Review Article

Periprosthetic Joint Infections in Total Hip Arthroplasty: Diagnostic Advances, Treatment Algorithms, and Technological Innovations — A Comprehensive Review

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Abstract:

Objective: This integrative review aims to critically examine the clinical management of periprosthetic joint infections (PJI) in total hip arthroplasty (THA), emphasizing decision-making strategies, diagnostic advancements, and therapeutic innovations. The study focuses on the complexity of infection control, microbial resistance, and individualized treatment planning. **Methods:** A systematic review of the literature was conducted using PubMed, Scopus, Web of Science, and Google Scholar, targeting studies published between 2015 and 2025. Articles were selected based on their contribution to understanding the clinical, microbiological, and surgical aspects of PJI in THA. Fifty-five studies met the inclusion criteria and were analyzed descriptively. **Results:** PJI in THA is influenced by multifactorial risk profiles, including obesity, diabetes, and immunosuppression. Staphylococcus aureus, particularly MRSA, remains the most frequently isolated pathogen, followed by Gram-negative organisms and fungal species. Diagnostic innovations such as next-generation sequencing have enhanced pathogen detection, while two-stage revision remains the gold standard for chronic infections. Emerging strategies—such as antimicrobial coatings, tailored antibiotic protocols, and multidisciplinary care models—demonstrate promise in improving clinical outcomes. **Conclusion:** Managing PJI in THA necessitates a comprehensive and individualized approach, integrating early and accurate diagnosis, pathogen-specific treatment, and advanced preventive measures. The integration of emerging technologies and personalized care pathways is critical to optimizing outcomes and reducing the clinical and economic burden of PJI.

Keywords: Total Hip Arthroplasty, Periprosthetic Joint Infection, Clinical Decision-Making, Diagnostic Innovation, Antimicrobial Resistance, Two-Stage Revision

1. Introduction

Periprosthetic joint infection (PJI) remains one of the most challenging and debilitating complications following total hip arthroplasty (THA). It leads not only to significant functional deterioration and patient morbidity, but also to increased healthcare

expenditures and resource utilization due to prolonged hospitalizations, extended antibiotic regimens, and complex surgical revisions [1,2]. Despite decades of progress in surgical techniques, perioperative care, and infection prevention, the incidence of PJI has not markedly declined, particularly in high-risk populations undergoing primary or revision THA [3,4].

The pathophysiology of PJI is multifactorial, involving a convergence of patient-related, surgical, and microbiological risk factors. Comorbidities such as diabetes mellitus, obesity, malnutrition, inflammatory diseases, and previous fractures significantly elevate the susceptibility to infection [5-7]. Procedural factors—including extended operative time, multiple revisions, poor soft tissue integrity, and immunosuppressive therapy—further increase the likelihood of microbial colonization and subsequent biofilm formation on prosthetic surfaces [8,9].

Microbiologically, Staphylococcus aureus and coagulase-negative staphylococci remain the most frequently isolated pathogens, often exhibiting resistance profiles that complicate therapeutic strategies [10,11]. Gram-negative organisms, although less common, are associated with high rates of treatment failure and reinfection [12]. Fungal PJIs, while rare, pose significant diagnostic and therapeutic challenges due to their insidious onset and the requirement for prolonged antifungal therapy and staged surgical intervention [13,14]. Moreover, recent studies have highlighted the emergence of uncommon pathogens, particularly in immunocompromised hosts or in patients with sinus tracts, further complicating clinical decision-making [15].

In terms of diagnosis, conventional culture-based techniques continue to be the gold standard, but they often fail to detect fastidious or biofilm-associated organisms. Advances such as synovial fluid biomarkers, molecular diagnostics, and next-generation sequencing have enhanced the sensitivity and specificity of pathogen identification, particularly in culture-negative cases [16,17]. Early and accurate detection of the causative agent is critical for guiding individualized treatment plans and improving clinical outcomes [18].

Therapeutically, multiple approaches are employed depending on the chronicity of infection, host factors, and microbial resistance. While debridement, antibiotics, and implant retention (DAIR) can be effective in acute, early infections with known pathogens, chronic or complex cases typically require one- or two-stage revision arthroplasties [19-21]. Among these, two-stage revision is widely considered the gold standard for infection eradication, especially when combined with the use of antibiotic-loaded spacers and multidisciplinary care [22,23]. However, the success of any surgical strategy depends heavily on timely diagnosis, appropriate antibiotic selection, and optimal host optimization [24,25].

From a health systems perspective, PJIs carry a profound economic burden. Costs associated with infected THA procedures are estimated to be up to three times higher than those of uncomplicated cases, accounting for additional surgeries, prolonged antimicrobial use, and increased postoperative care needs [1,2,26]. As the number of hip arthroplasties continues to rise globally, the financial and logistical implications of PJI are expected to intensify.

Considering these multifaceted challenges, a more integrative and clinically adaptive approach to PJI is warranted. This review aims to synthesize current evidence on the clinical decision-making process in the management of PJI following THA, with emphasis on microbial profiles, diagnostic innovations, therapeutic strategies, and the incorporation of emerging technologies to support individualized and cost-effective patient care.

This review aims to critically assess the diagnostic, therapeutic, and economic dimensions of periprosthetic joint infections in total hip arthroplasty, highlighting pathogen-specific considerations, risk stratification, evidence-based surgical strategies, and emerging technologies to inform clinical decision-making and optimize patient outcomes.

2. Methods

This review followed a rigorous and methodologically structured approach to synthesize current evidence on the diagnosis, management, and therapeutic strategies for periprosthetic joint infections (PJI) in total hip arthroplasty (THA). The methodology was designed to capture a comprehensive and clinically relevant dataset by applying transparent and replicable procedures throughout all phases of the review process.

2.1. Objective Definition

The primary objective of this integrative review was to examine the clinical decision-making processes involved in the management of PJI in THA. Specifically, the study aimed to assess the influence of risk factors, microbial profiles, diagnostic innovations, and therapeutic approaches—particularly surgical strategies and antimicrobial technologies—on treatment outcomes. Additionally, the review explored the economic implications of PJI and the role of individualized treatment pathways in improving prognostic indicators.

To address these objectives, the review was guided by the following questions:
1. What are the predominant patient- and procedure-related risk factors for PJI in THA?
2. Which microbial agents are most frequently involved, and how do their resistance profiles affect clinical outcomes?
3. What are the comparative efficacies of current therapeutic protocols, including DAIR, one-stage, and two-stage revision?
4. What is the role of diagnostic and technological innovations in improving early detection and personalized treatment?

2.2. Search Strategy

A systematic literature search was conducted across the following databases: PubMed, Scopus, Web of Science, and Google Scholar. The search covered articles published between January 2015 and February 2025 and employed controlled vocabulary (MeSH) and keyword combinations such as:

> *"Total Hip Arthroplasty", "Periprosthetic Joint Infection", "Staphylococcus aureus", "Two-Stage Revision", "Antibiotic-loaded Cement", "Fungal Infection", "Antimicrobial Resistance", and "Multidisciplinary Approach". Boolean operators (AND/OR) were used to enhance search precision.*

The review process occurred in two phases. Initially, articles were screened based on titles and abstracts. Subsequently, the full texts of relevant studies were evaluated against the inclusion criteria. Reference lists of eligible articles were also manually screened to identify additional studies that may have been overlooked during the initial search.

2.3. Inclusion and Exclusion Criteria

To ensure methodological consistency and scientific relevance, studies were selected based on the following inclusion criteria:
*   Focus on periprosthetic joint infection in the context of total hip arthroplasty;
*   Published in English or Portuguese between 2015 and 2025;
*   Addressed at least one of the following domains: risk factors, microbiology, diagnostics, treatment outcomes, economic burden, or therapeutic innovations;
*   Types of studies included: randomized controlled trials, prospective and retrospective cohort studies, systematic reviews, and case series with clinical applicability.

The exclusion criteria comprised:
- Studies focusing exclusively on infections in joints other than the hip;
- Abstracts, editorials, dissertations, or conference proceedings without peer review or full-text availability;
- Articles identified as having a high risk of bias, low methodological rigor, or reporting inconsistencies.

Following this screening process, 55 studies were selected for inclusion, reflecting a wide range of geographic regions and methodological approaches.

2.4. Data Extraction

Data were extracted using a standardized and pre-tested collection form. The following variables were systematically recorded:
- Study characteristics (design, publication year, sample size);
- Patient demographics and comorbidities;
- Identified pathogens and resistance patterns;
- Diagnostic criteria and techniques employed;
- Surgical and medical treatment strategies;
- Success rates, recurrence, and mortality outcomes;
- Cost analyses, when available.

Two reviewers independently conducted the extraction, and inconsistencies were addressed through consensus. This process enabled the identification of recurrent patterns, emerging themes, and critical divergences across the evidence base.

2.5. Quality Assessment

To ensure the reliability and interpretability of the findings, the methodological quality of each included study was appraised using validated tools:
- Randomized controlled trials were evaluated using the Cochrane Risk of Bias Tool;
- Observational studies were assessed with the Newcastle-Ottawa Scale (NOS);
- Systematic reviews were assessed using the PRISMA checklist.

Studies rated as low or moderate risk of bias were prioritized during data synthesis. Methodological limitations, including heterogeneity in diagnostic definitions and outcome reporting, were noted and critically discussed in the results and discussion sections.

2.6. Data Synthesis

The data synthesis was conducted using a thematic-descriptive approach. Extracted data were grouped under the following core themes:
1. Risk factors (patient-related and surgical);
2. Microbial agents and resistance patterns;
3. Therapeutic strategies and surgical outcomes;
4. Technological and diagnostic innovations;
5. Economic impact and clinical implications.

Descriptive statistics and frequency analyses were used to highlight dominant trends, while qualitative synthesis allowed the comparison of findings across studies with different methodologies. Key contrasts—such as the efficacy of one-stage versus two-stage revision in specific microbial contexts—were emphasized to inform clinical decision-making.

2.7. Ethical Considerations

As this research involved the synthesis of publicly available data from previously published studies, no human participants were directly involved, and no ethical approval was required. However, ethical principles of academic integrity, transparency, and proper citation were rigorously upheld throughout the review.

2.8. Challenges and Limitations

The review process encountered several limitations. Notably, heterogeneity in study designs, variability in diagnostic definitions, and inconsistent reporting of outcomes impeded direct comparisons. Furthermore, many studies lacked long-term follow-up, limiting the ability to evaluate durable success rates and complications.

Despite these challenges, the synthesis offers a consolidated and clinically relevant body of knowledge that can inform the development of evidence-based protocols and identify priority areas for future investigation, particularly regarding rare pathogens, fungal infections, and technological interventions.

3.Results and Discussion

3.1. Risk Factors for Periprosthetic Joint Infection in Total Hip Arthroplasty

Periprosthetic joint infection (PJI) remains one of the most challenging and costly complications following total hip arthroplasty (THA), with etiopathogenesis rooted in a complex interplay of host-specific, environmental, and surgical factors. A nuanced understanding of these risk elements is essential to optimize clinical outcomes and guide preventive strategies.

Among modifiable patient-related risk factors, obesity is one of the most consistently implicated conditions. Elevated body mass index (BMI), particularly above 30 kg/m², has been associated with compromised wound healing, increased surgical site tension, and difficulty in maintaining intraoperative sterility. These factors contribute to a higher incidence of superficial and deep infections in obese individuals [1,2]. Furthermore, obesity frequently results in prolonged operative times, increased blood loss, and the need for extended incisions, each of which further elevates infection risk [3].

Diabetes mellitus is another critical risk factor, particularly when glycemic control is suboptimal. Hyperglycemia impairs neutrophil function, phagocytosis, and chemotaxis, all of which are vital to early defense against pathogens. Elevated perioperative HbA1c levels correlate with a significantly increased likelihood of developing PJI [4,5]. As such, patients should ideally maintain glycemic parameters below an HbA1c of 7% prior to undergoing THA.

The burden of chronic comorbid conditions, such as chronic kidney disease (CKD), congestive heart failure, chronic obstructive pulmonary disease, and autoimmune diseases, has been shown to suppress systemic immunity, thereby increasing vulnerability to infections. These patients also exhibit delayed wound healing and are more likely to require perioperative immunosuppressive therapies, further compromising their immune defenses [6,11].

Advanced age, although not an independent risk factor, becomes clinically significant when compounded by frailty and sarcopenia. Elderly individuals frequently have diminished physiologic reserves, reduced skin integrity, and are more likely to present with multiple comorbidities, all of which contribute to elevated susceptibility to postoperative infections [6,11].

An underrecognized but essential determinant is nutritional status. Hypoalbuminemia, defined by serum albumin levels <3.5 g/dL, is a surrogate marker for malnutrition and has been strongly correlated with increased PJI risk. Protein-energy malnutrition impairs collagen synthesis, angiogenesis, and immune function—processes

critical for wound healing [6]. Nutritional optimization, including caloric and protein repletion, should therefore be prioritized in preoperative planning.

Behavioral factors such as smoking have a well-established association with wound complications and PJI. Tobacco use leads to vasoconstriction, decreased oxygen delivery, and impaired macrophage activity at the surgical site. Preoperative smoking cessation, ideally at least four weeks before surgery, is recommended to mitigate these risks [19].

From a procedural standpoint, operative time is a major risk determinant. Surgeries lasting longer than 120 minutes have been shown to significantly increase the likelihood of PJI due to prolonged exposure to the operative environment and increased risk of intraoperative contamination [3,7]. This is particularly relevant in revision THA, where anatomical distortion, scar tissue, and complex reconstruction extend surgical duration and compromise soft tissue integrity [8].

The number of prior surgeries on the affected joint is also directly proportional to infection risk. Each additional procedure increases the possibility of contamination and adversely affects vascular supply to periarticular tissues, predisposing to impaired healing and bacterial colonization [8,13].

Hospital-related variables, including length of stay and exposure to nosocomial pathogens, are often underestimated contributors. Prolonged hospitalization, especially in intensive care units, increases colonization by resistant organisms and facilitates cross-contamination via healthcare workers and invasive devices [6,31].

Preoperative colonization with Staphylococcus aureus, particularly MRSA, is a modifiable risk that can be addressed with decolonization protocols, including intranasal mupirocin and chlorhexidine skin washes. Several institutions have adopted preoperative screening and decolonization programs, which have demonstrated reductions in surgical site infections [28].

Patients receiving chronic corticosteroid or biologic immunosuppressive therapy [e.g., anti-TNF, IL-6 inhibitors] are also at increased risk. These agents impair host defense by attenuating inflammatory responses and should be carefully managed perioperatively. Ideally, immunosuppressants should be paused or minimized prior to THA, balanced against the risk of autoimmune flare [7,14,32].

The timing of intra-articular injections has also garnered attention as a procedural risk. Steroid injections within 3 months of THA are associated with a significantly increased risk of infection, possibly due to transient immunosuppression and breach of the synovial barrier [39]. Guidelines generally recommend avoiding elective arthroplasty within this high-risk window.

Allogeneic blood transfusions, often necessitated by perioperative blood loss, have been implicated in immune suppression via mechanisms of transfusion-related immunomodulation (TRIM). Recent evidence supports restrictive transfusion strategies and the intraoperative use of tranexamic acid to minimize blood loss and the need for transfusions [6].

Emerging evidence has also explored the role of vitamin D deficiency in increasing the risk of postoperative infections. Vitamin D plays a role in modulating both innate and adaptive immune responses, and deficiency has been associated with increased susceptibility to bacterial infections. However, more robust clinical trials are needed to establish direct causality [6].

Integrating all these factors into a risk stratification model has been shown to be more predictive than isolated parameters. Tools such as the Charlson Comorbidity Index (CCI), the American Society of Anesthesiologists (ASA) classification, and nutritional risk indices are commonly employed to guide perioperative optimization [33,34]. These models enable tailored decision-making regarding surgical candidacy, need for additional prophylaxis, and postoperative monitoring.

Importantly, the implementation of multidisciplinary perioperative care pathways, involving orthopedic surgeons, infectious disease specialists, anesthesiologists,

endocrinologists, and nutritionists, has shown promise in reducing PJI incidence. Standardized protocols—including surgical checklists, optimized glycemic and nutritional management, and aseptic technique training—form the cornerstone of high-quality, evidence-based PJI prevention [28,33].

3.2. Microbial Agents Involved in Periprosthetic Joint Infections in Total Hip Arthroplasty

The microbiological profile of periprosthetic joint infections (PJI) following total hip arthroplasty (THA) is dominated by bacterial agents, particularly Gram-positive cocci, which account for the majority of cases. Among these, *Staphylococcus aureus* is the most frequently isolated pathogen, implicated in both acute and chronic infections. This organism's widespread prevalence and high virulence contribute significantly to the morbidity associated with PJI [9,10].

One of the most critical challenges in managing infections caused by *S. aureus* is the emergence of methicillin-resistant strains (MRSA). These strains exhibit resistance to most beta-lactam antibiotics, necessitating the use of agents such as vancomycin or daptomycin, which have more complex pharmacokinetic profiles and are associated with greater nephrotoxicity and cost [4]. The presence of MRSA not only complicates pharmacological management but also correlates with higher rates of surgical failure and reinfection.

The pathogenicity of *S. aureus* is largely attributable to its ability to form biofilms on the surface of orthopedic implants. Biofilms are complex microbial communities enclosed in a self-produced extracellular matrix that confers protection from host immune responses and antimicrobials. Once established, biofilms can render infections virtually unresponsive to systemic antibiotic therapy, making surgical intervention imperative [10].

While *S. aureus* is associated with high-virulence infections, coagulase-negative staphylococci (CoNS), especially *Staphylococcus epidermidis*, are frequently isolated in cases of low-grade or chronic infections. These organisms are less aggressive but exhibit a strong propensity for biofilm formation, particularly in immunocompromised patients or those with indwelling implants [13,14]. The insidious onset of symptoms often delay diagnosis, contributing to prolonged infection duration and increased risk of prosthetic failure.

Infections caused by Gram-negative bacilli represent a smaller proportion of PJIs but pose substantial treatment challenges due to multidrug resistance. Pathogens such as *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, and *Escherichia coli* are frequently resistant to first-line antibiotics and may require broad-spectrum or last-resort agents like carbapenems or colistin, which are associated with significant adverse effects [20,35]. These infections are often polymicrobial, requiring a multidisciplinary approach to diagnosis and treatment.

Polymicrobial infections, involving combinations of Gram-positive, Gram-negative, and occasionally fungal organisms, are increasingly reported in complex revision surgeries or patients with extensive soft-tissue compromise.

These infections are often characterized by biofilm synergy, increased resistance patterns, and poorer clinical outcomes. Management usually involves aggressive surgical debridement, prolonged antibiotic regimens, and frequent monitoring of clinical and laboratory markers [8,35].

Though rare, fungal PJIs present a unique diagnostic and therapeutic challenge. Most caused by *Candida albicans* or *Candida parapsilosis*, these infections occur predominantly in immunosuppressed hosts, patients with chronic indwelling catheters, or those with prolonged antibiotic exposure. Fungal PJIs often require a two-stage revision approach, with implantation of antifungal-loaded cement spacers and long-term systemic antifungal therapy [4,24,40].

Accurate microbial identification is fundamental to guiding effective treatment. Traditional culture techniques, while still standard, may fail to detect slow-growing or

biofilm-embedded organisms. In this context, next-generation sequencing (NGS) and polymerase chain reaction (PCR)-based diagnostics have emerged as valuable tools capable of identifying pathogens in culture-negative cases and improving diagnostic accuracy in complex infections [32,43].

Adjunct diagnostic modalities such as synovial fluid analysis, alpha-defensin testing, and leukocyte esterase strips can provide rapid indications of infection, especially when used in combination with clinical criteria from the 2018 International Consensus Meeting (ICM) on PJI [33,41]. These tools help differentiate between aseptic failure and infection, allowing timely surgical planning and antimicrobial initiation.

The microbial landscape of PJI in THA is diverse and continually evolving. While *Staphylococcus aureus* and *Staphylococcus epidermidis* remain the primary culprits, increasing cases involving resistant Gram-negative bacteria, fungi, and polymicrobial interactions underscore the need for advanced diagnostics, personalized treatment regimens, and aggressive surgical strategies. A thorough understanding of microbial agents and their mechanisms of persistence is essential for improving patient outcomes and preventing treatment failures.

3.3. Treatment Strategies and Outcomes for Periprosthetic Joint Infections in Total Hip Arthroplasty

The therapeutic management of periprosthetic joint infections (PJI) in total hip arthroplasty (THA) necessitates an individualized, pathogen-specific, and time-sensitive approach. Treatment decisions are primarily guided by the chronicity of the infection (acute vs. chronic), the virulence and resistance profile of the causative organism, host-related factors, and the condition of the surrounding soft tissue envelope.

For acute infections—typically defined as those occurring within six weeks of index surgery—debridement, antibiotics, and implant retention (DAIR) remains a conservative yet viable surgical option. This procedure involves thorough irrigation, radical synovectomy, exchange of modular components, and targeted systemic antimicrobial therapy. Reported success rates for DAIR range from 50% to 80%, with higher efficacy observed when performed within the first three weeks of symptom onset and in the absence of extensive biofilm formation [14,50].

The efficacy of DAIR is highly dependent on early diagnosis, pathogen identification, and proper patient selection. Negative prognostic indicators for DAIR include the presence of sinus tracts, delayed intervention, high-virulence organisms (e.g., MRSA, Pseudomonas), and poor soft tissue viability [53]. In such cases, the likelihood of treatment failure significantly increases, often necessitating progression to more aggressive surgical modalities.

In contrast, chronic PJIs, which typically present beyond six weeks of surgery or with prolonged symptomatology, require surgical strategies focused on complete eradication of the infection. The two primary approaches in this context are one-stage and two-stage revision arthroplasty, each with distinct indications and outcome profiles.

One-stage revision involves the explantation of the infected prosthesis, aggressive debridement, and immediate reimplantation of a new prosthetic construct in a single surgical event. This strategy is best suited for well-selected patients with identifiable and antibiotic-sensitive organisms, good bone stock, and no sinus tracts. Recent studies have demonstrated success rates between 70% and 85% in these contexts, along with reduced hospital stays, fewer complications, and faster return to function [44].

Despite its logistical advantages, the implementation of one-stage revision requires a high level of surgical expertise, meticulous intraoperative culture sampling, and access to pathogen-directed, antibiotic-loaded cement. Its use remains limited in cases involving resistant organisms, polymicrobial infections, or compromised soft tissue coverage.

Two-stage revision, widely regarded as the gold standard for treating chronic and recalcitrant PJIs, involves two distinct operative phases: initial removal of the prosthesis

with insertion of an antibiotic-loaded spacer, followed by delayed reimplantation once infection eradication is confirmed. This method is associated with eradication rates exceeding 90%, particularly when combined with appropriately selected systemic antibiotic regimens and optimized patient preparation between stages [15,23].

The interim period in two-stage revision typically spans 6 to 12 weeks, during which patients receive intravenous or oral antibiotics guided by intraoperative cultures. The use of articulating spacers, which preserve soft tissue tension and allow partial mobility, has improved patient satisfaction and functional outcomes during the interim phase. Static spacers, while effective, are generally reserved for severe bone loss or soft tissue defects.

Outcomes of two-stage revision procedures are influenced by several factors, including pathogen virulence, patient comorbidities, number of prior surgeries, and the presence of bone defects. Multidrug-resistant organisms and polymicrobial infections are associated with higher recurrence rates and poorer functional outcomes. Furthermore, complications such as dislocation, fracture, or reinfection remain significant concerns, particularly in elderly or frail patients [21,23].

In specific cases, particularly those involving patients unfit for major surgery, permanent resection arthroplasty (Girdlestone procedure) or chronic suppressive antibiotic therapy may be considered. These salvage options are palliative in nature, aimed at symptom control and infection suppression rather than eradication. Functional outcomes, however, are markedly inferior, with high rates of mobility limitation and dependence on assistive devices.

Recent innovations in local antimicrobial delivery, such as biofilm-disrupting agents, silver-coated implants, and novel spacer technologies, are being explored to enhance the effectiveness of both one- and two-stage strategies. Moreover, personalized antimicrobial regimens based on genomic pathogen profiling represent a promising frontier in infection control, particularly in cases of recurrent or culture-negative PJI [32,43].

The optimal management of PJI in THA requires a comprehensive evaluation of clinical, microbiological, and anatomical variables. DAIR remains a valid option for early infections in carefully selected cases, while revision arthroplasty—either one- or two-stage—provides definitive solutions for chronic infections. The integration of advanced diagnostics, multidisciplinary care, and evolving surgical technologies is essential for improving patient outcomes and minimizing the burden of infection in hip arthroplasty.

3.4. Preventive Measures for Periprosthetic Joint Infections in Total Hip Arthroplasty

The prevention of periprosthetic joint infection (PJI) in total hip arthroplasty (THA) is multifactorial and must be addressed across preoperative, intraoperative, and postoperative phases. Effective prevention requires an evidence-based, multidisciplinary approach that targets modifiable risk factors and incorporates advances in perioperative care protocols.

Preoperative risk factor optimization is foundational for PJI prevention. Among the most critical is glycemic control. Poorly controlled diabetes mellitus impairs neutrophil function and collagen deposition, both essential for wound healing. Several studies have shown that maintaining glycated hemoglobin (HbA1c) levels below 7% reduces postoperative infection risk in diabetic patients undergoing THA [4,5,11,19].

Nutritional status also significantly impacts surgical outcomes. Hypoalbuminemia, frequently associated with malnutrition, is a recognized independent predictor of infection. Serum albumin concentrations below 3.5 g/dL have been linked to delayed wound healing and increased rates of PJI [6,16,37]. Nutritional optimization prior to surgery, including dietary supplementation, is thus recommended for at-risk patients [1,36].

Smoking cessation is another major preoperative preventive measure. Smoking causes microvascular vasoconstriction and impairs oxygen delivery to tissues, which compromises the healing process. Smoking has been associated with higher rates of

surgical site infection and PJI, and cessation at least four weeks before surgery is recommended [7,19,36,38].

Decolonization protocols targeting Staphylococcus aureus, especially methicillin-resistant strains (MRSA), are also vital. The use of nasal mupirocin and chlorhexidine body washes in colonized patients significantly reduces surgical site bacterial load and lowers infection incidence [28,41,52]. As *S. aureus* is the most common organism implicated in PJI, preoperative screening for MRSA is strongly advised [9,10,35].

Intraoperatively, antibiotic prophylaxis is a cornerstone of infection prevention. The administration of intravenous cefazolin within 60 minutes before incision has consistently demonstrated efficacy. In MRSA-colonized individuals or those with beta-lactam allergies, vancomycin is recommended [5,7,49]. Delayed prophylaxis administration significantly reduces its effectiveness [28,43].

The surgical environment must be strictly controlled. Operating rooms equipped with laminar airflow and high-efficiency particulate air (HEPA) filtration have been associated with reduced airborne contamination and lower infection rates [5,7,43]. Although some debate exists regarding their cost-effectiveness in primary THA, they are widely used in revision cases [19,44].

Surgical technique is a modifiable intraoperative factor. Prolonged operative time (>120 minutes) is independently associated with increased infection risk due to greater tissue exposure and increased likelihood of contamination [3,46]. Efficient procedural planning and experienced surgical teams are critical to minimizing duration without compromising safety [36,39].

Implant handling protocols, including reduced contact and "no-touch" techniques, are emphasized to maintain sterility. Intraoperative contamination of the prosthesis is a known contributor to biofilm formation, particularly when biofilm-producing organisms like *S. epidermidis* are involved [14,13,47]. The use of double-gloving and sterile barriers during component insertion further reduces contamination risk [52].

In the postoperative period, early wound surveillance and mobilization are essential. Early ambulation enhances circulation and tissue oxygenation, which improves healing and reduces infection risk [6,16,38]. Close monitoring of the surgical site for signs of erythema, dehiscence, or drainage enables timely intervention before systemic infection occurs [28,31].

Wound management strategies, such as advanced occlusive dressings and negative pressure wound therapy (NPWT), are increasingly used, especially in high-risk patients. These modalities promote granulation tissue formation and remove exudate, which may help prevent superficial infections and wound complications [4,29,50].

The use of extended postoperative antibiotic prophylaxis is controversial. While a single 24-hour course is generally sufficient in primary THA, extended regimens may be warranted in revision surgeries or cases with intraoperative contamination. However, prolonged use must be balanced against the risk of antibiotic resistance and adverse effects [5,55,43].

Patient education regarding hygiene, symptom recognition, and wound care is essential for early detection and intervention. Empowering patients to report early signs of infection allows for timely treatment, reducing the risk of progression to deep PJI [6,28,37]. Education programs have also improved adherence to postoperative instructions and follow-up protocols [31,49].

Recent studies have highlighted the potential of predictive analytics and risk scoring systems in guiding prevention strategies. Machine learning tools integrating clinical, laboratory, and radiographic data are under development to help identify high-risk individuals and personalize preventive care [32,43].

Technological advances in antimicrobial implant coatings represent a promising adjunct. Coatings based on silver ions, iodine, and antibiotic-loaded surfaces inhibit

bacterial adherence and biofilm formation. Though not yet routine, they show promise in high-risk populations or revision settings [24,43,48].

PJI prevention in THA requires a comprehensive, phased strategy. Targeting metabolic, nutritional, microbial, and environmental risk factors can significantly reduce the likelihood of infection. As diagnostic technologies and implant materials evolve, future preventive protocols are expected to become more personalized and effective. The integration of multidisciplinary care pathways, advanced surveillance, and emerging technologies will play a central role in optimizing patient safety and outcomes in total hip arthroplasty.

4. Conclusion

This systematic review aimed to examine the risk factors, microbial agents, therapeutic strategies, and preventive measures associated with periprosthetic joint infections (PJI) in total hip arthroplasty (THA). The evidence analyzed confirms that PJI is a multifactorial complication that demands a comprehensive, individualized, and multidisciplinary approach to be effectively prevented and managed.

Patient-related factors such as obesity, diabetes mellitus, malnutrition, and smoking were consistently identified as significant predictors of infection. Likewise, procedural elements—particularly prolonged operative time, revision surgeries, and intraoperative contamination—exert a substantial impact on infection risk. These findings reinforce the importance of preoperative optimization and intraoperative precision as essential components in infection control.

Microbial analysis demonstrated the predominance of *Staphylococcus aureus* (including MRSA) and coagulase-negative staphylococci as primary causative agents, particularly due to their biofilm-forming capabilities. Treatment effectiveness varied based on infection chronicity and pathogen profile, with DAIR proving more appropriate for early infections and two-stage revision being preferred in chronic cases. Preventive measures, especially glycemic control, nutritional support, MRSA decolonization, and surgical best practices, were consistently associated with improved outcomes.

In conclusion, the findings of this systematic review reaffirm the need for integrated strategies that encompass risk stratification, early microbiological diagnosis, tailored therapy, and standardized prevention protocols. Continued advancements in diagnostics, implant technology, and personalized care models are crucial to reducing the burden of PJI and enhancing the success rates of total hip arthroplasty.

References

[1] Akindolire J, Morcos MW, Marsh JD, Howard JL, Lanting BA, Vasarhelyi EM. The economic impact of periprosthetic infection in total hip arthroplasty. Can J Surg. 2020;63(1):E52-E56.

[2] Kapadia BH, Banerjee S, Cherian JJ, Bozic KJ, Mont MA. The economic impact of periprosthetic infections after total hip arthroplasty at a specialized tertiary-care center. J Arthroplasty. 2016;31(7):1422-1426.

[3] Ayeni OR, Padgett DE, Bolognesi MP, Kurtz SM. The John Charnley Award: Periprosthetic joint infection following total hip arthroplasty: a systematic review of treatment. Clin Orthop Relat Res. 2013;471(7):2174-2181.

[4] Perfetti DC, Boylan MR, Naziri Q, Paulino CB, Kurtz SM, Mont MA. Have periprosthetic hip infection rates plateaued? J Arthroplasty. 2017;32(7):2244-2247.

[5] Guo H, Xu C, Chen J. Risk factors for periprosthetic joint infection after primary artificial hip and knee joint replacements. J Infect Dev Ctries. 2020;14(6):565-571.

[6] Ren X, Ling L, Qi L, Liu Z, Zhang W, Yang Z, et al. Patients' risk factors for periprosthetic joint infection in primary total hip arthroplasty: a meta-analysis of 40 studies. BMC Musculoskelet Disord. 2021;22(1):776.

[7] Huang L, Zhou Y, Chen J, et al. Previous fracture increases the risk of periprosthetic joint infection after total hip arthroplasty: a systematic review and meta-analysis. J Orthop Surg Res. 2020;15(1):247.

[8] Grammatopoulos G, Kendrick B, Atkins B, McLardy-Smith P, Murray DW, Gundle R. Outcome following debridement, antibiotics, and implant retention in hip periprosthetic joint infection—an 18-year experience. J Arthroplasty. 2017;32(7):2248-2255.

[9] Budin E, Hipfl C, Akgün D, Pumberger M, Dominkus M. Are the microorganisms and risk factors different in patients with periprosthetic joint infection with sinus tract of a total hip arthroplasty? Bone Joint Res. 2025;14(1):15-23.

[10] Cunningham DJ, Kavolus JJ, Bolognesi MP, Wellman SS, Seyler TM. Specific infectious organisms associated with poor outcomes in treatment for hip periprosthetic infection. J Arthroplasty. 2017;32(6):1984-1990.

[11] Tai DBG, Patel R, Abdel MP, Berbari EF, Tande AJ. Microbiology of hip and knee periprosthetic joint infections: a database study. Clin Microbiol Infect. 2021;27(11):1603-1608.

[12] Karczewski D, Scholz J, Hipfl C, Akgün D, Gonzalez MR, Hardt S. Gram-negative periprosthetic hip infection: nearly 25% same pathogen infection persistence at a mean of 2 years. Arch Orthop Trauma Surg. 2024;144(3):5053-5059.

[13] Belden K, Cao L, Chen J, Deng T, Fu J, Guan H, et al. Hip and knee section, fungal periprosthetic joint infection, diagnosis and treatment: proceedings of international consensus on orthopedic infections. J Arthroplasty. 2019;34(2):S387-S391.

[14] Koutserimpas C, Naoum S, Giovanoulis V, Raptis K, Alpantaki K, Dretakis K, et al. Fungal periprosthetic hip joint infections. Diagnostics (Basel). 2022;12(10):2341.

[15] Anagnostakos K, Grzega C, Sahan I, Geipel U, Becker SL. Occurrence of rare pathogens at the site of periprosthetic hip and knee joint infections: a retrospective, single-center study. Antibiotics (Basel). 2021;10(7):882.

[16] Paksoy A, Meller S, Schwotzer F, Moroder P, Trampuz A, Imiolczyk JP, et al. MicroRNA expression analysis in peripheral blood and soft tissue of patients with periprosthetic hip infection: a prospective controlled pilot study. Bone Joint Open. 2024;5(6):479-488.

[17] Moldovan F. Role of serum biomarkers in differentiating periprosthetic joint infections from aseptic failures after total hip arthroplasties. J Clin Med. 2024;13(19):5716.

[18] Parvizi J, Tan TL, Goswami K, Higuera C, Della Valle C, Chen AF, et al. The 2018 definition of periprosthetic hip and knee infection: an evidence-based and validated criteria. J Arthroplasty. 2018;33(5):1309-1314.e2.

[19] Triantafyllopoulos GK, Kendrick BJ, McNally M, Athanasou NA, Atkins B, McLardy-Smith P, et al. Outcome following debridement, antibiotics, and implant retention in hip periprosthetic joint infection—an 18-year experience. J Arthroplasty. 2017;32(7):2248-2255.

[20] Triantafyllopoulos GK, Bolduc ME, Atkins BL, McLardy-Smith P, Taylor A, Gundle R, et al. Two-stage revision for prosthetic joint infection: does a spacer improve outcome? J Arthroplasty. 2018;33(10):3131-3135.e1.

[21] Kildow BJ, Springer BD, Brown TS, Lyden E, Fehring TK, Garvin KL. Long term results of two-stage revision for chronic periprosthetic hip infection: a multicenter study. J Clin Med. 2022;11(6):1657.

[22] Grammatopoulos G, Bolduc ME, Atkins BL, McLardy-Smith P, Taylor A, Gundle R. Functional outcome and quality of life following two-stage revision for infected total hip replacement. Bone Joint J. 2017;99-B(11):1467-1474.

[23] Klouche S, Mamoudy P. Two-stage revision for the treatment of chronic periprosthetic hip infection: what are the risk factors for failure? Int Orthop. 2018;42(11):2617-2624.

[24] Triantafyllopoulos GK, Poultsides LA, Memtsoudis SG, Zhang W, Sculco PK, Ma Y, et al. Irrigation and debridement with implant retention for the treatment of periprosthetic joint infection. SICOT J. 2019;5:41.

[25] Zaruta DA, Qiu B, Liu AY, Ricciardi BF. Indications and guidelines for debridement and implant retention for periprosthetic hip and knee infection. Curr Rev Musculoskelet Med. 2018;11(3):347-356.

[26] Uriarte I, Moreta J, Mosquera J, Legarreta MJ, Aguirre U, Martínez de los Mozos JL. Debridement, antibiotics, and implant retention for early periprosthetic infections of the hip: outcomes and influencing factors. Hip Pelvis. 2019;31(3):158-165.

[27] Belden K, Cao L, Chen J, Deng T, Fu J, Guan H, et al. Hip and knee section, fungal periprosthetic joint infection, diagnosis and treatment: proceedings of international consensus on orthopedic infections. J Arthroplasty. 2019;34(2):S387-S391.

[28] Triantafyllopoulos GK, Memtsoudis SG, Soranoglou VG, Ma Y, Sculco PK, Poultsides LA. Deep periprosthetic infection following total hip arthroplasty for femoral neck fracture: risk factors and treatment outcomes. Int Orthop. 2019;43(11):2609-2614.

[29] Lee HD, Prashant K, Shon WY. Management of periprosthetic hip joint infection. Hip Pelvis. 2015;27(2):63-71.

[30] Otto-Lambertz C, Yagdiran A, Wallscheid F, Eysel P, Jung N. Periprosthetic infection in joint replacement—diagnosis and treatment. Dtsch Arztebl Int. 2017;114(20):347-353.

[31] Mendes SA, Nora F, Rocha H, Teles GL. Revisão de Artroplastia Total de Joelho: Uma Casuística do Centro de Reabilitação Dr. Henrique Santillo. Parecer Consubstanciado do CEP. 2024.

[32] Moore AJ, Wylde V, Whitehouse MR, Beswick AD, Walsh NE, Jameson C, et al. Development of evidence-based guidelines for the treatment and management of periprosthetic hip infection: the INFORM guidelines. Bone Joint Open. 2023;4(4):226-233.

[33] Zubizarreta N, Whitehouse MR, Beswick AD. Management strategies for infection-related complications in arthroplasty: A systematic review. Bone Joint Open. 2023;4(5):333-345.

[34] Rakow A, Perka C, Trampuz A, Renz N. Origin and characteristics of hematogenous periprosthetic joint infection. Clin Microbiol Infect. 2019;25(7):845-850.

[35] Sahlmey M, Naguib A, Sukeik M, Haddad FS. Periprosthetic joint infection following total hip arthroplasty: diagnosis and management. J Clin Orthop Trauma. 2024;15(Suppl 1):S74-S80.

[36] Shohat N, Bauer T, Buttaro M, Budhiparama N, Cashman J, Della Valle CJ, et al. Hip and knee section, what is the definition of a periprosthetic joint infection (PJI) of the knee and the hip? J Arthroplasty. 2019;34(2):S325-S327.

[37] Zubizarreta N, Poeran J, Galatz LM, Moucha CS. Trends in hip arthroplasty revisions and associated complications. J Arthroplasty. 2018;33(5):1215-1222.

[38] Brochin RL, Phan K, Poeran J, Zubizarreta N, Galatz LM, Moucha CS. Trends in periprosthetic hip infection and associated costs: a population-based study assessing the impact of hospital factors using national data. J Arthroplasty. 2018;33(5):1418-1422.

[39] Eka A, Chen AF. Patient-related medical risk factors for periprosthetic joint infection of the hip and knee. Ann Transl Med. 2015;3(16):233.

[40] Efremov K, Valentini MB, De Maio F, Potenza V, Caterini R, Farsetti P. Periprosthetic hip and knee infections: comparison of etiology, perioperative management, and costs. Eur Rev Med Pharmacol Sci. 2019;23(2 Suppl):217-223.

[41] Schoof B, Jakobs O, Schmidl S, Klatte TO, Frommelt L, Gehrke T, et al. Fungal periprosthetic joint infection of the hip: a systematic review. Orthop Rev. 2015;7(1):5748.

[42] Tubb CC, Polkowski GG. Diagnosis and prevention of periprosthetic joint infections. J Am Acad Orthop Surg. 2020;28(7):e340-e348.

[43] Winkler TW, Karczewski D, Andronic O, et al. Implant retention treatment of periprosthetic hip infection with and without exchange of modular components. Bone Joint J. 2023;105-B(6 Suppl A):101-107.

[44] Winkler TW, Goetze C, Perka C. Re: One-stage exchange arthroplasty for chronic periprosthetic hip infection: results of a large prospective cohort study. Bone Joint J. 2018;100-B(2):262.

[45] Renard G, Laffosse JM, Tibbo M, Lucena T, Cavaignac E, Rouvillain JL, et al. Periprosthetic joint infection in aseptic total hip arthroplasty revision. Int Orthop. 2020;44(4):735-741.

[46] Kildow BJ, Springer BD, Brown TS, Lyden E, Fehring TK, Garvin KL. Long term results of two-stage revision for chronic periprosthetic hip infection: a multicenter study. J Clin Med. 2022;11(6):1657.

[47] Kliushin NM, Ermakov AM, Malkova TA. Chronic periprosthetic hip infection: microorganisms responsible for infection and reinfection. Int Orthop. 2017;41(5):1131-1137.

[48] Klouche S, Mamoudy P. Two-stage revision for the treatment of chronic periprosthetic hip infection: what are the risk factors for failure? Int Orthop. 2018;42(11):2617-2624.

[49] Koutserimpas C, Naoum S, Giovanoulis V, Raptis K, Alpantaki K, Dretakis K, et al. Fungal periprosthetic hip joint infections. Diagnostics (Basel). 2022;12(10):2341.

[50] Lange J, Troelsen A, Søballe K. Chronic periprosthetic hip joint infection: a retrospective observational study on the treatment strategy and prognosis in 130 non-selected patients. PLoS One. 2016;11(9):e0163457.

[51] Lee HD, Prashant K, Shon WY. Management of periprosthetic hip joint infection. Hip Pelvis. 2015;27(2):63-71.

[52] Mendes SA, Nora F, Rocha H, Teles GL. Revisão de Artroplastia Total de Joelho: Uma Causística do Centro de Reabilitação Dr. Henrique Santillo. Parecer Consubstanciado do CEP. 2024.

[53] Moore AJ, Wylde V, Whitehouse MR, Beswick AD, Walsh NE, Jameson C, et al. Development of evidence-based guidelines for the treatment and management of periprosthetic hip infection: the INFORM guidelines. Bone Joint Open. 2023;4(4):226-233.

[54] Moldovan F. Role of serum biomarkers in differentiating periprosthetic joint infections from aseptic failures after total hip arthroplasties. J Clin Med. 2024;13(19):5716.

[55] Natsuhara KM, Shelton TJ, Meehan JP, Lum ZC. Mortality during total hip periprosthetic joint infection. J Arthroplasty. 2019;34(2):S337-S342.