DOI: 10.17058/reci.v14i3.19177

REVIEW ARTICLE

Identification, resistance, and susceptibility of microorganisms on healthcare workers' hands: a systematic review and meta-analysis

Identificação, resistência e suscetibilidade de microrganismos nas mãos de profissionais de saúde: revisão sistemática e meta-análise

Identificación, resistencia y susceptibilidad de microorganismos en las manos de trabajadores de la salud: una revisión sistemática y meta-análisis

Nolbedir Saza Ramírez[1] ORCID 0000-0002-8080-2788
Fernando Rojas Páez[1] ORCID 0000-0003-2730-412X
Julieth Yadira Serrano Riaño[2] ORCID 0000-0002-8882-5407
Jairo Vaca-González[3] ORCID 0000-0003-3829-2558

[1]Facultad de Ciencias de la Salud, Universidad del Quindío, Armenia, Colombia.
[2]Departamento de Investigación. Universidad Colegio Mayor de Cundinamarca. Bogotá, Colombia.
[3]Universidad Nacional de Colombia, Sede La Paz, Bolívia.

Endereço: Universidad Nacional de Colombia, Sede La Paz. Kilómetro 9, Vía Valledupar – La Paz, 202017.
E-mail: jjvacag@unal.edu.co

Submetido: 19/02/2024
Aceite: 12/09/2024

ABSTRACT

Background and Objectives: The aim of this study is to analyze, through a systematic review and meta-analysis, the identification, resistance and susceptibility of microorganisms present in healthcare workers' hands, identifying the most relevant antimicrobial resistant bacteria and their prevalence. **Methods:** Several scientific databases were reviewed to summarize contributions of the past 10 years. A meta-analysis was conducted to assess bacteria on healthcare workers' hands and their resistance and susceptibility profiles. **Results:** healthcare workers were colonized by 35 types of bacteria, highlighting *Staphylococcus aureus., Acinetobacter spp.,* and *Escherichia. coli*. Although a lower number of bacteria was present on healthcare workers' hands, doctors acquired more bacteria. Specifically, health personnel contracted *Enterococcus spp.*, *Staphylococcus. epidermis*, *Acinetobacter spp.*, *Escherichia. coli*, among others. Resistance and susceptibility profiles showed that *S. aureus* was susceptible to antibiotics; nevertheless, *S. aureus* was resistant to ceftriaxone, erythromycin and amoxicillin-clavulanic acid. **Conclusion:** Detected microorganisms trigger pathologies of clinical importance such as skin infections, sepsis, gastroenteritis, among others; in addition, bacteria are the cause of pathologies of greater clinical importance, such as nosocomial pathologies due to work activity in the hospital environment, which require invasive treatment. Even if new drugs are developed, the way of prescribing and using antibiotics needs to be changed to reduce antibiotic resistance.

Keywords: *Cross Infection. Community-Acquired Infections. Bacterial Drug Resistance. Hand Disinfection. Health Personnel.*

RESUMO

Justificativa e Objetivos: O objetivo deste estudo é analisar, por meio de uma revisão sistemática e metanálise, a identificação, resistência e suscetibilidade de microrganismos presentes nas mãos de profissionais de saúde, identificando as bactérias mais relevantes e sua prevalência à resistência aos antibióticos. **Métodos:** Diversas bases de dados científicas foram revisadas para resumir as contribuições dos últimos 10 anos. Foi realizada uma meta-análise para avaliar bactérias nas mãos dos profissionais de saúde e os seus perfis de resistência e suscetibilidade. **Resultados:** os profissionais de saúde foram colonizados por 35 tipos de bactérias, destacando-se *Staphylococcus aureus., Acinetobacter spp.* e *Escherichia. coli*. Embora o número de bactérias nas mãos dos profissionais de saúde fosse menor, os médicos adquiriram mais bactérias. Especificamente, o pessoal de saúde contraiu *Enterococcus spp., Staphylococcus. epiderme, Acinetobacter spp., Escherichia. coli,* entre outras. Os perfis de resistência e suscetibilidade mostraram que *S. aureus* era suscetível a antibióticos; no entanto, *S. aureus* foi resistente à Ceftriaxona, Eritromicina e Amoxicilina-Ácido Clavulânico. **Conclusão:** Os microrganismos detectados desencadeiam patologias de importância clínica como infecções de pele, sepse, gastroenterites, entre outras; além disso, as bactérias são causadoras de patologias de maior importância clínica, como as patologias nosocomiais decorrentes da atividade laboral no ambiente hospitalar, que requerem tratamento invasivo. A forma de prescrever e usar antibióticos precisa ser alterada, mesmo que novos medicamentos sejam desenvolvidos, para reduzir a resistência aos antibióticos.

Descritores: *Infecção Hospitalar. Infecções Comunitárias Adquiridas. Farmacorresistencia Bacteriana. Desinfecção das Mãos. Pessoal de Saúde.*

RESUMEN

Justificación y Objetivos: El objetivo de este estudio es analizar, mediante una revisión sistemática y un metaanálisis, la identificación, resistencia y susceptibilidad de los microorganismos presentes en las manos de los trabajadores de la salud, identificando las bacterias más relevantes y su prevalencia de resistencia a los antibióticos. **Métodos:** Se revisaron varias bases de datos científicas para resumir las contribuciones de los últimos 10 años. Se realizó un metaanálisis para evaluar las bacterias en las manos de los trabajadores de la salud y sus perfiles de resistencia y susceptibilidad. **Resultados:** los trabajadores de la salud fueron colonizados por 35 tipos de bacterias, destacando *Staphylococcus aureus., Acinetobacter spp.* y *Escherichia. coli.* Aunque las bacterias en las manos de los trabajadores de la salud fueron menores, los médicos adquirieron más bacterias. En concreto, personal sanitario contrajo *Enterococcus spp., Staphylococcus. epidermis, Acinetobacter spp., Escherichia. coli,* entre otros. Los perfiles de resistencia y susceptibilidad mostraron que *S. aureus* era susceptible a los antibióticos; sin embargo, el *S. aureus* fue resistente a ceftriaxona, eritromicina y amoxicilina-ácido clavulánico. **Conclusión:** Los microorganismos detectados desencadenan patologías de importancia clínica como infecciones de la piel, sepsis, gastroenteritis, entre otras; además, las bacterias son causantes de patologías de mayor importancia clínica, como las patologías nosocomiales debidas a la actividad laboral en el ámbito hospitalario, que requieren un tratamiento invasivo. Es necesario cambiar la forma de prescribir y utilizar los antibióticos, incluso si se desarrollan nuevos medicamentos, para reducir la resistencia a los antibióticos.

Palabras Clave: *Infección Hospitalaria. Infecciones Comunitarias Adquiridas. Farmacorresistencia Bacteriana. Desinfección de las Manos. Personal de Salud.*

INTRODUCTION

According to the World Health Organization (WHO), inequalities between high- and lower-income countries regarding proper hand hygiene facilities need to be reduced, since only 1 in 10 healthcare workers have appropriate hand hygiene practices while caring for patients at high risk of healthcare-associated infections (HAIs).[1] Inadequate hygiene can lead to the spread of high-risk bacteria. Notably, healthcare workers' hands have tested positive for gram-negative bacteria such as *Enterococcus spp.* (19.7%), *Pseudomonas spp.* (13.7%), *Escherichia. coli.* (*E. coli)* (4.2%), *Klebsiella oxytoca* (1.4%), and *Enterococcus faecalis* (1.4%).[2] Similarly, a study focused on hands of nurses showed that they were colonized by *S. epidermidis* (64.7%), *Staphylococcus. warneri* (63%), *Enterococcus faecalis* (7.5%), *Staphylococcus hominis* (5.1%) and *Enterobacter agglomerans* (4.2%).[3] A recent study of doctors, residents and nurses was conducted to assess bacterial load on their hands. Results showed that hands were colonized by *S. aureus* (10.6%), *Coagulase Negative Staphylococcus* (7.4%), aerobic spore bearing bacilli (3.2%), *E. coli* (3.2%), *Pseudomonas spp.* (1.1%) and *Acinetobacter spp.* (1.1%).[4] These data indicates that healthcare workers' hands elevate the risk of transmitting pathogens to vulnerable patients, potentially leading to HAIs. Additionally, the presence of multidrug-resistant bacteria on hands can contribute to the dissemination of antibiotic-resistant strains, further compromising treatment efficacy. In fact, there is evidence that HAIs result from nosocomial cross-infection propagated by microorganism transmission between patients, primarily via healthcare professionals' hands.[5] Elevated bacterial presence on personnel hands also relates to heightened bacterial resistance and multi-resistant strains,[6] linked to healthcare system collapse, self-medication, rampant hospital antibiotic use, false security, and improper protective equipment use.[7] Some studies have detected multidrug-resistant bacteria on healthcare workers' hands, including methicillin-resistant *Staphylococcus aureus* (11.2%), vancomycin-resistant *Enterococci* (10%), multidrug-resistant *Pseudomonas aeruginosa* (17.4%), and multidrug-resistant *Acinetobacter baumannii* (29.3%).[8] Salehi et al. highlighted *Acinetobacter baumannii's* extensive drug resistance (40%) and multidrug resistance (100%)

against various antimicrobials (e.g., ceftriaxone, ciprofloxacin, meropenem, gentamicin, tigecycline).[9] Regarding bacteria isolated from healthcare workers' hands, significant resistance was observed: *S. aureus* to oxacillin (59.6%), *A. baumannii* to imipenem (54.4%), ciprofloxacin (63.3%), amoxiclav (100%), lomefloxacin (63.3%), cefotaxime (100%), piperacillin (54.5%), cefepime (54.4%), *Streptococci* to gentamicin (100%), sulfamethoxazole (62.5%), and *Enterococcus spp.* to sulfamethoxazole (100%).[10] Most multidrug-resistant bacteria stem from patients with infected wounds, with coagulase negative staphylococci and *S. aureus* displaying 100% resistance to penicillin and ampicillin. Both demonstrated 100% and 91.7% resistance to oxacillin, respectively.[11] Colombia's Ministry of Health analysis in ICUs noted *K. pneumoniae* and *E. coli* resistance to cephalosporins (37% and 26.9%, respectively), while *A. baumannii* and *P. aeruginosa* showed carbapenem resistance (31% and 37.8%, respectively). Gram-positive bacteria are oxacillin-resistant (37.8%), and *E. faecium* showed vancomycin resistance (22.3%).[12]

Building upon the previously mentioned, the identification, resistance, and susceptibility of microorganisms isolated from the hands of healthcare workers represent a critical area of concern. Bacterial resistance and susceptibility, though subject to advances in pharmacological research, pose significant threats to overall health. Governmental interventions and research endeavors play essential roles in mitigating the adverse effects of these microorganisms on healthcare workers' hand hygiene practices.[13] Studies have underscored the need for periodic bacterial population assessments among healthcare workers to discern pathogen prevalence and distribution based on professional roles.[14] Adherence to established clinical and surgical handwashing protocols remains a crucial aspect to ensure effective hygiene practices. Based on this, conducting a systematic review and meta-analysis on the identification, resistance, and susceptibility of microorganisms on healthcare workers' hands will address critical gaps, including global disparities in hand hygiene practices, comprehensive identification of bacterial colonization, and in-depth understanding of resistance patterns. It will assess variations in bacterial load and pathogen prevalence among different professional roles, develop evidence-based infection control strategies, identify common trends and variations in resistance, and highlight gaps to guide future research. Moreover, this study aims to enhance overall healthcare safety by reducing pathogen transmission, thereby protecting both healthcare professionals and patients from microbial resistance threats. By pooling data from diverse sources, it becomes possible to derive more accurate and generalized insights, identifying common trends, variations, and potential outliers. This approach offers a more nuanced understanding of the prevalence, mechanisms, and implications of bacterial resistance and susceptibility, contributing to evidence-based strategies for infection control. Furthermore, such an approach can highlight gaps in knowledge, guide future research directions, and inform decisions aimed at optimizing hand hygiene practices among healthcare workers. Ultimately, a systematic review with meta-analysis serves as a crucial tool for evidence-driven advancements in healthcare practices, safeguarding both medical professionals and patients against the threats posed by microbial resistance.[15] For this reason, the objective of this investigation is to analyze, through a systematic review and meta-analysis, the identification, resistance and susceptibility of microorganisms present in healthcare workers' hands, identifying the most relevant antimicrobial resistant bacteria and their prevalence. Although the field of research is broad on this topic, the constant change in hospital practices and microbial behavior requires an in-depth analysis based on what has been published by other authors. Research studies, especially those utilizing meta-analysis, enable informed decision-making in everyday hospital settings by revealing resistance and susceptibility patterns, the prevalence of microorganisms among healthcare workers, and thus help reduce the risk of HAIs in patients. Additionally, this information is valuable for healthcare professionals themselves, as it contributes to the proactive management and prevention of disease transmission. Overall, this study moves forward on developing targeted intervention strategies to improve hand hygiene practices across different healthcare settings, especially in low-income countries. Additionally, the results may be useful to perform longitudinal studies that monitor the effectiveness of these interventions over time and assess changes in bacterial colonization and resistance patterns. Research should also explore the molecular mechanisms of resistance to develop new antimicrobial agents and enhance existing treatments. Furthermore, investigations into the impact of education and training programs on healthcare workers' adherence to hand hygiene protocols could provide valuable insights. Finally, implementing real-time surveillance systems to track pathogen prevalence and resistance trends would be crucial for informing dynamic, evidence-based infection control policies.

METHODS

This research was executed within the framework defined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA - 2020) guidelines, serving as a methodological avenue to comprehensively, transparently, and accurately dissect data pertaining to the resistance and susceptibility profiles of microorganisms isolated by healthcare personnel.

This systematic review included studies focused on identifying microorganisms present on the hands of healthcare personnel, as well as those examining bacterial resistance and susceptibility profiles of such microorganisms. The inclusion criteria for this study were observational studies that investigated the colonization of healthcare workers' hands by microorganisms and their antibiotic resistance profiles. Eligible studies involved healthcare professionals, including doctors, nurses, and nursing assistants, who were exposed to microorganisms in clinical settings, and reported data on bacterial identification and susceptibility/resistance to antibiotics using standardized methods such as antibiograms. Additionally, the studies needed to clearly report the number of healthcare professionals with and without bacterial colonization, allowing for direct comparison between these two groups. Only studies published between 2010 and 2020 in English or Spanish were considered. Exclusion criteria encompassed intervention studies, clinical trials, and studies focusing solely on patient populations or non-clinical staff. Studies lacking detailed microbiological data, without standardized methods for resistance testing or with a high risk of bias were excluded, as were non-peer-reviewed sources like conference abstracts, book chapters, and gray literature.

A systematic inquiry was conducted to gather scientific evidence concerning the categorization, resilience, and vulnerability of microorganisms isolated from healthcare workers' hands. The investigation adhered to a structured PECO approach: P: Healthcare professionals, including doctors, nurses, nursing assistants, surgical instrumentalists, exposed to colonization by resistant microorganisms on their hands and practicing hand hygiene to mitigate HAIs. E: Exposure to microorganisms on the hands of healthcare personnel, measuring the prevalence of antibiotic-resistant bacteria. C: A comparison was made between the groups of healthcare personnel with the presence of the most frequent bacteria; moreover, an assessment of the resistance of these bacteria to different antibiotics commonly used in the hospital setting was performed. O: Identification of the most common bacterial groups in healthcare personnel, as well as the determination of those bacteria with the greatest resistance to different antibiotics, characterizing the resistance profiles to key antibiotics among the predominant bacteria. Simultaneously, a comprehensive search strategy was implemented to identify relevant research articles across various medical databases and governmental health entities. The databases searched included PubMed/MEDLINE, Web of Science, CINAHL, Embase, Cochrane CENTRAL, and SciELO. The search strategy was developed using a combination of controlled vocabulary terms derived from the Spanish (Descriptores en Ciencias de la Salud, DeCS) and English (Medical Subject Headings, MeSH) thesaurus, as well as free-text keywords. Both English and Spanish language articles were considered. Key search terms included 'bacteria,' 'microbial resistance,' 'healthcare workers,' and 'hand hygiene,' among others. Boolean operators, specifically 'AND', were used to combine search terms effectively. Additionally, the search strategy was refined iteratively by including terms such as 'antibiotic sensitivity,' 'health personnel,' 'drug-resistant bacteria,' 'hand,' 'antibiogram,' and 'susceptibility.' Filters and limits were not applied during the initial search to ensure inclusivity of relevant literature.

Two independent investigators conducted the screening process using the designated keywords and methodologies outlined in the study protocol. All titles and abstracts retrieved from the search engines were reviewed for potential inclusion in the analysis. Any discrepancies between the two reviewers were resolved through discussion or consultation with a third reviewer if necessary. Full-text articles of potentially relevant studies were obtained and assessed against the predetermined inclusion criteria. Data extraction was performed using a standardized data collection form, which included fields for recording information such as resistant and multi-resistant bacterial strains, quantification methodologies, clinical relevance, and significance to hand hygiene practices. The organized tabulation facilitated systematic assimilation and identification of pertinent data regarding bacterial agents associated with hand hygiene.

To assess the risk of bias within included studies, each investigator independently evaluated various elements including random sequence generation, blinding procedures, handling of incomplete data and outcomes, and other potential sources of bias, using established tools such as the Cochrane Risk of Bias Tool or the Newcastle-Ottawa Scale for observational studies. Any discrepancies in the assessment of bias were resolved through discussion or consultation with a third reviewer. Furthermore, the quality appraisal of included studies, data synthesis methods, assessment of study duplication, blinding procedures, and potential sources of bias were collaboratively reviewed by the two investigators to ensure consistency and accuracy in the interpretation of findings. Automation tools were not utilized in the screening or data extraction process.

The data preparation for presentation and synthesis involved employing the Mantel-Haenszel statistical approach to analyze dichotomous data, utilizing risk ratios (RR) accompanied by a 95% confidence interval (CI). The RR was calculated to compare the likelihood of bacterial colonization between the two defined groups. The first group consisted of healthcare professionals with bacterial presence on their hands, while the second group included those without bacterial colonization. Although the total population size was the same for both groups, the RR was used to quantify the difference in colonization risk between them. The RR calculations were based on 2x2 contingency tables, comparing the events (bacterial colonization) and non-events. A meticulous review of the literature was conducted to address missing summary statistics, and efforts were made to contact study authors for any necessary data clarification or supplementation. Tabulation and visual display of results were achieved through the use of forest plots, allowing for a clear representation of individual study findings and facilitating comparison across studies. The synthesis of results was based on a rationale grounded in the nature of data and the research question. Statistical heterogeneity was assessed using the I^2 statistic, with a threshold of $I^2 > 50\%$ indicating substantial heterogeneity. A fixed-effects model was employed in the absence of significant heterogeneity ($I^2 < 50\%$, $P > 0.1$), while a random-effects model was utilized when heterogeneity was observed. Sensitivity analyses were conducted to assess the robustness of synthesized results, ensuring the reliability of findings. The statistical software Revman 5.4.1 (Cochrane, London, United Kingdom) was utilized for analysis, with a significance level set at $p < 0.05$. These rigorous methods allowed for comprehensive exploration and synthesis of the available evidence, while maintaining transparency and reproducibility in accordance with PRISMA guidelines.[16]

RESULTS AND DISCUSSION

Data selection

Thirteen research articles were discerned for executing the respective systematic review and meta-analysis. Adhering to the PRISMA-2020 guidelines, the selection process is illustrated in Figure 1. Initially, 80 articles pertinent to hand hygiene in healthcare professionals were identified, of which 67 were excluded due to non-conformance with inclusion criteria. Subsequently, 14 research articles were deemed suitable for inclusion in the meta-analysis.

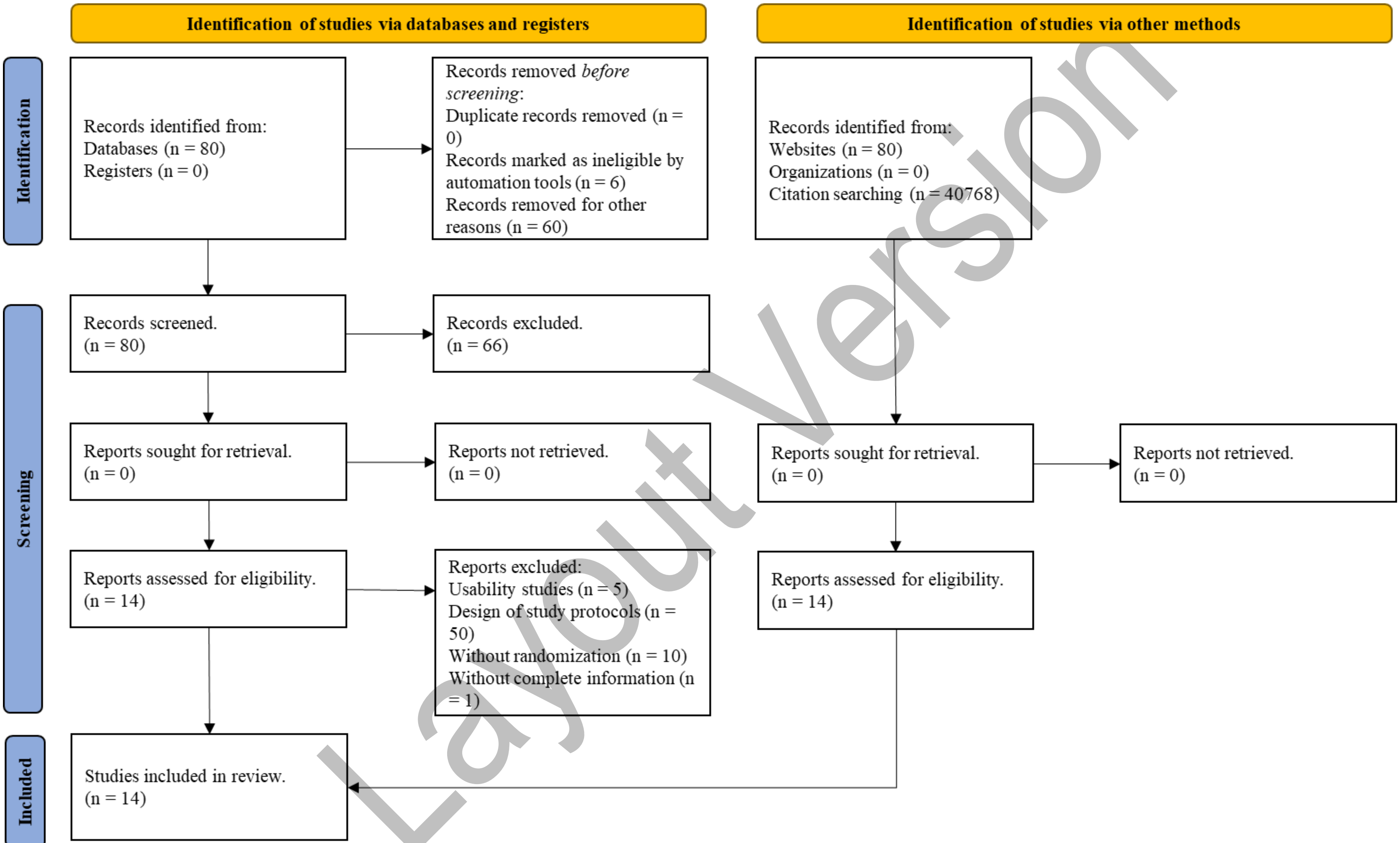


Figure 1. Illustrative schematic of the study selection procedure for conducting the meta-analysis.

Bacteria identification on hands of healthcare personnel

The frequency of the most prevalent bacteria identified in the research studies concentrating on hand hygiene practices among healthcare personnel is delineated in supplementary material 1. Conforming to the frequency analysis, a Total staff/Total bacteria ratio was discerned, highlighting a cumulative total of 3,187 healthcare workers participating in hand hygiene activities, within which 2,257 bacterial specimens were ascertained. Particularly noteworthy among the bacteria frequently encountered on healthcare personnel's hands were *S. aureus* (377), *Acinetobacter spp.* (339), *Staphylococcus spp.* (316), *S. epidermidis* (294), *CoNS* (284), *Enterobacter* (109), and *E. coli* (75), among others. Conversely, less frequently observed bacteria included *Citrobacter spp* (7), *K species* (5), *Klebsiella spp.* (5), *Enterobacter aerogenes* (4), *Serratia* (4), and *Streptococcus pneumoniae* (2).

Resistance profiles and susceptibility to antibiotics in the bacteria present in the hands of healthcare personnel

The presence and absence of bacteria on the hands of healthcare personnel are delineated in Figure 2A. The outcomes revealed that 571 healthcare workers manifested bacterial colonization on their hands, while 901 health personnel demonstrated an absence of pathogenic bacteria. However, the research conducted by Sun et al.[17] indicated that their study cohort stood as the singular group in which the presence of bacteria on healthcare personnel's hands exhibited statistical significance ($p < 0.00001$). Considering the aforementioned information, a more comprehensive analysis was undertaken to ascertain the specific healthcare personnel vulnerable to bacterial exposure. In this context, Figure 2B illustrates that in general, doctors, nurses, and other healthcare staff do not exhibit predisposition to bacterial colonization on their hands ($p < 0.00001$); however, the study by Sun et al.[17] revealed that the subgroup of doctors has the most substantial risk of bacterial acquisition ($p < 0.00001$).[17]

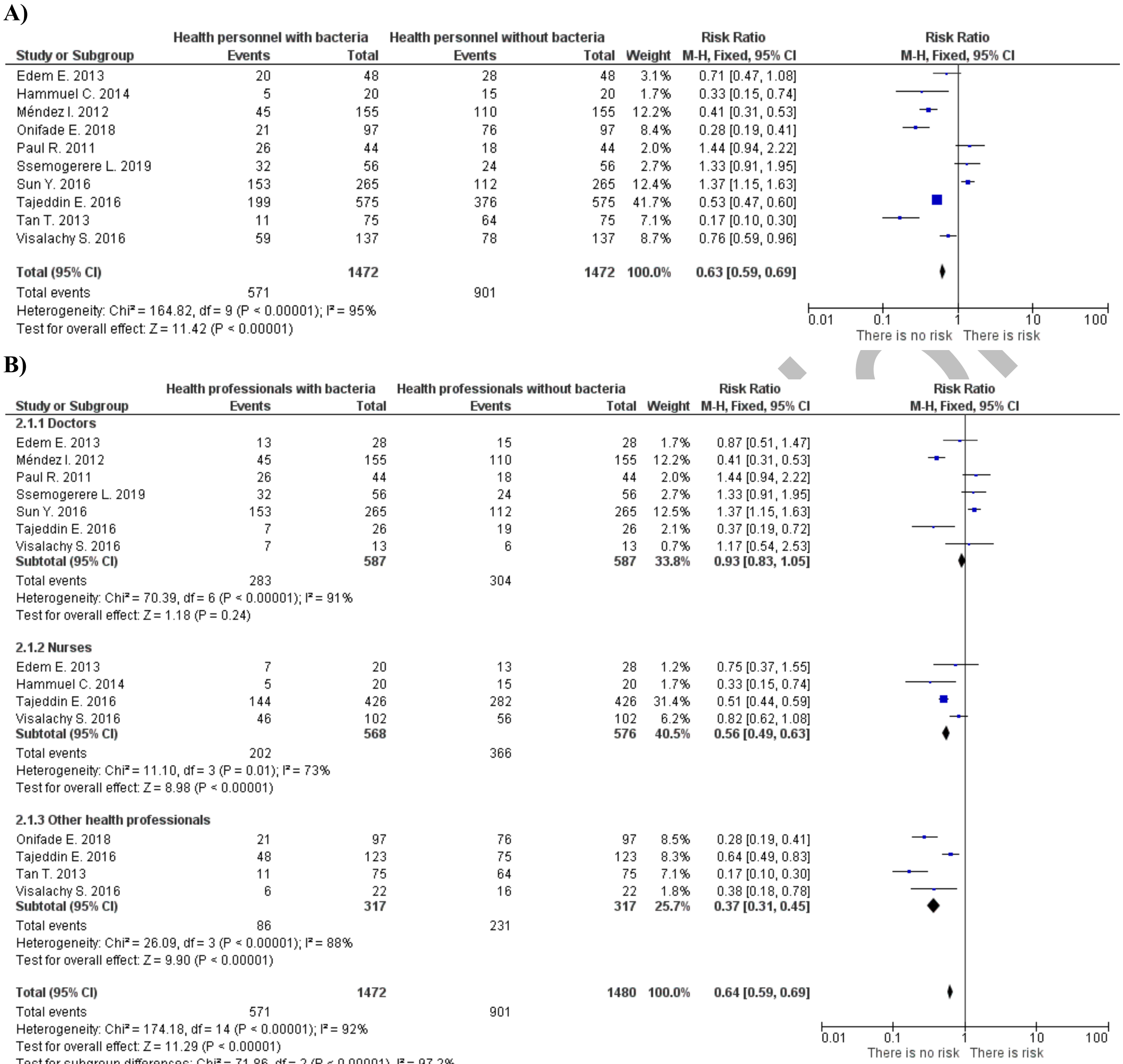


Figure 2. **A)** Presence and absence of bacteria in healthcare workers (studies conducted between 2011-2019). **B)** Bacterial occurrence among doctors, nurses, and other healthcare personnel (studies conducted between 2011-2019).

An analysis was executed to discern the bacterial taxonomy evident on the hands of healthcare workers (Figure 3). In accordance with the conducted analysis, healthcare personnel did not exhibit exposure to pathogens such as *Enterococcus spp.*, *Acinetobacter spp., E. coli, Pseudomonas spp.,* and *Bacillus spp.*[8] Nonetheless, studies undertaken by Sun et al.[17] and Tajeddin et al.[10] demonstrated that the hands of healthcare personnel harbored *S. aureus* and *S. epidermidis*, respectively ($p < 0.00001$).

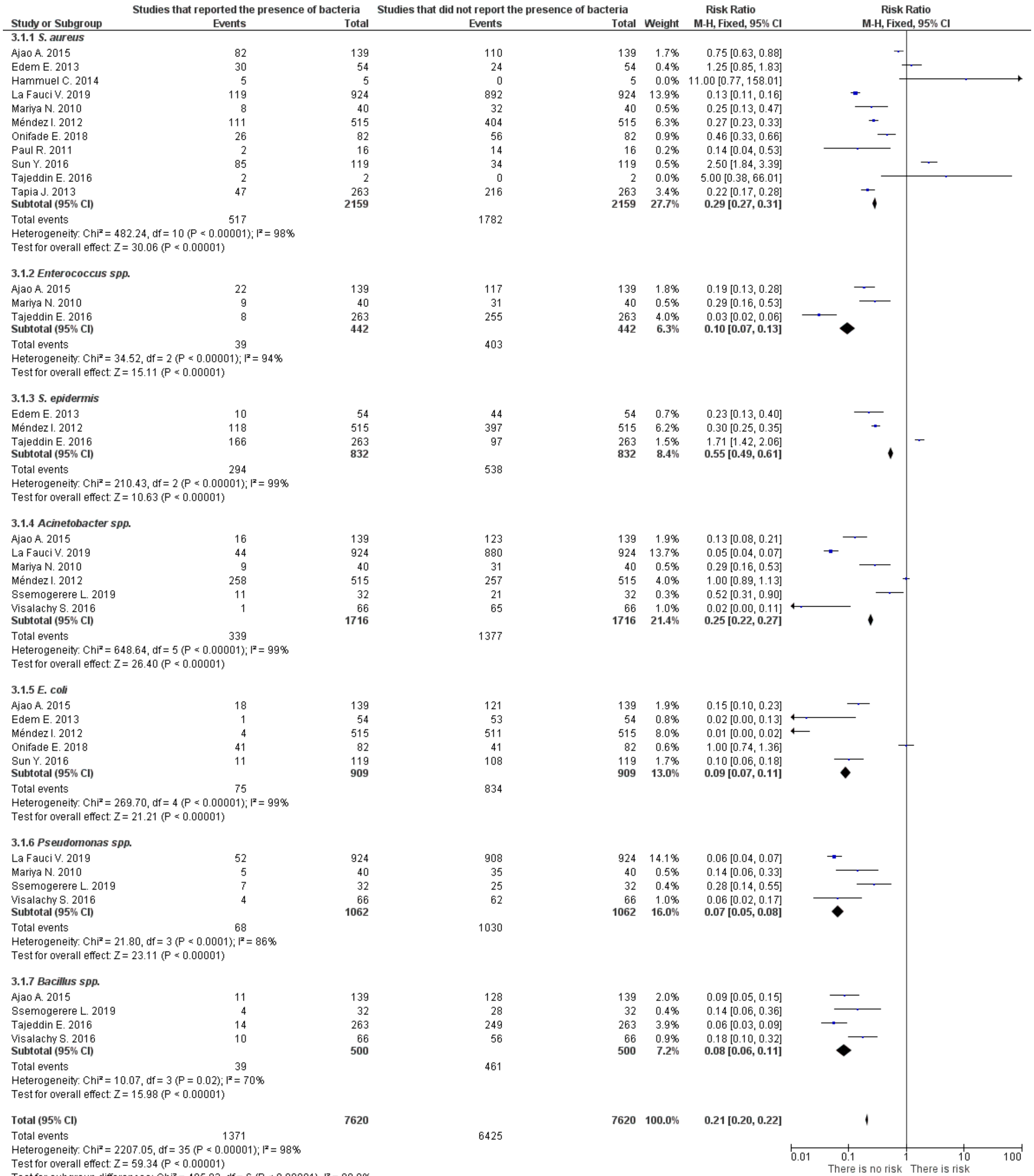


Figure 3. Taxonomic categorization of distinct bacterial species detected and absent on the hands of healthcare workers (studies conducted between 2011-2019).

According to the findings of our analysis, *S. aureus* emerges as the predominant bacteria on healthcare personnel's hands. Significantly, the statistical analysis underscored the susceptibility of *S. aureus* to antibiotics including ampicillin, vancomycin, and ofloxacin ($p < 0.00001$). Consequently, a statistical examination was conducted to delineate the resistance and susceptibility pattern of this pathogen towards various antibiotics (Figure 4). The results revealed that antibiotics such as erythromycin,[17,18] oxacillin,[10] ceftriaxone,[18,19] gentamicin and augmentin,[18] erythromycin and ciprofloxacin,[20] exhibited a substantial degree of resistance in combating the effects induced by *S. aureus* ($p < 0.00001$).

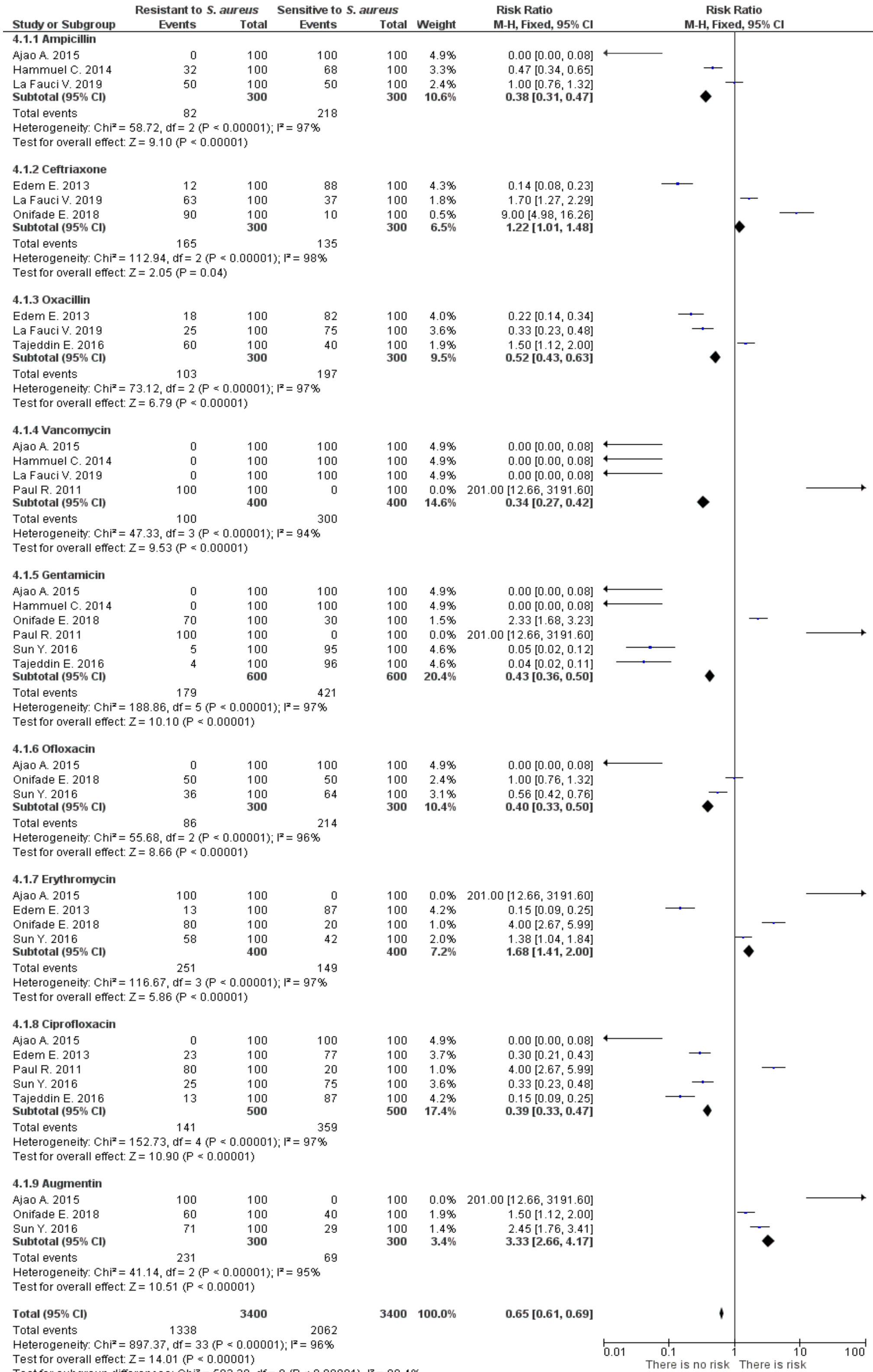
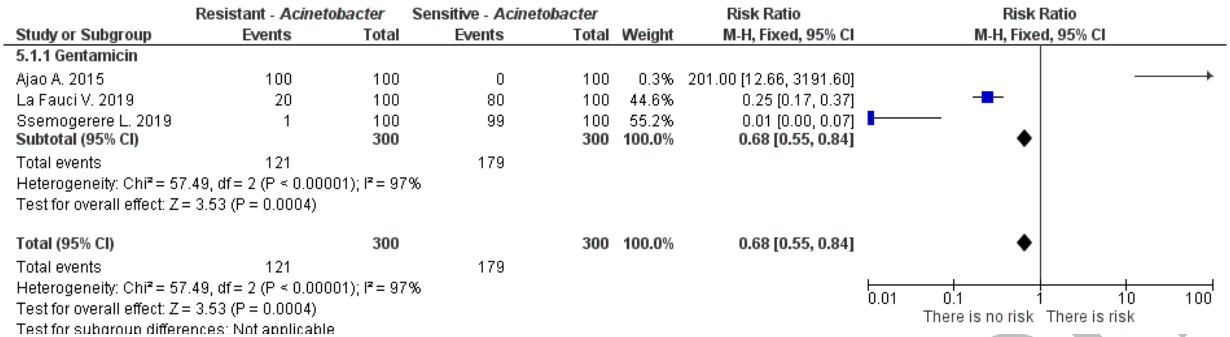


Figure 4. Bacterial resistance and susceptibility of *S. aureus* to different antibiotics (studies conducted between 2011-2019).

Acinetobacter is another bacterial genus displaying antimicrobial resistance among healthcare workers' hands. For instance, the study conducted by Ajao et al. ascertained that *Acinetobacter* demonstrated resistance against gentamicin ($p < 0.00001$) (Figure 5A).[21] No statistical significance was observed in the remaining investigations. Another highly relevant microorganism that was identified in this meta-analysis was *E. coli* (Figure 5B). The analysis evidenced that *E. coli* tends to be sensitive to antibiotics such as gentamicin, ofloxacin and ciprofloxacin ($p < 0.00001$). However, in the study carried out by Ajao et al. it was found that *E. coli* was resistant to Amoxicillin ($p < 0.00001$).[21]

This study associates bacterial presence/absence with healthcare workers' hands, thus evidencing that out of a total of 587 doctors, only 283 were in contact with bacteria. The study conducted by Sun et al.[17] was the most representative, revealing 156 bacteria; followed by the studies carried out by,[20,22–24] all of which identified bacterial colonization on the hands of the medical personnel.[24–28] Similarly, in comparison to,[29] this study demonstrates the presence of pathogens like *S. aureus* and *Pseudomonas aeruginosa* on healthcare personnel's hands. Conversely, bacteria correlate with presence/absence, highlighting 23% *S. aureus* incidents in all samples (517/2,159). This emphasizes significant risk of bacterial acquisition according to several authors.[10,17,23–26,30] Likewise, 39 instances *of Enterococcus spp* were identified out of a total of 442 reviewed bacteria. However, data found during the analysis were insufficient to statistically identify the presence of bacteria on healthcare workers' hands. In a similar vein, there were 294 occurrences of *S. epidermidis* out of 832 reviewed bacteria. Consequently, it was observed that, as per Tajeddin et al.[10] *S. epidermidis* holds a relatively noteworthy potential for contraction.[23] Correspondingly, the *Acinetobacter spp.* were identified in 339 instances out of 1,716, indicating that these bacteria do not hold significant prominence in the risk of contraction.[31] As for *E. coli* bacteria, they were identified in 75 occurrences out of a total of 909 reviewed bacteria. This shows that these bacteria carry a relatively noteworthy potential for contraction, as indicated by the study conducted by Onifade et al.[18] Concerning *Pseudomonas*, 68 instances were identified; however, upon analysis, it was observed that there is no significant data supporting the acquisition of the pathogen. Lastly, 39 occurrences were discovered for *Bacillus spp*, presenting statistically significant data that indicate the potential for contracting this type of bacteria.

A)



B)

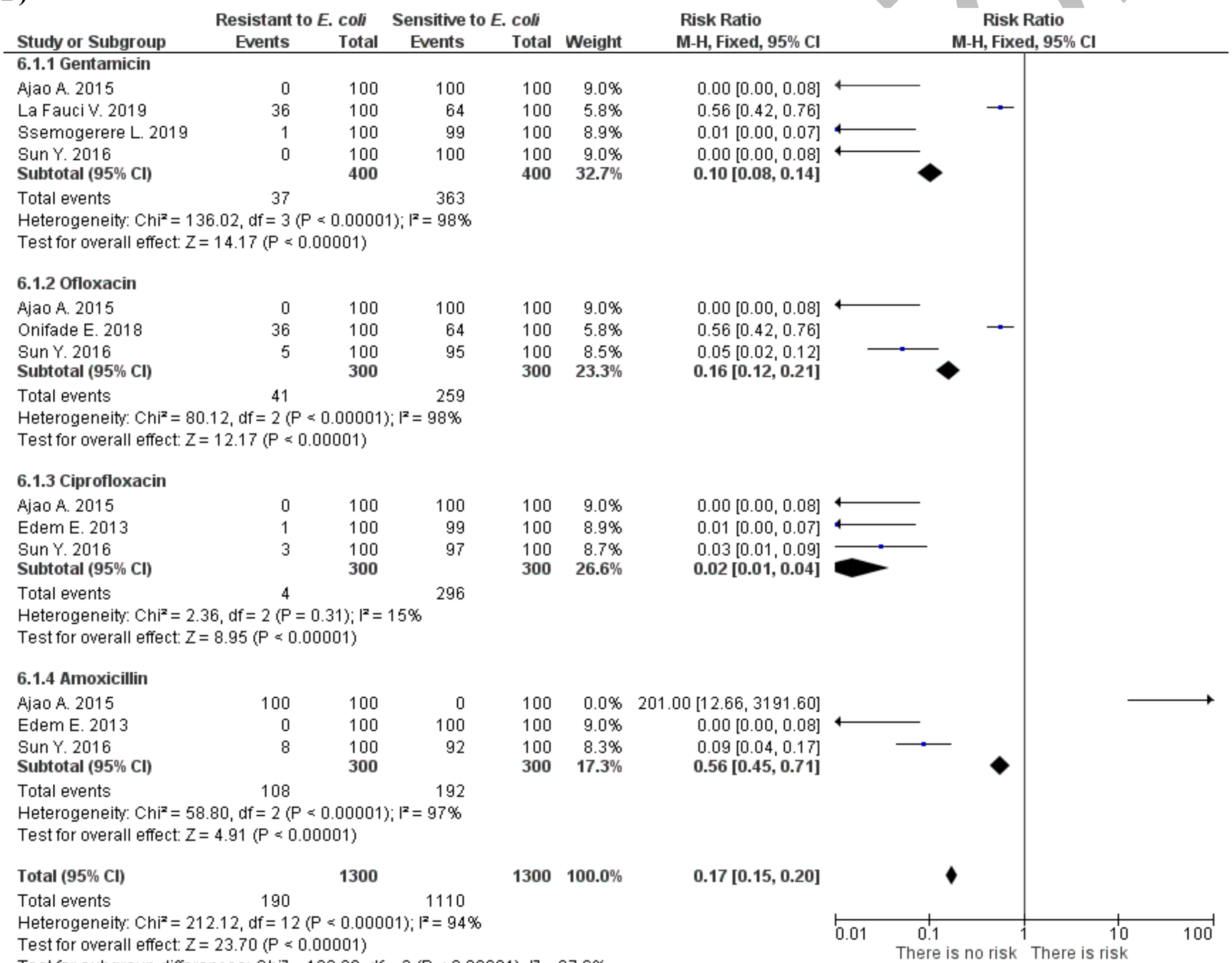


Figure 5. **A)** Bacterial resistance and susceptibility of *Acinetobacter* to gentamicin (studies conducted between 2015-2019). **B)** Resistance and sensitivity of antibiotics to *E. coli* to different antibiotics (studies conducted between 2013-2019).

Concerning bacterial presence among healthcare workers, this investigation unveiled 571 instances out of 1,472. Notably, doctors, nurses, and other healthcare professionals display limited awareness of hand bacterial colonization,[22,24] whereas doctors and nurses, according to,[17,20,23] exhibit relatively significant susceptibility to diverse bacterial strains. As supported by Avadhani et al. proper hand hygiene is vital in curbing infection transmission by medical and nursing personnel.[32] Similarly, *E. coli* pathogens are detected in healthcare personnel's hands due to fecal contamination, signaling deficient post-toilet hand hygiene. The analyzed studies identify a minimum presence of two pathogens among 20 healthcare workers, contrasting with up to 924 bacteria in 1,848 health professionals.[24,26,27,30]

Based on the sensitivity profile and bacterial resistance, it has been identified that, according to the list of antibiotic-resistant microorganisms released by the PAHO in 2021, *S. aureus* currently exhibits sensitivity to broad-spectrum antibiotics.[33] Among these, the clinical significance of vancomycin's action spectrum is noteworthy, as it displays reduced efficacy in counteracting bacterial effects during potential infections. In the study conducted by Paul et al.[20] a reduced risk of *S. aureus* acquisition was observed; however, the efficacy of protective measures through drug intervention is diminishing due to the emergence of resistant strains.[28] Similarly, as indicated by Rodríguez et al.[34] vancomycin resistance is indeed present in *S. aureus*, attributed to cell wall modifications that sequester the antibiotic before it reaches the site of action, thereby failing to achieve the desired bactericidal effect. According to the findings of this study, it was evident that 82 cases out of a total of 300 occurrences of *S. aureus* were resistant to ampicillin, while 218 cases exhibited sensitivity. Consequently, a significant risk in harboring the pathogen is evident.[19] Accordingly to the PAHO, *S. aureus* resistance, particularly in cases involving methicillin and vancomycin, constitutes the highest critical risk, yet devoid of clinical significance.[33] Bacterial resistance and susceptibility of *Acinetobacter* to gentamicin were observed in 121 cases, while 179 occurrences demonstrated sensitivity. In the study conducted by La Fauci et al.[19] insignificance in the risk of bacterial containment was noted. According to the PAHO, gentamicin has shown resistance against *Acinetobacter*, as it is categorized as an aminoglycoside rather than a carbapenem.[33] In studies carried out by,[18,19] *E. coli* exhibited a heterogeneity of 97% in comparison to gentamicin and ofloxacin, signifying insignificance in risk. Conversely, against ciprofloxacin and amoxicillin, it presented a very low point estimate with weak evidence, suggesting no statistical difference from effects shown in studies by various authors. This demonstrates sensitivity of this pathogen to ciprofloxacin (77.1%) and amoxicillin (93.1%), highlighting effective management against its impact on at-risk populations' health.[35]

Various antibiotics—such as gentamicin, ofloxacin, oxacillin, vancomycin, ciprofloxacin, Augmentin, ampicillin, and ceftriaxone—are employed to counter pathogens including *S. aureus, Enterococcus spp., S. epidermidis, Acinetobacter spp., E. coli, Pseudomonas spp.*, and *Bacillus spp.* Nonetheless, varying degrees of bacterial resistance emerge. Verification requires cultures and antibiograms for optimal management considering cost, availability, administration, and response times to bacterial colonization. Studies evaluating healthcare workers' hand hygiene practices, conducted by,[33,35] reveal that 45% perceived good knowledge, while 55% perceived moderate knowledge. These findings underscore the responsibility of health professionals to ensure habitual hand hygiene adherence, prioritizing it institutionally. Limitations surfaced during analysis, with some studies failing to distinguish between bacterial resistance and susceptibility percentages. Certain studies even omitted pathogen identification despite stated focus. Similarly, biological constraints emerged, accompanied by lack of precision in defining the healthcare professional population and study sample for hand hygiene assessment.

In general terms, hand hygiene has gained prevalence over the last two years as a prominent defense against COVID-19.[36] Yet, its significance extends beyond recent times, encompassing years of use in combating HAIs and the dissemination of multidrug-resistant microorganisms.[37] Despite handwashing being championed as an efficient, cost-effective approach to curbing HAIs, compliance remains notably low among healthcare workers in both developed and developing nations.[38] An investigation examining hand hygiene awareness among 289 healthcare workers observed noteworthy outcomes. After interventions, handwashing adherence considerably improved in pediatrics, internal medicine, and obstetrics-gynecology departments. Health personnel perception concerning the likelihood of hospitalized patients developing HAIs also significantly rose from 49.7% to 58.6% post-intervention.[39] In a comparable study, findings revealed gaps in handwashing infrastructure, where units lacked hand hygiene posters or policies, alcohol-based hand rubs, and few toilets had flowing tap water throughout the day. In terms of healthcare workers behavior, some of them performed handwashing before patient contact, before aseptic procedures, after potential body fluid exposure, and following patient interactions.[39] Genc et al. investigated to gauge nasal *S. aureus* carriage rates and methicillin-resistant *S. aureus* among health personnel by analyzing the relationship between carriage, individual risk factors and hand hygiene practices. Outcomes revealed a 20.1% prevalence of *S. aureus* carriage within 54 *S. aureus* carriers. Notably, *S. aureus* culture positivity exhibited a significant decrease in tandem with heightened handwashing frequency.[40] In this sense, health education is crucial to promote handwashing and support not only medical staff, but also patients to enhance hand hygiene frequency and technique.[15]

In the realm of research, the wide range of diseases linked to healthcare is acknowledged, particularly given the ongoing changes in hospital practices and the evolving nature of microbial behavior. This underscores the pressing need for a comprehensive review of the existing literature. As a consequence of this, the main objective of the present study was the identification of the predominant microbial strains, as well as the evaluation of their degree of resistance to antibiotics, specifically among the microorganisms present in the hands of healthcare personnel. The use of meta-analysis, in particular, is a fundamental methodological tool in this type of research. This technique enables the synthesis and analysis of data from multiple studies, which facilitates obtaining robust conclusions and making informed decisions in everyday clinical practice. The insights gained from this study are vital for reducing the risk of disease transmission within healthcare environments. This is advantageous for both patients and healthcare personnel, as the latter can act as active carriers of pathogens. However, certain limitations were noted; for example, studies included in the review may differ significantly in terms of sample collection methods, microbial identification techniques, and antimicrobial susceptibility testing. For example, some studies might use swabbing, others might use imprint methods, and the types of media or growth conditions can vary. Additionally, differences in defining and measuring outcomes, such as what constitutes "resistance" or "colonization" versus transient contamination, can vary. This variability can make it difficult to compare results across studies or aggregate data in a meaningful way. Other limitations are related to publication and reporting bias, as the detail in which methods and results are reported can vary, and some studies may not provide sufficient data on resistance mechanisms, or the specific microorganisms identified. This lack of detailed reporting can limit the ability to perform a thorough meta-analysis and may skew the understanding of the true scope of microbial resistance and susceptibility patterns on healthcare workers' hands. Finally, the resistance profiles of microorganisms can change over time due to factors such as the introduction of new antimicrobial agents or changes in infection control practices. Moreover, microbial flora and resistance patterns can vary significantly between different regions and healthcare settings. A systematic review and meta-analysis might aggregate data from different time periods and geographic locations, potentially obscuring important trends and making it difficult to draw specific, actionable conclusions for current practice in a particular setting.

CONCLUSION

Bacterial resistance and susceptibility pose a pervasive health hazard. Despite promising advancements in pharmacological research for prevention and treatment, governmental interventions and health researchers play pivotal roles in mitigating the adverse impact of bacteria on healthcare workers' hand hygiene. Conducting periodic bacterial population studies on healthcare workers individually is recommended to ascertain pathogen presence and distribution based on professional roles. Adherence to established clinical and surgical handwashing protocols is imperative, ensuring comprehensive technique assessment through implementation, monitoring, and enforcement if needed. Furthermore, broader studies encompassing bacterial resistance and susceptibility through meta-analyses are imperative. Such investigations guide decisions on managing pathogens prevalent on healthcare workers' hands, minimizing risks for personnel and surroundings. According to the Clinical Laboratory Standards Institute, doctors depend significantly on microbiology laboratories for patient care, highlighting the necessity for testing in well-equipped, modern laboratories. These facilities must adhere to current guidelines for drug selection, interpretation, and quality control, which aids in making informed assessments of bacterial resistance and susceptibility in the hand microbiomes of healthcare workers. Considering the limitations previously noted, certain measures could be implemented to enhance the results of the meta-analysis; for example, subgroup analyses to handle variations in study designs, techniques, and definitions could be implemented to reduce variability. This involves grouping studies by similar methods (e.g., type of microbial testing) or by healthcare settings (e.g., intensive care units vs. general wards). On the other hand, conducting sensitivity analyses to determine how the inclusion or exclusion of certain studies affects the results. This can help identify the impact of potentially biased studies. Finally, stratifying the results by different time periods and geographic regions can help to identify specific trends and differences in microbial resistance patterns over time or across locations. Although implementing these solutions requires meticulous planning and execution, it can significantly enhance the quality and applicability of a systematic review and meta-analysis in understanding microbial resistance on healthcare workers' hands.

REFERENCES

1. World Health Organization. WHO calls for better hand hygiene and other infection control practices: Urgent need to reduce inequalities between high and lower income countries. WHO. Published 2021. https://www.who.int/news/item/05-05-2021-who-calls-for-better-hand-hygiene-and-other-infection-control-practices

2. Sasahara T, Ae R, Watanabe M, et al. Contamination of healthcare workers' hands with bacterial spores. J Infect Chemother. 2016;22(8):521-525. doi:10.1016/j.jiac.2016.04.007

3. Aiello A, Cimiotti J, Della-Latta P, et al. A comparison of the bacteria found on the hands of "homemakers" and neonatal intensive care unit nurses. J Hosp Infect. 2003;54(4):310-315. doi:10.1016/s0195-6701(03)00146-4

4. Niveditha S, Umamageswari S, Aruna D, et al. Study of Hand Carriage of Multi drug resistant bacteria using Glove Juice Technique in Health Care Workers. Res J Pharm Tech. 2021;14(2):650-656. doi:10.5958/0974-360X.2021.00116.5

5. Queiroz J, Melo I, Calado G, et al. Identification and resistance profile of bacteria isolated on stethoscopes by health care professionals: Systematic review. Am J Infect Control. 2021;49(2):229-237. doi:10.1016/j.ajic.2020.07.007

6. Lotfinejad N, Peters A, Tartari E, et al. Hand hygiene in health care: 20 years of ongoing advances and perspectives. Lancet Infect Dis. 2021;21(8):209-221. doi:10.1016/S1473-3099(21)00383-2

7. Arteaga-Livias K, Pinzas-Acosta K, Perez-Abad L, et al. A multidrug-resistant Klebsiella pneumoniae outbreak in a Peruvian hospital: Another threat from the COVID-19 pandemic. Infect Control Hosp Epidemiol. 2022;43(2):267-268. doi:10.1017/ice.2020.1401

8. Mariya N, Sistla S, Dutta T, et al. Role of intensive care unit environment and health-care workers in transmission of ventilator-associated pneumonia. J Infect Dev Ctries. 2010;4(5):1-10. doi:10.3855/jidc.800

9. Salehi B, Goudarzi H, Nikmanesh B, et al. Emergence and characterization of nosocomial multidrug-resistant and extensively drug-resistant Acinetobacter baumannii isolates in Tehran, Iran. J Infect Chemother. 2018;24(7):515-523. doi:10.1016/j.jiac.2018.02.009

10. Tajeddin E, Rashidan M, Razaghi M, et al. The role of the intensive care unit environment and health-care workers in the transmission of bacteria associated with hospital acquired infections. J Infect Public Health. 2016;9(1):13-23. doi:10.1016/j.jiph.2015.05.010

11. Zahran W, Zein-Eldeen A, Hamam S, et al. Surgical site infections: Problem of multidrug-resistant bacteria. Menoufia Med J. 2017;30(4):1005-1013. doi:10.4103/mmj.mmj_119_17

12. Gaviria A, Correa L, Dávila C, et al. Programa de Prevención, Vigilancia y Control de Infecciones Asociadas a La Atención En Salud-IAAS y La Resistencia Antimicrobiana. Minsalud; 2018. https://www.minsalud.gov.co/sites/rid/Lists/BibliotecaDigital/RIDE/VS/PP/PAI/programa-iaas-ram.pdf

13. Serwecińska L. Antimicrobials and Antibiotic-Resistant Bacteria: A Risk to the Environment and to Public Health. Water. 2020;12(12):2-17. doi:10.3390/w12123313

14. Pegu K, Perrie H, Scribante J, et al. Microbial contamination of hands of healthcare providers in the operating theatre of a central hospital. South African J Infect Dis. 2021;36(1):1-7. doi:10.4102/sajid.v36i1.221

15. Xun Y, Shi Q, Yang N, et al. Associations of hand washing frequency with the incidence of illness: a systematic review and meta-analysis. Ann Transl Med. 2021;9(5):1-11. doi:10.21037/atm-20-6005

16. Suarez-Charpentier G, Jiménez-Céspedes L, Serrano-Riaño J, et al. Presence of fungal agents in healthcare workers that practice handwashing: a systematic review and metaanalysis. Conoc Glob. 2021;6(1):291-307. doi:https://conocimientoglobal.org/revista/index.php/cglobal/article/view/218

17. Sun Y, Yu L, Sun M, et al. Microorganisms from hands of traditional chinese medical doctors in a central hospital environment. Afr J Tradit Complement Altern Med. 2016;13(1):95-98. doi:http://dx.doi.org/10.4314/ajtcam.v13i1.13

18. Onifade O, Ogbonna I, Aremu S. Efficacy of some antibiotics on nosocomial bacteria isolates from selected hospitals in Makurdi, Nigeria. FUW Trends Sci Technol J. 2018;3(2A):389-394. doi:https://www.ftstjournal.com/uploads/docs/32A%20Article%2012.pdf

19. La Fauci V, Costa G, Genovese C, et al. Drug-resistant bacteria on hands of healthcare workers and in the patient area: an environmental survey in Southern Italy's hospital. Rev Esp Quimioter. 2019;32(4):303-310. doi:https://seq.es/wp-content/uploads/2019/06/fauci28jun2019.pdf

20. Paul R, Das N, Dutta R, et al. Bacterial contamination of the hands of doctors: A study in the medicine and dermatology wards. Indian J Dermatol Venereol Leprol. 2011;77(3):307-313. doi:10.4103/0378-6323.79700

21. Ajao A, Yakubu S. Identification, Characterization and Plasmid Profiling of Multi Drug Resistant Nocomial Pathogens Isolated from Selected Hospitals in Ilorin Metropolis. Br Microbiol Res J. 2015;5:33-43. doi:10.9734/BMRJ/2015/10554

22. Ssemogerere L, Sendagire C, Mbabazi C, et al. Hand Colonization with Gram-Negative Organisms of Healthcare Workers Accessing the Cardiac Intensive Care Unit: A Cross-Sectional Study at the Uganda Heart Institute. Crit Care Res Pract. 2019;2019(6081954):1-8. doi:10.1155/2019/6081954

23. Visalachy S, Palraj K, Kopula S, et al. Carriage of Multidrug Resistant Bacteria on Frequently Contacted Surfaces and Hands of Health Care Workers. J Clin Diagn Res. 2016;10(5):18-20. doi:10.7860/JCDR/2016/19692.7772

24. Edem E, Onwuezobe I, Ochang E, et al. Antibiogram of Bacterial Isolates from the Anterior Nares and Hands of Health Care Workers in University of Uyo Teaching Hospital (UUTH) Uyo, AkwaIbom State, Nigeria. J Bacteriol Parasitol. 2013;4(2):1-5. doi:10.4172/2155-9597.1000168

25. Tan T, Tan J, Tay H, et al. Multidrug-resistant organisms in a routine ward environment: differential propensity for environmental dissemination and implications for infection control. J Med Microbiol. 2013;62(5):766-772. doi:https://doi.org/10.1099/jmm.0.052860-0

26. Tapia J, Gomez A, Marcelo J, et al. Identificación y Antibiograma de Pseudomonas aeruginosa y Staphylococcus aureus en el Pabellón Infantil de Quemados del Hospital Viedma Agosto-2013. Rev Cient Cienc Med. 2014;17(1):19-22. doi:http://www.scielo.org.bo/scielo.php?script=sci_arttext&pid=S1817-74332014000100006

27. Méndez R, Calixto O, Becerra C, et al. Microorganismos presentes en fonendoscopios, manos, cavidad oral y nasal de estudiantes de una facultad de medicina. Revista Med. 2012;20 (1):90-100. doi: 10.18359/rmed.1227

28. Hammuel C, Jatau D, Whong C. Prevalence and Antibiogram Pattern of Some Nosocomial PathogensIsolated from Hospital Environment in Zaria, Nigeria. Aceh Int. J. Sci. Technol. 2014;3(3):131-139. doi: 10.13170/aijst.3.3.1593

29. Tula M, Filgona J, Kyauta S, et al. Screening for some virulent factors among bacterial isolates from surfaces of hospital fomites and hands of healthcare workers. Cell Mol Biomed Reports. 2023;3(1):9-16. doi:10.55705/cmbr.2022.355120.1054

30. Arango A, López S, Vera D, et al. Epidemiología de las infecciones asociadas a la asistencia sanitaria. Acta Médica del Cent. 2018;12(3):262-272. doi:https://www.medigraphic.com/pdfs/medicadelcentro/mec-2018/mec183c.pdf

31. Sánchez Z, Hurtado G. Lavado de manos. Alternativa segura para prevenir infecciones. MediSur. 2020;18(3):492-495. doi:http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1727-897X2020000300492

32. Avadhani C, Udayasuriyan G, Rao K. Common Health Hazards in Healthcare Facilities & Impact on Healthcare Workers/Professionals/Patients – Remedial Measures – An Analysis. Int J Multidiscip Res. 2023;5(1):1-20. doi:https://www.ijfmr.com/papers/2023/1/1335.pdf

33. Organización Panamericana de la Salud. Patógenos multirresistentes que son prioritarios para la OMS. PAHO. Published 2021. https://www.paho.org/es/noticias/4-3-2021-patogenos-multirresistentes-que-son-prioritarios-para-oms#:~:text=Helicobacter pylori%2C Staphylococcus aureus%2C Streptococcus,riesgo la salud de la

34. Rodríguez C, Vesga O. Staphylococcus aureus resistente a vancomicina. Biomédica. 2005;25(4):575-587. doi:10.7705/biomedica.v25i4.1384

35. Castañeda-Narváez J, Hernández-Orozco H. Higiene de manos con soluciones alcoholadas. Acta pediátrica México. 2016;37(6):358-361. doi:https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0186-23912016000600358

36. Acter T, Uddin N, Das J, et al. Evolution of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) as coronavirus disease 2019 (COVID-19) pandemic: A global health emergency. Sci Total Environ. 2020;730:1-19. doi:https://doi.org/10.1016/j.scitotenv.2020.138996

37. Zingg W, Park B, Storr J, et al. Technology for the prevention of antimicrobial resistance and healthcare-associated infections; 2017 Geneva IPC-Think Tank (Part 2). Antimicrob Resist Infect Control. 2019;8(83):1-5. doi:10.1186/s13756-019-0538-y

38. Alotaibi A, Alsuraimi A, Bawazir A, et al. To What Extent the Hand Hygiene among Health Care Workers Become the Core of Best Practice in the COVID-19 Era? Int Arch Nurs Heal Care. 2020;6(2):966-977. doi:10.23937/2469-5823/1510144

39. Santosaningsih D, Erikawati D, Santoso S, et al. Intervening with healthcare workers' hand hygiene compliance, knowledge, and perception in a limited-resource hospital in Indonesia: a randomized controlled trial study. Antimicrob Resist Infect Control. 2017;6(23):1-10. doi:10.1186/s13756-017-0179-y

40. Genc O, Arikan I. The relationship between hand hygiene practices and nasal Staphylococcus aureus carriage in healthcare workers. Med Lav. 2020;111(1):54-62. doi:10.23749/mdl.v111i1.8918

Author's contributions:

Nolbedir Saza Ramírez and **Fernando Rojas Páez** collected and analyzed data on the identification, resistance, and susceptibility of microorganisms on the hands of healthcare professionals. They also implemented the statistical analysis of the data. **Julieth Yadira Serrano Riaño** and **Juan Jairo Vaca-González** evaluated the collected data and analyzed the risk of bias in individual studies. All authors contributed to the study design, acquisition of data from medical science databases, classification of data using a checklist, analysis and interpretation of data, and interpretation, writing, and critical editing of the manuscript.

All authors approved the final version to be published and are responsible for all aspects of the work, including ensuring its version and integrity.