



OPEN The implications of healthcare professionals wearing jewelry on patient care biosafety: observational insights and experimental approaches

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The use of jewelry among healthcare professionals poses a risk of cross contamination due to potential bacterial accumulation and spread. Through a mixed-method design, this study first analyzed the implications of healthcare professionals wearing jewelry on patient care biosafety as well as on the residual bacterial load of hands and rings after hand hygiene. Firstly, an observational prevalence study to verify whether nursing professionals wear personal accessories during healthcare assistance was carried out. Second, an experimental design involving intentional contamination and hygiene of the hands, with and without a ring, was conducted. The bacterial load of both hands and rings was measured by counting colony forming units. The observational study showed that nursing workers frequently wear jewelry during healthcare assistance. Nonetheless, the experimental study did not indicate differences in bacterial contamination between hands with and without a ring, despite the hand hygiene procedure applied. In conclusion, many nursing workers wear jewelry in the workplace. Although hands with and without a ring exhibited similar microbial load, rings appeared as a potential source of bacterial contamination, reinforcing the need to remove jewelry during working hours. Hand hygiene using alcohol, or soap and water significantly decreased the bacterial load on the participants' hands, with handwashing proving to be the most efficient method for removing intentional contamination.

Keywords Biosafety, Hand hygiene, Health workers, Hospital infection, Jewelry

The hands of healthcare workers are among the main routes of transmitting microorganisms responsible to cause healthcare-associated infections (HAIs)¹. Besides hands, other environmental factors such as contaminate hospital surfaces, equipment, mobile phones and workers' clothing are associated with pathogen transmission^{2,3}. Hence, it is important to consider that wearing personal accessories could be an additional factor that contributes to the spread of microorganisms^{4,5}.

Considering the critical status of ESKAPE pathogens (i.e. *Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa* and *Enterobacter* spp.), and multidrug-resistant microorganisms, the importance of hand hygiene in preventing HAIs transmission has repeatedly been pointed out⁶. Many studies have linked the use of personal accessories with increased risk of transferring microorganisms. It is generally accepted that the skin covered by a ring remains contaminated even after hand

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hygiene^{7–12}. Khodavaisy et al. reported that 73.1% of hands and rings of health workers were contaminated by bacteria and fungi frequently associated with nosocomial infections⁵.

Wearing jewelry during healthcare assistant procedures raises concerns about its impact on regular and appropriate hand hygiene¹³. This issue, added to the low adherence of health workers to hand hygiene guidelines, can be associated with pathogen transmission and a source of HAIs transmission⁴. Although the Brazilian guideline (Regulatory Standard 32)¹⁴ bans the wearing personal accessories by healthcare workers and international guidelines^{15,16} recommend their removal before beginning surgical hand preparation, their use is frequently associated with relationships (wedding), professional jewelry (graduation rings), and religious reasons. Since previous reports indicate that the use of jewelry contribute to overall hand hygiene protocols^{10,12,13}, attempts have been made to address the quality of the hand hygiene technique among health workers wearing jewelry. However, most studies addressing this topic lack standardized methodological approaches, hindering the ability to draw definitive conclusions¹⁶. Hence, there is still a need to investigate the real impact of wearing a single plain ring on hand hygiene in order to obtain evidence on whether it significantly influences and compromises the quality of the procedure.

Therefore, this study aimed to identify the prevalence and the reasons why nursing workers fail to adhere to the Brazilian guideline (Regulatory Standard 32)¹⁴ and international guidelines^{15,16} that discourage personal adornments and accessories in the workplace. In parallel, in an in situ microbiological assay, it was evaluated whether the use of rings alters the bacterial load of hands, as well as whether it implies hand hygiene by hand-washing with soap and water is more effective than rubbing with 70% alcohol.

Methods

Study design

This study was conducted in two stages: (I) The first step comprised an observational prevalence study that provided insights into the wearing of jewelry by healthcare workers. (II) In the second step, an in situ microbiological experiment, which intentionally contaminated the participants' hands in the presence or absence of a ring, was carried out. The study was approved by the local Human Research Ethics Committee under protocol CAAE: 11213219.0.0000.5393 and all methods were carried out in accordance with relevant guidelines and regulations. The research protocol was started only after securing written informed consent from all participants and/or their legal guardian(s), confirming their informed and voluntary approval.

Observational prevalence study

To carry out the prevalence study, the adherence of nursing workers to the Brazilian guideline (Regulatory Standard 32)¹⁴ and international guidelines¹⁵ that discourage the use of jewelry during working hours in health facilities, and the barriers impeding their adherence were assessed. The sampling method was the “virtual snow-ball”, started by sending invitations with the access link to the electronic questionnaire (mandatory response to all questions) through the WhatsApp virtual social network or by email for nursing workers in various hospitals across the Brazil to collect information concerning social, cultural, and institutional aspects of wearing jewelry (Supplementary document 1). All professionals responded voluntarily, without any remuneration or compensation for their responses. It is noteworthy that before submitting the questionnaire to the study participants, the process of content validation by experts according to the Delphi technique was carried out to ensure the clarity and objectivity of the questions in the questionnaire. Data were collected from March 22nd to April 30th, 2021, in a groups of nursing workers in Brazil (i.e., nurses, nursing auxiliaries, and technicians). The inclusion criteria were nursing workers providing direct care to hospitalized patients and accepting the invitation.

In situ microbiological experiment

To carry out the microbiological experiment, 60 volunteers (healthcare professionals and students from the nursing, medical, dentistry, and pharmacy school) of both sexes were invited. Volunteers with skin lesions on their hands, treating fungal nail infections, taking immunosuppressant or antimicrobial agents (topical or cutaneous) or wearing artificial nails were excluded. Stainless steel wedding rings without external notches, grooves, and stones were selected according to the volunteers' finger size.

A standard test method for evaluation of the effectiveness of healthcare personnel handwash formulations was followed, with modification, for intentional contamination of participants' hands, hands hygiene, and microbial recovery¹⁷. Briefly, the participants were trained to wash their hands with non-antimicrobial neutral liquid soap (Protex baby; Colgate Palmolive, São Paulo, SP, Brazil) according to the standard technique recommended by WHO to reduce dirt and microbial load^{1,15}. The participants then dried their hands using six sheets of previously sterilized paper towels to avoid carrying microorganisms from another source. The volunteers received a sterile ring on their right hand (ring finger) and both hands were artificially contaminated with 50 mL of Tryptic Soy Broth (BD Difco, Sparks, MD, USA) containing *Lactobacillus casei* (ATCC 334) [10^8 Colony Forming Units per milliliter (CFU/mL)]. Contamination occurred by immersing each of the participants' hands into plastic bags with 50 mL of the culture medium with bacterium inoculum. Two researchers simultaneously massaged the participants' palms, backhands, and fingers for one minute; each researcher massaged one hand for 30 s and then swapped hands to prevent bias between the researchers. Subsequently, the hands were removed from the polyethylene bags, kept suspended for three minutes to dry, and finally considered contaminated in a standard manner.

The volunteers were randomly assigned into one of three groups each having 20 members. These groups were based on one of two standard hand hygiene techniques recommended by WHO and a control group: Group 1 [hand hygiene with alcohol-based handrub (Start Química, RJ, Brazil)]; Group 2 (handwashing with non-antimicrobial liquid soap); Group 3 (Control, no hand hygiene)¹.

To proceed with the collection of microorganisms after the hand hygiene procedure the participants were instructed to individually immerse their hands into plastic bags containing 50 mL of Lethen Broth medium (BD Difco). Two researchers simultaneously massaged the participants' hands as mentioned previously. Afterward, the participant removed the ring using sterilized gauze and transferred it to a polystyrene conical tube (50 mL; TPP, Trasadingen, Switzerland) containing 15 mL of Lethen Broth. Aliquots of 50 μ L from the hands (polyethylene bags) and rings (polystyrene conical tubes) were immediately seeded onto Rogosa Agar (BD Difco) and Mannitol Salt Agar (BD Difco) in Petri dishes (60 $\times$ 15 mm). Petri dishes and polystyrene conical tube were incubated at 37 °C for 24 to 48 h or until reaching turbidity. After turbidity was registered the suspension was seeded onto Rogosa Agar and Mannitol Salt Agar in Petri dishes to verify the growth of *L. casei* and *Staphylococcus* spp. The number of CFU was registered and presented as $\log_{10}$ CFU/mL. An overview of the methodological design is presented in Fig. 1.

Statistical analysis

Data from the observational prevalence study were presented as absolute frequency values.

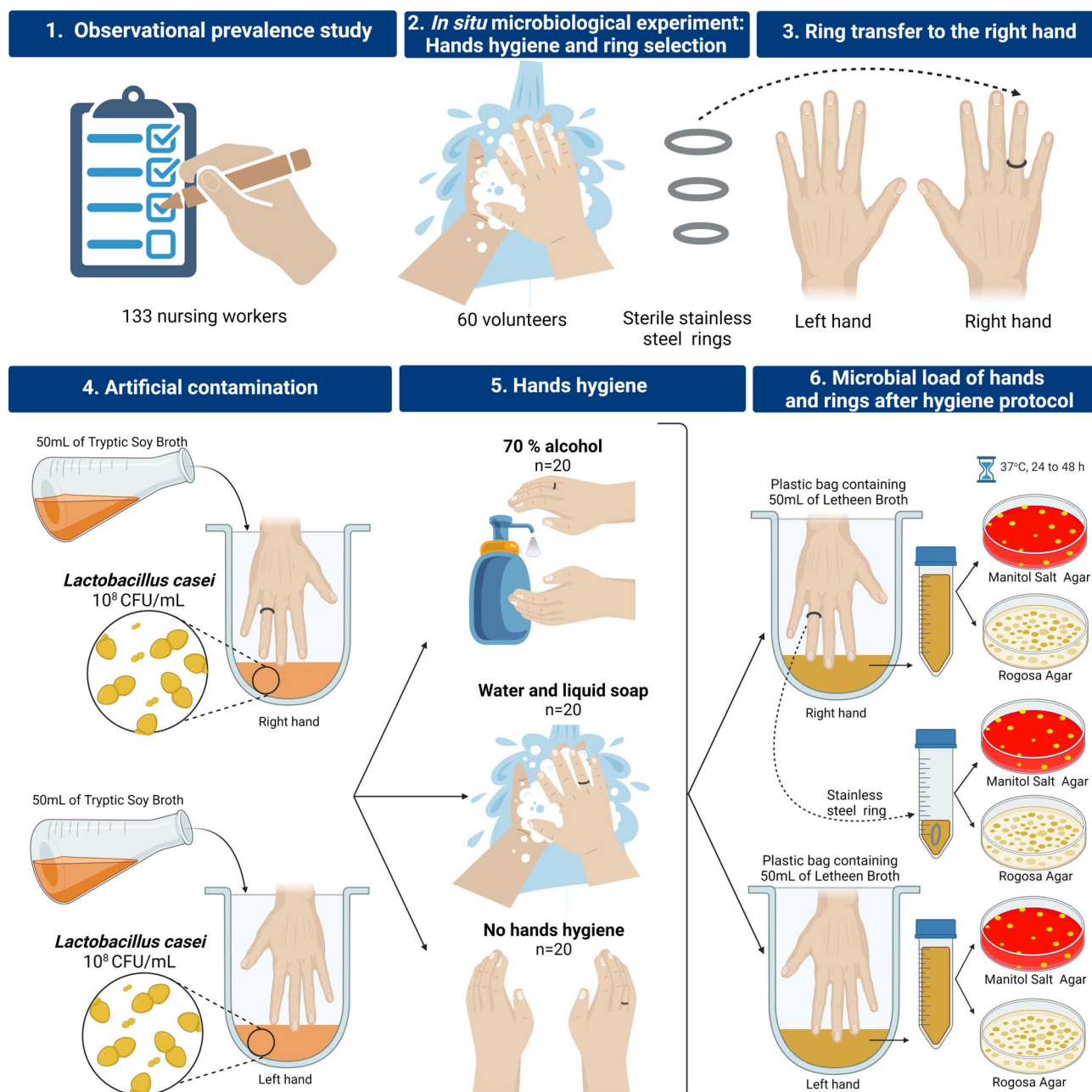


Figure 1. Methodological design overview. This figure provides an overview of the methodological design used in the study, illustrating the step-by-step process and key components involved in the research methodology.

For the in situ microbiological experiment, the sample size was estimated by considering statically significant changes in the bacterial counts ($\log_{10}$ CFU/mL). Based on the study of Trick et al. it was admitted that the hand wearing ring would be associated with tenfold ($\log 1$) higher skin organism counts¹⁰. A pilot study with five participants indicated that the standard deviation in the bacterial counts of intentional contaminated hands is $1.5 \log_{10}$ CFU/mL. Thus, a total of 20 participants / group were considered sufficient to detect relevant differences ($\alpha = 0.05$; $\beta = 0.20$)¹⁸.

The normality and homogeneity of variances of data were verified using the Shapiro–Wilk test, and Levene test, respectively. Due to the non-normal distribution, Brunner and Langer’s non-parametric analysis of longitudinal data in factorial experiments (nparLD package¹⁹) was used (The R foundation for statistical computing, version 3.6.2). Turbidity in the polystyrene conical tubes was analyzed using Fisher’s exact test. The significance level was set at 0.05 for all the analyses.

Results

Observational prevalence study

A total of 133 nursing workers participated of the study: 113 (85.0%) were women, and 20 (15.0%) were men. Nurses were the workers who most frequently completed the questionnaire among all the professionals. Regarding the workplace of nursing workers, the critical ward appeared most frequently (55.0%). Regarding wearing jewelry in the work environment, the following stood out: rings (14.1%), badges with strings (12.3%), and wristwatches (9.5%). The participants who did not wear any personal accessories presented the highest prevalence (35.3%). When asked about what accessories the participants considered important to remove at the workplace, 14.4% reported rings, 12.1% wedding rings, and 12.1% wristwatches. Regarding training programs provided by their institutions, 66.1% of the participants reported having received training, while 24.8% reported that no training regarding the use of personal accessories was provided; 9.0% did not know. Whether the institutions supervised the use of personal accessories, 62.4% participants reported supervision on the part of their employers, 31.5% reported no supervision, and 6.0% did not know. As for the health workers’ knowledge regarding the consequences of wearing personal accessories at work, most participants (88.7%) reported that these are related to an increased spread of microorganisms, while 9.8% reported that the use of accessories is not related with the spread of microorganisms in a hospital setting. Table 1 summarizes the variables of the observational prevalence study.

In situ microbiological experiment

There were no statistically significant differences in the bacterial load of the hands with and without rings (*L. casei*: $p = 0.465$; *Staphylococcus* spp.: $p = 0.985$), as well the ringed hand had no impact across all the three hand hygiene protocols (*L. casei*: $p = 0.126$; *Staphylococcus* spp.: $p = 0.667$). Therefore, the null hypothesis could not be rejected, indicating that wearing a ring did not change the *L. casei* or *Staphylococcus* spp. load on hands (Table 2). Only the hand hygiene protocol, evaluated as an isolated factor, altered the bacterial load ($p < 0.001$). Handwashing with soap and water significantly reduced the load of *L. casei* (Median: 3.60; 95% Interval confidence of mean: 2.74–3.55) in comparison with hand hygiene with 70% alcohol-based handrub (Median: 4.72; 95% Interval confidence of mean: 4.02–4.84) and no hand hygiene (Median: 6.46; 95% Interval confidence of mean: 5.91–6.42). However, no statistically significant differences ($p = 0.094$) were found among the groups when *Staphylococcus* spp. was analyzed (Table 2).

Table 3 shows that 80% (16), 10% (2), and 90% (18), of the polystyrene conical tubes with rings from Groups 1, 2, and 3, respectively, showed *L. casei* after 48 h of incubation. This finding indicates that the *L. casei* load on the rings decreased after handwashing with soap and water ($p < 0.001$). Regarding *Staphylococcus* spp., no statistically significant difference was found among the groups ($p = 0.302$).

Integration of results

The integration of results from the observational and in situ studies allowed to assess the potential risk posed by nursing professionals wearing personal accessories during healthcare assistance. In fact, nursing professionals wear jewelry in the work environment. Nonetheless, when quantifying the bacterial load of the hands with and without rings no difference was observed. The findings suggested that the practice of wearing one ring that does not feature with any decorative notches or gemstones is not associated with an elevated microbial load on hands. The results also underscore the importance of adhering to hand hygiene protocols to minimize the risk of microbial transmission in healthcare settings.

Discussion

Personal accessories were prevalent among nursing workers, mainly wristwatches, string hanging badges, neckties, earrings, and rings. This fact was explored in 2011 by a study assessing the hygiene conditions of health workers’ nails and how frequently they wore jewelry. The study reported that 49% out of 344 health workers wore one or more jewelry pieces, and more than half of the sample wore wedding rings and wristwatches²⁰.

Removing jewelry at the workplace is an organizational policy change recommended decades ago in Brazil and supported by the Brazilian guideline (Regulatory Standard 32)¹⁴. Here, the evidence suggests that health workers do not fully adhere to this recommendation in their practices. This matter was recently discussed by Greenshield and collaborators in 2020 who highlighted that nurses should remove or move away jewelry when performing antisepsis of the skin surfaces superimposed by jewelry¹³. Although the use of personal accessories has been discouraged by health regulations, it remains a cultural issue that demands attention.

The findings reveal that the participants fail in removing personal accessories because they do not recognize the importance of the action or do not consider that the objects are a source of transmission of microorganisms.

Variables	n	%
Gender		
Female	113	85.0
Male	20	15.0
Professional category		
Nursing assistant	2	1.5
Nurse	101	76.0
Nursing technician	30	22.5
Hospital sector		
Critical area	73	55.0
Non-critical area	20	15.0
Semi-critical area	40	30.0
Use of jewelry		
Don't use jewelry	47	35.3
Wristwatch	13	9.5
Metal hair clip	5	3.6
Bracelet	4	2.7
Piercing exposed	2	1.8
Necktie	1	0.5
Badges with strings	16	12.3
Necklace	7	5.0
Earring	12	19.1
Ring	8	3.6
Marriage ring	19	14.1
Important to remove during assistance		
Wristwatch	2	12.1
Metal hair clip	8	6.0
Bracelet	9	7.0
Piercing exposed	15	11.6
Necktie	15	11.3
Badges with strings	15	11.1
Necklace	17	13.1
Earring	11	8.3
Ring	19	14.4
Marriage ring	16	12.1
Knowledge about regulatory standard		
Know	113	85.0
Don't know	4	3.0
Knows in part	16	12.0
Received training on regulatory standard		
Yes	88	66.2
No	33	24.8
They did not answer	12	9.0
Institution supervised the use of personal accessories		
Yes	83	62.4
No	42	31.6
They did not answer	8	6.0
Comply with regulatory standard		
Yes	91	68.4
No	28	21.1
They did not answer	14	10.5
Relationship between jewelry and cross infection		
There is relationship	118	88.7
There is no relationship	13	9.8
They did not answer	2	1.5

Table 1. Frequency (n) and percentage (%) of variables of the observational prevalence study.

Hygiene protocols	Site		Protocol*
	Right hand	Left hand	
<i>Lactobacillus casei</i>			
Alcohol	5.51 (4.89—5.75)	5.08 (3.90; 5.58)	4.72 (4.02; 4.84) ^b
Soap	3.54 (2.42—3.71)	3.60 (2.69; 3.76)	3.60 (2.74; 3.55) ^c
Control	6.41 (5.78—6.54)	6.46 (5.78; 6.55)	6.46 (5.91; 6.42) ^a
Hands*	5.24 (4.41—5.28)	4.96 (4.25; 5.17)	
<i>Staphylococcus</i> spp.			
Alcohol	5.43 (5.09—5.76)	5.29 (5.11; 5.78)	5.30 (5.10; 5.47)
Soap	5.34 (4.56—5.37)	5.04 (4.59; 5.30)	5.22 (4.73; 5.22)
Control	5.24 (3.77—5.46)	5.17 (4.11; 5.50)	5.24 (4.21; 5.20)
Hands*	5.33 (4.68—5.30)	5.26 (4.83; 5.35)	

Table 2. Median (95% Confidence interval of mean) of *Lactobacillus casei* and *Staphylococcus* spp. counts, showed in log₁₀CFU/mL, on right hand (with ring) and left hand (without ring) after different hygiene protocols. Statistical comparisons were carried out through Brunner and Langer’s non-parametric analysis of longitudinal data in factorial experiment (nparLD)¹¹. *In absence of interaction between hands and hygiene protocol the isolated effect of each factor was evaluated. ^{ab}Different lowercase letters indicate statistically significant difference among hygiene protocol.

<i>Lactobacillus casei</i>				<i>Staphylococcus</i> spp.			
	No	Yes	p*		No	Yes	p*
Alcohol	4 (20%)	16 (80%)	< 0.001	Alcohol	0 (0%)	20 (100%)	0.302
Soap	18 (90%)	2 (10%)		Soap	2 (10%)	18 (90%)	
Control	2 (10%)	18 (90%)		Control	0 (0%)	20 (100%)	

Table 3. Assessment of bacterial residual contamination of the rings after hygiene protocol. *Fisher’s exact test.

Additionally, some participants reported that there is a fear of removing jewelry in the workplace and losing it. A previous Brazilian study showed the relationship between the banishment of personal accessories and professional self-concept. The study demonstrated that professional self-concept were influenced by the lack of jewelry, time since graduation, and position. The participants reported they missed wearing jewelry at work, especially earrings, wristwatches, and wedding rings²¹. In this sense, it is important to note that institutions need to encourage and demand workers to remove jewelry and personal accessories. Improved leadership is critical to ensuring success in these situations. The number of nurses wearing jewelry decreased from 15 to 3%, mainly in the wards where a strategy was implemented by teams and leaders²².

Even though most nursing workers reported that they had received some training and were aware of regulatory guidelines, many workers reported partial or total ignorance of the standard recommending that workers do not wear personal accessories in health facilities. These results corroborate the study conducted in 2012 in which nurses revealed unfamiliarity about regulatory guidelines. The authors reported that 80% of the professionals revealed they had never received any training addressing this topic, 67% did not know the purpose of the regulatory guideline, and 57% reported poor knowledge about the topic²³.

The hands and rings of health workers are contaminated with various types of microorganisms, including fungi and bacteria such as *Staphylococcus* spp. Greenshield and collaborators in 2020 implemented a descriptive and comparative study to assess bacteria on the skin of nurses, from an intensive care unit, at baseline and 30 days after removing jewelry. The bacteria identified included: *Bacillus*, *Micrococcus*, *Staphylococcus* coagulase-negative, *diphtheroid*, *streptococci*, and non-enteric gram-negative rods. The number of bacteria decreased significantly after the intervention, corroborating the need to remove or move jewelry when washing hands or rubbing hand sanitizers to clean the underlying skin¹³. Additionally, the perforation rate of gloves was demonstrated to be higher at the base of the ring finger when professionals wear wedding rings²⁴.

This study, however, did not indicate a difference regarding the bacterial load of artificially contaminated hands with and without rings. Moreover, the presence of a ring has not influenced the hand hygiene protocol by washing with soap and water or rubbing with 70% alcohol. In agreement with our findings, recent studies showed that the presence of single plain ring was not associated with an increased hand bacterial load or impacted the transmission of *Staphylococcus aureus* and glucose-nonfermenting gram-negative bacteria^{11,25}. Nonetheless, healthcare workers should remove rings when wearing gloves because glove leak rates were significantly higher when wearing rings²⁶. Other studies also revealed no differences on the microbial load of hands with and without rings^{27,28}. In contrast, some studies indicate a larger number of microorganisms on the hands of workers wearing rings than of those who do not^{12,29,30}. Trick et al. in a multivariate analysis of 564 hands demonstrated

that health workers wearing a ring were ten times more likely to harbor microorganisms (*Staphylococcus aureus*, gram-negative bacilli, or *Candida* spp.)¹⁰. Besides, Hoffman et al. evaluated 50 nurses in medical and surgical wards who wore rings permanently, showing that the microbial load was greater on the surface of the fingers under the rings than on the fingers without the rings³¹. Moreover, the pattern of isolation of gram-negative bacilli suggested that these bacteria were colonizers than transient contaminants because the same strains were persistently isolated over several months.

It is widely accepted that hand hygiene is vital to prevent hospital-acquired infections, since it has been proven that hand hygiene considerably decreases the number of microorganisms on the skin surface³². Hautemienere and collaborators indicated that wearing a ring was associated with decreased hand hygiene quality³³. A literature review reports that wearing a ring while performing hand hygiene impairs the technique's effectiveness, corroborating that wearing a ring when providing care to patients can considerably impact microbial contamination of hands³³. Most studies evaluated health workers, such as physicians, nurses, and nursing technicians to perform microbiological analyses of hands and rings. Here nursing professionals were included because these workers are directly and constantly in contact with patients during care delivery, and for this reason, are considered the primary agents of microbial transmission in health settings³⁴.

It was expected that a greater bacterial load was present on the right hand (with ring). Thus, in view of the inconsistency with preceding results, we suggest the chosen ring, with a stone, notches or grooves could have influenced the result. Nonetheless, a previous study carried out in a pediatric emergency care unit, assessed the effect of wearing a ring and types of rings on the contamination of hands and the effectiveness of alcohol-based sanitizer among nurses working in ICUs. The results showed that the nurses randomly assigned to wear a plain ring or a ring with a stone presented a higher amount of gram-positive and gram-negative bacteria after rubbing alcohol than those not wearing a ring. However, no differences were found between the plain ring and the ring with a stone²⁹.

The findings of this study indicate that handwashing with soap and water considerably decreased the contamination with *L. casei*. Breidablik et al. also suggested that hand washing with soap and water is effective to decrease microbial load³⁵. Overall, it is considered that handwashing with soap and water or rubbing with alcohol are efficient methods, even though both present limitations³⁵. Different studies have pointed that alcohol-based hand sanitizer can be used to perform hand hygiene before and after direct contact with patients receiving clinical care^{36–38}. One deviation from this indication occurs when hands are visibly soiled or potentially contaminated with body fluids, thereby recommending the use of soap and water for hand hygiene, while acknowledging that in inadequate settings, hand hygiene with alcohol can be particularly beneficial^{36,37}. According to Hillier, handwashing with soap and water is accompanied by a mechanical process that helps remove contaminants from hands³⁹. Our findings corroborate the author's statement, indicating that mechanical process on handwashing may explain the reduction in the microbial load in comparison to rubbing with alcohol.

Certainly, an advance on current knowledge was reached; however, we are aware that our research may have limitations. It includes the small number of participants in the prevalence observational stage and the fact that the participants do not represent all professions in the health field listed in the Brazilian Code of Occupations. Additionally, the fact that a non-pathogenic food-borne bacterium (*L. casei*) was used to artificially contaminate the participants' hands in the microbiological stage configures a limitation because it does not represent the microbiota prevalent in HAIs. However, this technique was selected to prevent exposing volunteers to *Serratia marcescens*, a pathogenic bacterium preconized by ASTM as alternative to *E. coli*¹⁷. However, it is important to highlight that scientific literature suggests that alcohol works by denaturing proteins and rendering cell membranes permeable, offering similar effects against Gram-positive and Gram-negative bacteria⁴⁰.

Despite such limitations, our study provides new insight on the knowledge related to the onset of the jewelry-wearing context among health workers in a hospital setting and the reasons for the low adherence to regulatory guidelines that discourage the use of jewelry. Additionally, it revealed the need to provide opportunities for workers to obtain information regarding regulatory guidelines due to its importance for occupational safety. Regarding the microbiological experiment stage, two hand hygiene techniques were assessed against two different bacteria species, one artificially contaminating the participants' hands and rings and one that belonged to the volunteers' microbiota. Overall, both gram-positive bacteria were highly resistant to physical and chemical agents, enabling the inference that rings are a potential source of bacterial contamination even when hand hygiene decreases the hands' bacterial load.

In conclusion, contrary to the recommendation of the Brazilian guideline (Regulatory Standard 32), many nursing workers wear jewelry in the workplace. Although hands with and without a ring exhibited similar microbial load, rings appeared as a potential source of bacterial contamination, reinforcing the need to remove jewelry during working hours. Hand hygiene using alcohol, or soap and water significantly decreased the bacterial load on the participants' hands, with handwashing proving to be the most efficient method for removing intentional contamination.

Data availability

The data that support the findings of this study are available on request from the corresponding author (E.W.).

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Author contributions

I.F.L.F. and M.H.P.M.: conceived the original idea. I.F.L.F. took responsibility for performing the experiments and managing and reporting the data under supervision of E.W. D.A.: involved in constructing ideas or hypotheses for research and the manuscript. V.C.O.: provided critical feedback and helped to shape the research, data analysis and manuscript writing. M.B.M., F.L.B. and L.L.B.: contributed to performing the experiments, and interpreting the results. All authors thoroughly reviewed and approved the final manuscript.

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