Review

IMPACT OF ROBOTIC-ASSISTED ORTHOPAEDIC PROCEDURES ON SURGICAL SITE INFECTIONS AND PROSTHETIC JOINT INFECTIONS: A SYSTEMATIC REVIEW OF THE LITERATURE

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ABSTRACT

Robotic-assisted technology in orthopedic surgery has gained significant attention in recent years due to its potential to improve surgical precision and patient outcomes. However, concerns have been raised regarding prolonged operative times, increased surgical site complexity, and the potential impact on rates of surgical site infections (SSIs) and prosthetic joint infections (PJIs). Understanding this relationship is essential for optimizing surgical outcomes and clinical decision-making. This systematic review aims to investigate whether robotic-assisted orthopedic procedures increase the risk of subsequent SSIs or PJIs. Comprehensive research was conducted on PubMed, EMBASE, and other databases according to PRISMA guidelines. A total of 69 studies were included in the review. The results indicate no significant difference in SSI/PJI rates between robotic-assisted and conventional techniques, although factors such as prolonged operative times, increased operating room traffic, and additional equipment may temporarily elevate risks during the learning curve. Further long-term, high-quality studies are required to confirm these findings.

KEYWORDS: *robotic-assisted orthopedic surgery, robotic-assisted technology, surgical site infections, prosthetic joint infections*

INTRODUCTION

The adoption of robotic-assisted technology in orthopedic surgery has gained significant attention in recent years, especially in joint arthroplasties and spinal surgeries (1, 2). Initially developed in the 1980s, robotic systems aimed to enhance implant alignment and reduce complications compared to traditional methods (3). Over the years, robotic-assisted surgical systems have advanced considerably, providing greater precision and the ability to tailor surgical procedures to individual patients. By incorporating cutting-edge imaging technologies, real-time feedback mechanisms, and complex algorithms, these systems support surgeons in optimizing surgical outcomes (4).

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In joint arthroplasties, they allow for appropriate preoperative planning, optimal selection of implants, and accurate placement of artificial joints (5). Similarly, in spinal surgeries, robotics facilitates minimally invasive approaches, improves screw positioning, and reduces complications (6).

Despite these advancements, concerns persist regarding their impact on infection rates, particularly surgical site infections (SSIs) and prosthetic joint infections (PJIs). Factors such as prolonged operative times, increased operating room traffic, and the use of additional equipment may increase the risk of contamination. Furthermore, the learning curve associated with adopting new technologies may temporarily compromise procedural efficiency and outcomes.

This systematic review aims to investigate whether patients undergoing robotic-assisted orthopedic procedures face an increased risk of subsequent PJI.

By summarising data from various studies in the literature, this review evaluates the risks and benefits of robotic procedures in the field of orthopedics, emphasizing their clinical significance.

MATERIALS AND METHODS

This systematic review aims to assess whether patients undergoing robotic-assisted orthopedic procedures face an increased risk of developing subsequent SSI and/or PJI.

A comprehensive search of the literature was conducted in October 2024 using PubMed, Medline, Web of Science, and Scopus databases, adhering to the PRISMA guidelines. Out of an initial pool of 268 identified articles, 69 studies were included after thorough full-text screening (Fig. 1).

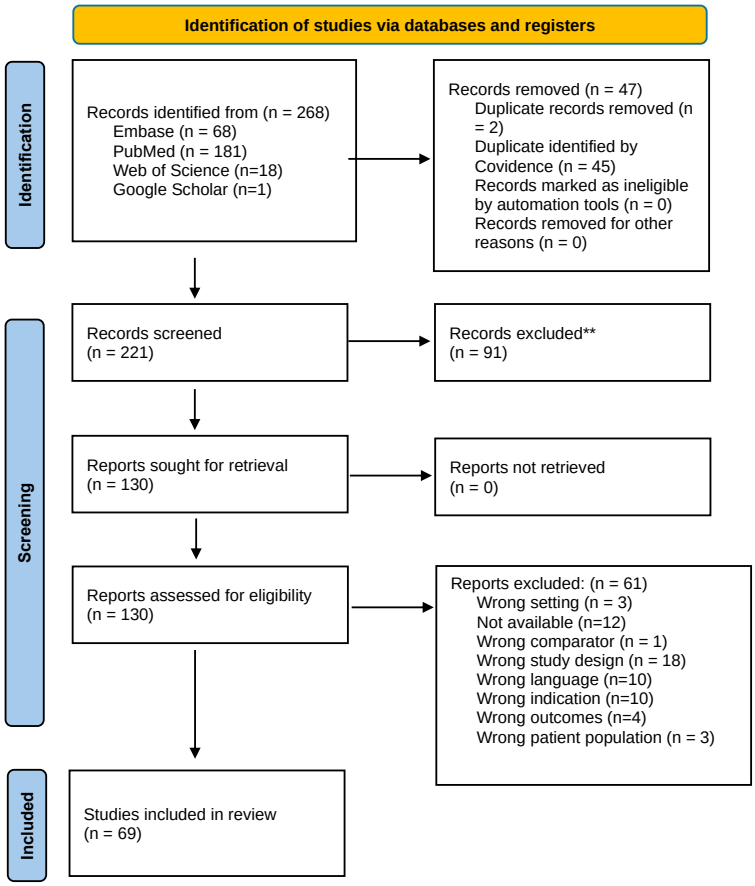

Fig. 1. *PRISMA flowchart of included studies.*

Notably, half of the included studies were published in 2023 and 2024, reflecting the timeliness and relevance of the available evidence.

Most studies on robotic-assisted orthopedic procedures have primarily investigated radiological and functional outcomes. However, a smaller subset focused explicitly on the incidence and risk factors associated with SSI and PJI, providing critical insights into the safety profile of these advanced surgical techniques.

RESULTS

This systematic review summarizes evidence from 69 studies investigating the impact of robotic-assisted orthopedic procedures on infection outcomes, specifically surgical site infections (SSIs) and prosthetic joint infections (PJIs). The findings highlight the current understanding and limitations in assessing infection risks associated with robotic-assisted surgeries.

Joint arthroplasties

Most of the selected studies primarily focus on radiological and functional outcomes of robotic-assisted joint arthroplasties, with only a limited subset specifically addressing infection-related outcomes.

Notably, the follow-up periods among the different studies are variable. Only three studies included in the review had a follow-up duration of at least 10 years. Of these, a randomized controlled trial (RCT) conducted by Kim et al. in 2020 offers the longest follow-up period of 13 years. This study reports no statistically significant differences in infection or complication rates between robotic-assisted and manual total knee arthroplasty (TKA) (7). Similarly, retrospective analyses by Jeon et al. and Lee et al. also demonstrated comparable rates of PJI across both surgical techniques (8, 9). These findings emphasize that, over the long term, robotic-assisted and conventional surgical methods have similar infection outcomes.

In 2023, a systematic review and meta-analysis by Alrajeb et al. provided further support to the evidence. This study synthesized data from seven RCTs encompassing 1,942 knees, comparing robotic-assisted and conventional knee arthroplasties. The results indicated no significant differences in infection rates, clinical outcomes, and functional outcomes, sustaining the equivalency of these approaches concerning PJI and SSI risks (10).

All other included studies, RCTs, prospective and retrospective, had shorter follow-up periods but consistently reported no significant differences in infection rates between robotic-assisted and conventional arthroplasty surgery (11-25).

In 2024, Burgio et al. published a retrospective study focused exclusively on PJI in the context of robotic-assisted TKA without comparison to manual TKA. It was the only study that clearly defined and used criteria for diagnosing PJI, highlighting the importance of standardizing criteria and definitions for PJI (26).

Certain studies highlighted procedural aspects unique to robotic-assisted surgeries that could influence infection risks. Honl et al. observed that prolonged operative times associated with robotic procedures were initially linked to higher rates of SSI. However, these complications were shown to decline as surgeons gained proficiency with the technology, highlighting the impact of the learning curve (25).

Li et al. reported comparable PJI rates between robotic and conventional TKA groups despite robotic-assisted procedures having increased operative times (27, 28)

Other studies, such as those by LaValva et al., pointed to additional procedural factors, including pin-site complications and increased operating room traffic, which could elevate the risk of contamination (29, 30).

Interestingly, some studies suggested that robotic-assisted techniques might offer advantages in minimizing infection risks. Retrospective analyses by O'Rourke et al., Aggarwal et al., Katzman et al., and Khanna et al. reported lower rates of PJI in robotic-assisted surgeries compared to conventional methods (31-34). However, the interpretability of these findings is limited by the lack of detailed follow-up data in these studies. While the results suggest a potential advantage of robotic systems in minimizing infection risks, the absence of robust longitudinal data prevents drawing definitive conclusions about their long-term effectiveness.

In contrast with those studies, Piple et al.'s study reported higher rates of PJI in robotic-assisted total hip arthroplasty, an outlier that necessitates further investigation (35).

Despite these challenges, most studies indicate that robotic-assisted joint arthroplasty does not intrinsically elevate the risk of PJI when compared to conventional methods.

Improvements in surgeon proficiency over the learning curve and advancements in robotic technology have mitigated earlier concerns, as evidenced by the findings of St. Mart (36, 37). Higher infection rates observed with earlier

robotic systems were largely attributed to technical and procedural shortcomings rather than inherent deficiencies in the robotic technology itself.

Spinal surgeries

In the field of spinal surgery, infection-related outcomes varied more widely. Yang et al. reported increased complication rates, including SSI, in robotic-assisted lumbar spinal fusion (38). However, other studies presented a more favorable perspective. Keric et al. demonstrated that robotic systems could reduce infection rates in minimally invasive spine surgeries, particularly in high-risk populations (39). This benefit was also observed in studies by Zawar et al., which found that robotic-guided open spine surgeries had lower infection rates than conventional methods (40).

Notably, robotics in spinal surgery was often associated with reduced operative times, potentially lowering intraoperative contamination risks, a finding that contrasts with the extended durations seen in joint arthroplasties.

Overall, the results suggest that robotic-assisted orthopedic procedures do not inherently increase the risk of SSI or PJI. However, factors such as the surgeon's learning curve, procedural intricacies, and operating room conditions are critical in determining infection outcomes. While advancements in technology and surgical experience have decreased many early concerns, the limited number of long-term studies and the heterogeneity of research methodologies underline the need for further investigation.

DISCUSSION

The introduction of robotic-assisted technology in orthopedic surgery represents a significant innovation, offering numerous benefits, including enhanced precision in implant alignment and the ability to tailor implant selection and positioning to individual patient needs. Despite these advantages, concerns persist regarding infection risks and extended operative times. Nevertheless, the lack of a notable increase in infection rates, such as SSI and PJI, indicates that robotic-assisted surgeries are largely comparable to conventional methods in terms of safety. However, the findings emphasize the critical role of procedural intricacies, ongoing technological advancements, and the surgeon's proficiency in optimizing outcomes.

In joint arthroplasties, studies with long-term follow-up, such as the RCT by Kim et al. (7), provide evidence that robotic-assisted techniques do not lead to higher infection rates. This finding is also supported by retrospective analyses and meta-analyses, including the comprehensive review by Alrajeb et al. (10), which analyzed data from multiple RCTs.

These studies have shown that robotic-assisted knee arthroplasty achieves clinical and functional outcomes comparable to those of traditional methods without compromising infection safety.

Nevertheless, certain procedural aspects unique to robotic surgeries need attention. The extended surgical durations commonly associated with these techniques, particularly during the initial learning curve, have been linked to higher SSI rates. Honl et al.'s findings demonstrate that these complications tend to resolve as surgeons gain experience (25). Additionally, the potential for increased operating room traffic and pin-site complications, as reported by LaValva et al. (29, 30), suggests that strict adherence to infection control protocols is essential to reduce these risks. In contrast to these findings, Piple et al. reported a higher PJI rate in robotic-assisted total hip arthroplasty; highlighting the complexity of evaluating infection risks (35).

In spinal surgeries, the interplay between infection risks and procedural efficiency represents an important factor. While Yang et al. reported increased SSI rates in robotic-assisted lumbar spinal fusion (38). Other studies, however, showed the opposite results. For instance, Keric et al. demonstrated that robotic systems significantly reduced infection rates in minimally invasive spine surgeries, particularly for high-risk patients (39). This benefit is reinforced by Zawar et al., who found that robotic-guided open spine procedures achieved lower infection rates than conventional procedures (40).

The reduced operative times frequently observed in robotic spinal surgeries further underline their potential advantages. Unlike joint arthroplasties, where robotic assistance often prolongs procedures, spinal surgeries benefit from the time efficiency gained by robotic systems.

Early robotic systems were criticized for higher infection rates due to technical and procedural limitations. However, as reported in studies by St Mart et al., these issues have largely been resolved through innovations in robotic technology and improvements in surgical techniques (36, 37) .

Limitations

This study has several limitations that may affect the validity of its findings. First, the heterogeneity in study designs introduces variability in how the studies were conducted, which could influence the consistency of results. Additionally, the follow-up durations varied across studies, with some providing short-term data while others only reported intermediate-term outcomes. Another limitation is the varying definitions of infection, such as the criteria used to diagnose periprosthetic joint infection (PJI). Furthermore, the relatively small sample sizes limit the statistical power to detect significant differences.

CONCLUSIONS

In conclusion, although robotic-assisted orthopedic procedures do not seem to increase the risk of infections, the results underline the importance of procedural and technological factors in determining surgical outcomes. The use of robotic technology in orthopedic procedures should be evaluated, ensuring that their advantages, such as improved precision and consistency, are fully optimized while minimizing potential risks. Future research should focus on generating more evidence about the long-term safety and effectiveness of robotic-assisted surgeries.

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