loading between male and female residents' bedsheets, with male bedsheets showing higher levels of contamination ($p < 0.0001$). In terms of total bacteria, the upper section of untreated bedsheets (control) displayed a mean count of 5.44 log CFU·m^{-2}, which decreased to 4.84 log CFU·m^{-2} with MAP-1 treatment, resulting in 74.67% reduction. Likewise, the middle and lower sections of MAP-1 treated bedsheets exhibited percentage reductions of 83.77% and 78.39%, respectively, with mean counts decreasing from 5.72 log CFU·m^{-2} to 4.94 log CFU·m^{-2} and from 6.00 log CFU·m^{-2} to 5.33 log CFU·m^{-2}, as depicted in Fig. 3a.

Table 1 Total viable bacteria and MRSA counts on bedsheets: control vs. intervention across different observation periods and gender

		Total Viable Bacteria					Total MRSA				
Characteristics (Outcome Measures)	**Type of Bedsheets**	**Mean (viable bacteria) log (CFU·m^{-2}) with SD**	**SD error**	**Log reduction (CFU·m^{-2})**	**Reduction (%)**	***p*-value**	**Mean (viable bacteria) log (CFU·m^{-2}) with SD**	**SD error**	**Log reduction (CFU·m^{-2})**	**Reduction (%)**	***p*-value**
Overall Study	Ctrl group ($n = 144$)	5.72 (±0.6)	0.08	0.69	79.28%	0.00001§	4.21 (±0.7)	0.06	0.89	87.31%	0.00001§
	Int group ($n = 144$)	5.03 (±0.7)	0.09				3.31 (±0.7)	0.05			
Observation Period 1	Ctrl group ($n = 36$)	6.44 (±0.2)	0.2	0.52	69.60%	0.00001§	4.47 (±0.7)	0.11	1.22	94.03%	0.00001§
	Int group ($n = 36$)	5.93 (±0.3)	0.05				3.25 (±0.6)	0.10			
Observation Period 2	Ctrl group ($n = 36$)	5.59 (±0.6)	0.10	0.65	77.88%	0.00001§	4.21 (±0.7)	0.12	0.82	84.82%	0.00001§
	Int group ($n = 36$)	4.93 (±0.5)	0.09				3.39 (±0.6)	0.11			
Observation Period 3	Ctrl group ($n = 36$)	4.21 (±0.7)	0.12	0.82	84.82%	0.00001§	4.18 (±0.7)	0.13	0.87	86.62%	0.00001§
	Int group ($n = 36$)	3.39 (±0.6)	0.11				3.30 (±0.7)	0.12			
Observation Period 4	Ctrl group ($n = 36$)	5.43 (±0.6)	0.11	0.84	85.45%	0.00001§	3.97 (±0.8)	0.15	0.67	78.57%	0.00001§
	Int group ($n = 36$)	4.59 (±0.6)	0.11				3.30 (±0.8)	0.13			
Male Resident's beds	Ctrl group ($n = 72$)	6.02 (±0.6)	0.07	0.58	74.07%	0.00001§	4.34 (±0.7)	0.08	1.02	90.48%	0.00001§
	Int group ($n = 72$)	5.43 (±0.6)	0.08				3.32 (±0.6)	0.08			
Female Resident's beds	Ctrl group ($n = 72$)	5.41 (±0.5)	0.07	0.79	84.12%	0.00001§	4.07 (±0.8)	0.09	0.77	83.07%	0.00001§
	Int group ($n = 72$)	4.61 (±0.6)	0.07				3.30 (±0.7)	0.08			

Ctrl = Control; Int = Intervention; SD = Standard deviation; § ($p < 0.05$)

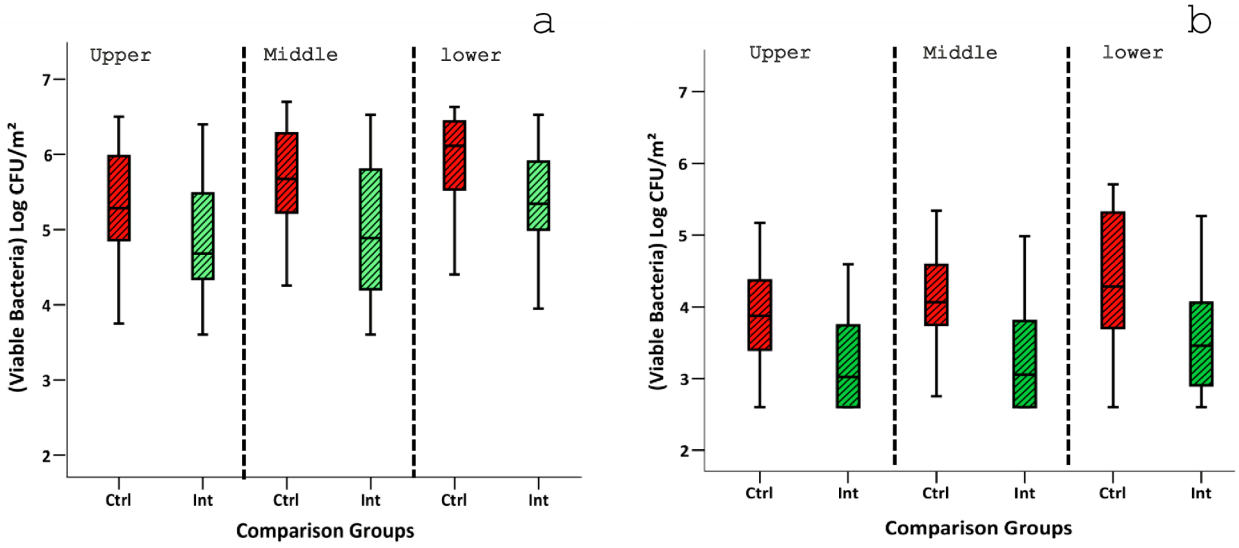

Fig. 3 Plots of total viable bacteria (**a**) and MRSA (**b**) recovered from upper, middle, and lower sections of the bedsheets. (Note: *Crtl* is the control group and *Int* is the intervention or treatment group)

The MRSA reduction was notably more significant (Fig. 3b). In the upper section, the mean count decreased from 3.98 log CFU· m^{-2} in regularly washed sheets to 3.20 log CFU· m^{-2} in MAP-treated ones, signifying a percentage reduction of 83.42%. The middle section's MRSA loading decreased from 4.21 log CFU· m^{-2} to 3.23 log CFU· m^{-2}, or 89.39% reduction, while the lower section shows an 86.60% decrease.

Table 1 compares the total viable bacteria retrieved from untreated bedsheets of male and female LTCF residents. The results indicate that bedsheets from male residents (6.02 log CFU· m^{-2}) are generally more contaminated with bacteria than those from female residents (5.43 log CFU· m^{-2}), with a statistically significant difference ($p < 0.0001$). Additionally, the MRSA load in untreated bedsheets was lower for female residents compared to male residents ($p = 0.032$, which is less than 0.05).

In terms of MAP-1 treated bedsheets, male residents experienced a reduction of 74.07% in total bacteria and 90.48% in MRSA compared to the control group. Conversely, female residents saw a decrease of 84.12% in total bacteria and 83.07% in MRSA in their MAP-1 treated bedsheets. These findings highlight the effectiveness of MAP-1 in reducing microbial contamination for both male and female residents' bedsheets.

The intervention led to an 80.37% reduction in total viable bacteria and an 87.31% reduction in MRSA. These reductions were consistent across all observational periods, suggesting that MAP-1 is a reliable antimicrobial treatment for bedding in LTCFs.

Discussion

The findings from this study underscore the critical issue of microbial contamination on bedsheets in LTCFs, particularly with the prevalence of MDROs, particularly MRSA. The baseline bacterial load of 10^6 CFU·m^{-2}, with MRSA accounting for 41% of this load, raises significant concerns regarding the potential for nosocomial infections in vulnerable populations. The presence of antibiotic-resistant strains, including Vancomycin-resistant Enterococci (VRE) and multidrug-resistant Acinetobacter, further complicates the infection control landscape, as these organisms can lead to treatment failures and increased morbidity [27, 28].

The observed gender differences in bacterial contamination levels, with male residents exhibiting higher levels of microbial load ($p < 0.0001$), may be attributed to variations in hygiene practices and personal care habits. Previous studies have indicated that male individuals may have less stringent hygiene routines compared to females [29], which could contribute to the elevated microbial counts observed on their bedsheets. The concentration of bacteria, particularly MRSA, in the lower sections of the bedsheets, suggests that areas in close contact with the skin are particularly susceptible to microbial colonization. This finding is consistent with existing literature that emphasizes the importance of targeted hygiene interventions in mitigating microbial transmission [30], especially in healthcare settings where the risk of infection is heightened.

The intervention with MAP-1 demonstrated significant efficacy in reducing microbial presence on bedsheets.

The substantial reductions of 79.28% in total viable bacteria and 87.31% in MRSA over seven days of use indicate that MAP-1 has a long-term efficacy. The sustained differences in microbial counts between the control and intervention groups throughout the four-week study period provide compelling evidence for the robustness and durability of MAP-1's antimicrobial properties.

Moreover, the pronounced reductions in MRSA, particularly in the lower sections of the bedsheets, highlight the potential role of MAP-1 treatment in infection control strategies. The ability of MAP-1 to maintain lower microbial counts, even during weeks with heightened overall microbial levels, suggests that the coating's antimicrobial properties are not only immediate but also long-lasting. This is particularly important in LTCFs, where the risk of infection transmission is exacerbated by the presence of vulnerable residents who may have compromised immune systems [31].

The persistent presence of MRSA on all sampled bedsheets reinforces the need for effective antimicrobial solutions. The implications of MRSA colonization are significant, as it poses a considerable risk for the development of severe infections, which can lead to prolonged hospital stays and increased healthcare costs [32]. By integrating MAP-1 treated bedsheets into standard care practices, LTCFs can substantially reduce the microbial load on bedding, thereby lowering the risk of infection transmission.

Furthermore, the training of staff on best practices for cleaning and handling contaminated linens is essential for strengthening infection control efforts. The observed gender-specific differences in microbial load necessitate tailored educational programs that address these disparities [33, 34]. Effective dissemination and implementation of infection control measures are crucial for supporting the health and safety of residents, particularly the elderly, who are at increased risk for infections.

Conclusion

The study shows that MAP-1 treated bedsheets significantly reduce microbial contamination, particularly MRSA, in LTCFs. This highlights both the effectiveness of MAP-1 and the importance of strong hygiene and infection control measures. Beyond healthcare, these results suggest wider applications for antimicrobial treatments in hospitals, nursing homes, and households. Implementing MAP-1 technology offers a promising solution for combating resistant strains and improving hygiene standards, potentially boosting public health by reducing infection spread.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13756-025-01555-0.

Supplementary Material 1

Supplementary Material 2

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Author contributions

AF contributed to data collection, methodology, data analysis and statistical software, writing of original draft. HW and JK helped in funding application, methodology, review, and editing of draft. KLY contributed to conceptualization, funding application, project supervision and administration, review, and editing of draft.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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