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Nosocomial infections and their relationship with invasive procedures. Review of the evidence and current challenges

Infecciones nosocomiales y su relación con procedimientos invasivos. Revisión de la evidencia y desafíos actuales

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ABSTRACT

Introduction: nosocomial infections represent a critical problem in hospital settings, especially in intensive care units (ICUs), where patients are exposed to invasive procedures that increase the risk of infectious complications. Among the most frequent infections are catheter-associated urinary tract infections, vascular catheter-related bloodstream infections, and ventilator-associated pneumonia.
Methods: a systematic search of scientific literature was conducted in the electronic databases PubMed/MedLine, Google Scholar, and SciELO to compile up-to-date evidence on nosocomial infections (NIs) associated with invasive procedures in intensive care units (ICUs). The search included publications from the last 10 years (2015–2025) to ensure the relevance and currency of the information, considering the advances in prevention strategies and the changing profile of pathogenic microorganisms.
Results: the etiology of nosocomial infections and their relationship to invasive procedures is multifactorial and involves interactions between pathogens, host susceptibility, and the healthcare environment.
Conclusions: nosocomial infections associated with invasive procedures, such as urinary tract infections, bacteremia, and ventilator-associated pneumonia, remain a significant challenge in intensive care units (ICUs). Despite advances in preventive strategies, the persistence of these infections highlights the urgent need to improve adherence to protocols and standardize clinical practices. The future of nosocomial infection management depends on a more effective

integration of preventive measures, along with ongoing research into new therapeutic and diagnostic interventions. This will reduce the impact of these infections and improve the quality of life of critically ill patients.

Keywords: Nosocomial Infections; Urinary Tract Infections; Invasive Procedures; Vascular Catheters.

RESUMEN

Introducción: las infecciones nosocomiales representan un problema crítico en los entornos hospitalarios, especialmente en las unidades de cuidados intensivos (UCI), donde los pacientes están expuestos a procedimientos invasivos que incrementan el riesgo de complicaciones infecciosas. Entre las infecciones más frecuentes se encuentran las infecciones del tracto urinario asociadas a catéteres, las bacteriemias relacionadas con catéteres vasculares y la neumonía asociada a ventilación mecánica.
Métodos: se realizó una búsqueda sistemática de literatura científica en las bases de datos electrónicas PubMed/MedLine, Google Scholar y SciELO, con el objetivo de recopilar evidencia actualizada sobre las infecciones nosocomiales (IN) asociadas a procedimientos invasivos en unidades de cuidados intensivos (UCI). La búsqueda abarcó publicaciones de los últimos 10 años (2015-2025) para garantizar la relevancia y vigencia de la información, considerando el avance en las estrategias de prevención y el perfil cambiante de los microorganismos patógenos.
Resultados: la etiología de las Infecciones nosocomiales y su relación con procedimientos invasivos es multifactorial e implica interacciones entre patógenos, la susceptibilidad del huésped y el entorno sanitario.
Conclusiones: las infecciones nosocomiales asociadas a procedimientos invasivos, tales como las infecciones del tracto urinario, bacteriemias y neumonías asociadas a ventilación mecánica, siguen siendo un desafío significativo en las unidades de cuidados intensivos (UCI). A pesar de los avances en estrategias preventivas, la persistencia de estas infecciones resalta la necesidad urgente de mejorar la adherencia a los protocolos y estandarizar las prácticas clínicas. El futuro del manejo de infecciones nosocomiales depende de una integración más eficaz de las medidas preventivas, junto con la investigación constante sobre nuevas intervenciones terapéuticas y diagnósticas. De esta manera, se podrá reducir el impacto de estas infecciones y mejorar la calidad de vida de los pacientes críticos.

Palabras clave: Infecciones Nosocomiales; Infecciones Del Tracto Urinario; Procedimientos Invasivos; Catéteres Vasculares.

INTRODUCTION

Nosocomial infections represent a critical problem in hospital settings, especially in intensive care units (ICUs), where patients are exposed to invasive procedures that increase the risk of infectious complications. These infections are associated with increased morbidity, mortality, prolonged hospital stays, and high costs for health systems (Mazzeffi et al., 2021; Chant et al., 2011). Among the most common infections are catheter-associated urinary tract infections (CAUTIs), vascular catheter-related bacteremias (VCRBs), and ventilator-associated pneumonia (VAP) (Quintanilla Chanez et al., 2011; Ferrer & Almirante, 2014). In developing countries, the incidence of nosocomial infections is up to five times higher than in developed countries, due to factors such as the lack of infection control programs, scarce resources, and the use of obsolete technology (Bizuayehu et al., 2022). In addition, the emergence of multidrug-resistant

microorganisms complicates therapeutic management and increases the risk of treatment failure (Bagshaw & Laupland, 2006; Laupland et al., 2005). Despite advances in preventive strategies, such as the use of closed urinary drainage systems, the implementation of packages of measures for central venous catheter insertion, and the elevation of the head of the bed in ventilated patients, significant challenges remain in adhering to protocols and standardizing clinical practices (Hooton et al., 2010; Kalil et al., 2016). This review aims to analyze current evidence on nosocomial infections associated with invasive procedures, with an emphasis on their epidemiology, risk factors, microbiology, diagnostic methods, therapeutic strategies, and prevention measures. It also discusses the current challenges in controlling these infections and prospects for reducing their impact on public health.

METHODS

To prepare this review, a systematic search of the PubMed/Medline, Google Scholar, and SciELO databases was conducted, with the aim of compiling updated evidence on nosocomial infections (NIs) associated with invasive procedures in intensive care units (ICUs). The search covered publications from the last 10 years (2015-2025) to ensure the relevance and validity of the information, considering advances in prevention strategies and the changing profile of pathogenic microorganisms. Advanced search strategies were used, employing key terms in Spanish and English, selected according to their relevance and need for the topic. The Spanish terms included: “nosocomial infections,” “invasive procedures,” “urinary catheter-associated infection,” “vascular catheter-associated infection,” and “ventilator-associated pneumonia.” Their English equivalents were: “nosocomial infections,” “invasive procedures,” “catheter-associated urinary tract infection,” “central line-associated bloodstream infection,” and “ventilator-associated pneumonia.” These terms were combined using Boolean operators (“AND,” “OR,” “NOT”) in search formulas tailored to each database’s specific syntax. Based on the results, articles written in Spanish or English that provided significant information on the epidemiology, risk factors, etiology, diagnosis, treatment, and prevention of NI associated with invasive procedures were selected. Case series studies, original articles, and systematic reviews were prioritized, excluding non-peer-reviewed publications, studies with unclear methodologies, or those with data prior to 2015, unless they were seminal references cited in recent works.

RESULTS

The etiology of nosocomial infections and their relationship to invasive procedures are multifactorial and involve interactions among pathogens, host susceptibility, and the healthcare environment. The most frequent and clinically important infections acquired in the intensive care unit (ICU) are those associated with the support devices patients often require. These include bloodstream infections associated with intravascular catheters, ventilator-associated pneumonia, and catheter-associated urinary tract infections. Several factors contribute to the high incidence of these infections in the ICU. Compared to hospitalized patients in general, ICU patients have more chronic comorbidities, often receive immunomodulatory therapies, and suffer from more severe acute physiological disturbances (Brandtner et al., 2020). The high frequency of permanent catheters in ICU patients facilitates the entry of microorganisms into vital organs and areas. The use and maintenance of these catheters requires frequent contact with healthcare personnel, predisposing patients to colonization and infection by nosocomial pathogens. In addition, the equipment necessary for the proper maintenance of these devices can act as a reservoir and vector for pathogens and facilitate the horizontal transmission of pathogens between patients.

Central line-associated bloodstream infections are a major cause of morbidity and mortality worldwide. However, their incidence may be declining in some areas due to widespread prevention measures (Centers for Disease Control and Prevention, 2011; Fagan et al., 2013). Although ICU patients are typically exposed to more medical devices and are in more serious health than other hospitalized patients, central line-associated bloodstream infections remain common in hospital wards outside the ICU (Centers for Disease Control and Prevention, 2024). Permanent catheters are also a frequent source of infection in many populations requiring long-term venous access, including hemodialysis and cancer patients, as well as those receiving total parenteral nutrition. Bloodstream infections associated with the widespread use of permanent catheters may have contributed to changes in the epidemiology of other infections.

Intravascular catheter-associated bloodstream infections occur with peripheral intravascular (IV) catheters and central venous catheters (CVCs; Figure 1) (Raad et al., 2007). CVCs are increasingly used in hospital and outpatient settings to provide long-term venous access. They are considered the most preventable type of healthcare-associated infection (HAI). Infection usually occurs when skin flora migrates across the outer surface of the catheter into the bloodstream.

Figure 1. Risk factors for primary catheter-related bloodstream infections

Risk factors

These include those related to the catheter; all intravascular (IV) devices carry an infection risk (Mermel et al., 2001). In the case of central venous catheters (CVCs), the insertion site influences the risk of infection. Some studies have reported a lower risk with the subclavian route, making it the preferred insertion site in ICU patients (Lorente et al., 2005; Maki et al., 2006). The insertion of peripheral intravenous catheters in the hand may be associated with a lower risk of bacteremia compared to more proximal sites. In general, the risk of catheter-

associated bacteremia is comparatively higher in the following circumstances: femoral or internal jugular placement compared to subclavian placement (Mermel et al., 1991; Richet et al., 1990; Merrer et al., 2001; Ronco, 2005), use for hyperalimentation or hemodialysis compared to other indications (Wilcox, 2009), and multilumen peripherally inserted central catheters compared to single-lumen catheters (Lam et al., 2018). It has been estimated that one in three healthcare-associated Staphylococcus aureus catheter-related bloodstream infections is due to peripheral intravenous catheters. Peripheral intravenous catheters with a diameter ≤16 G may be associated with an increased risk of bloodstream infection (Chopra et al., 2013). In addition to host and catheter risk factors, institutional factors and safety culture may be associated with catheter-related bloodstream infections (Faltoni et al., 2024).

Sources of infection

Bloodstream infection (BSI) associated with CVC can be attributed to four main sources: most commonly skin colonization or intraluminal or connector contamination, less commonly secondary seeding of a BSI (Maki, 1992). The most common cause of central venous catheter (CVC)-related infections is colonization of the intracutaneous and intravascular (IV) portions of the catheter by microorganisms originating from the patient's skin and, occasionally, from the hands of healthcare personnel (during insertion or manipulation) (Snydman et al., 1982; Bjornson et al., 1982). In addition, several studies have found a strong correlation between intense skin colonization and both catheter colonization and subsequent catheter-related infection, especially with short-term IV devices (Cooper & Hopkins, 1985; Raad et al., 1995; Guidet et al., 1994; Armstrong et al., 1990). Microorganisms enter the catheter wound and migrate along the catheter-subcutaneous path to the fibrin sheath surrounding IV catheters. Scanning electron micrographs reveal that microorganisms can colonize both the external and internal surfaces of catheters. Intraluminal or connector contamination is a major source of bacteremia in patients with CVCs implanted for more than two weeks or in patients with surgically implanted devices (Liñares et al., 1985). Hematogenous spread from the device can occur during bacteremia originating from another focus of infection, often gastrointestinal in origin; this is more likely in critically ill patients or those with long-term catheters (Mermel et al., 1991). Recurrent catheter-associated bacteremia can be difficult to distinguish from worsening of the primary focus of infection; removal of the catheter may help to differentiate between these possibilities. The use of diluted chlorhexidine via contaminated atomizers for skin disinfection has also been associated with at least two outbreaks of bacteremia and should be avoided.

Microbiology

Prior to the 1980s, Gram-negative aerobes were the predominant microorganisms associated with nosocomial bloodstream infections (BSIs). Since then, Gram-positive aerobes (coagulase-negative staphylococci, S. aureus, and Enterococcus) and Candida species have become more important. The results of a recent study conducted in the United States identified S. aureus (23 %), Candida species (13 %), coagulase-negative staphylococci (12 %), Enterococcus species (12 %), Streptococcus species (12 %), E. coli (8 %), and Bacteroides species (6%) as common pathogens. However, some studies continue to report coagulase-negative staphylococci as the most frequent microorganism (Magill et al., 2018). Fungi, especially Candida species, are responsible for up to 27 % of bloodstream infections associated with central venous catheters (Chitnis et al., 2012).

Catheter-associated urinary tract infections (CAUTIs)

Catheter-associated urinary tract infections (CAUTIs) are among the most common nosocomial infections in ICUs (Vilca Yahuita et al., 2020). They are classified as extraluminal or

intraluminal. Extraluminal infections result from bacterial migration along the external surface of the catheter, from the urethral meatus to the bladder. Intraluminal infections arise from urinary stasis or from ascending infection via the contaminated catheter lumen. The use of a urinary catheter is the main risk factor for urinary tract colonization. Other factors include female sex, length of ICU stay, severity of illness, and prior antibiotic use (Chant et al., 2011). In addition, colonization can occur through the catheter lumen, the urinary meatus, or a distant source (Hooton et al., 2010). Most urinary tract infections are monomicrobial, with Escherichia coli, Pseudomonas aeruginosa, and Enterococcus spp. being the most common.

Urine culture is considered the gold standard for the diagnosis of CAUTI, with cutoff points of 10^5 CFU/mL in patients without a catheter and 10^3 CFU/mL in patients with a catheter. Urinalysis may be useful, but it has low specificity. Treatment should be specific for patients with symptoms and documented bacteriuria. Treatment of asymptomatic bacteriuria is not recommended due to the risk of bacterial resistance.

Preventive measures include using urinary catheters only when necessary, early catheter removal, using aseptic techniques during insertion and handling, and maintaining a closed drainage system (Brandtner et al., 2020). Studies have shown that implementing quality programs can significantly reduce the incidence of CAUTI (Brandtner et al., 2020).

Table 1. Vascular Catheter-Related Infections (VCRIs)

Author(s)	Year	Main Findings	Catheter Type
Raad et al.	1997	They identified that colonization of the insertion site predicts the onset of systemic infections; they recommended total barrier measures when inserting catheters.	CVC, tunneled catheter
Mermel et al.	2001	They defined diagnostic criteria for CRBSI: fever without other cause, positive catheter and/or blood cultures, and resolution after device removal.	All types
Lorente et al.	2005	A comparative study showed a higher risk of CRBSI with femoral catheters than with subclavian or jugular catheters, due to a higher local bacterial load.	CVC
Maki et al.	2006	They compared different types of catheters and showed that those impregnated with chlorhexidine or antimicrobials significantly reduce bacteremia.	CVC
Timsit et al.	2009	They confirmed that antimicrobial coatings reduce colonization and infection rates, especially in long-term catheters.	CVC, arterial catheters
Zimlichman et al.	2013	Cost-effectiveness study: each episode of catheter-related bacteremia increases costs by up to $45 000 USD and prolongs hospital stay by 10-20 days.	CVC
CDC & NHSN (US)	2023	They reported an overall 20 % decrease in CVC-related infections post-pandemic, thanks to the reinforcement of preventive measures and the use of advanced catheter technologies.	CVC, arterial catheters
López-Medrano et al. (Spain)	2024	They evaluated Candida spp. infections in catheters, observing an increase in patients with prolonged parenteral nutrition and immunosuppressive therapy.	CVC, feeding catheters

Current challenges in controlling nosocomial infections in Latin America and Bolivia

Controlling nosocomial infections associated with invasive procedures poses serious challenges in Latin America, including Bolivia. Despite advances in preventive strategies globally, the region continues to struggle with structural problems that hinder the effective implementation

of control measures. The scarcity of financial and human resources, coupled with inadequate infrastructure, limits hospitals' ability to establish standardized protocols and conduct effective monitoring. In many Latin American countries, including Bolivia, the lack of ongoing training for healthcare personnel and the frequent turnover of professionals contribute to poor adherence to prevention guidelines, increasing the incidence of nosocomial infections. In addition, the prolonged use of invasive devices, such as urinary and central catheters, combined with a growing prevalence of multidrug-resistant microorganisms, further aggravates the situation, as available treatments are not always effective. Disparities in the availability of advanced technology, such as rapid diagnostic systems and ventilation support equipment, also hinder early diagnosis and timely intervention.

This context is accentuated by unequal access to quality health care, especially in rural areas and in less complex hospitals, where sanitary conditions and compliance with standards are more precarious. In Bolivia, the implementation of infection control programs is still in its infancy, and the lack of robust legislation and dedicated resources limits their effectiveness. There is an urgent need to promote more effective integration of public policies, continuing education, and monitoring at all levels of the health system, with a special focus on improving hospital infrastructure and accessibility to state-of-the-art diagnostic technologies.

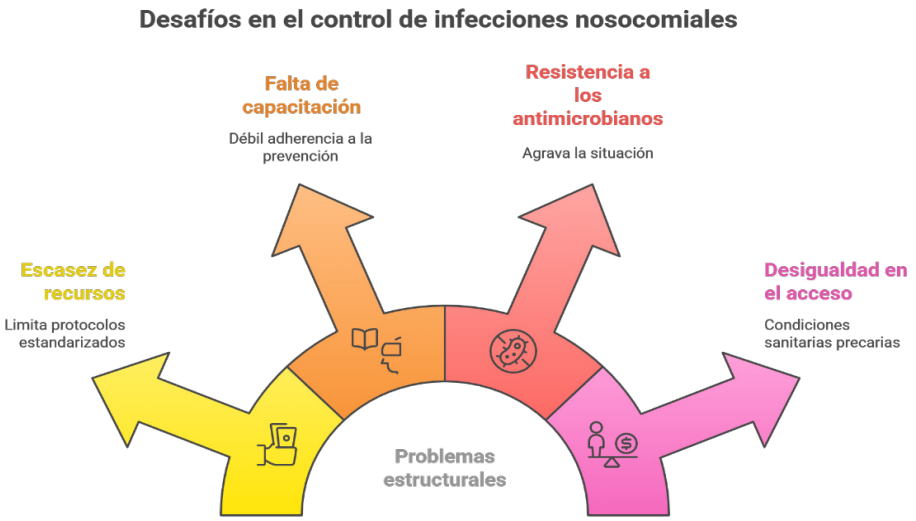

Figure 2. Challenges in nosocomial infection control

CONCLUSIONS

Nosocomial infections associated with invasive procedures, such as urinary tract infections, bacteremia, and ventilator-associated pneumonia, remain a significant challenge in intensive care units (ICUs). These infections not only increase morbidity and mortality but also impose a considerable economic burden on health systems, especially in developing countries, where incidence rates are significantly higher. Despite advances in preventive strategies, the persistence of these infections highlights the urgent need to improve adherence to protocols and standardize clinical practices. Antimicrobial resistance and limited resources further complicate the control of these infections, underscoring the importance of multidisciplinary approaches that include continuing education, ongoing surveillance, and the implementation of appropriate technologies. The future of nosocomial infection management depends on more

effective integration of preventive measures, along with ongoing research into new therapeutic and diagnostic interventions. In this way, the impact of these infections can be reduced, and the quality of life of critically ill patients can be improved.

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