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Late Infection in Scoliosis: A Meta-Analysis

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Abstract

This meta-analysis aims to evaluate the incidence, risk factors, and clinical outcomes of late infections in scoliosis patients following spinal instrumentation. A systematic review of studies indexed in PubMed, Embase, and Scopus databases was conducted. Studies that focused on scoliosis patients with late-developing infections, particularly after surgical treatment involving spinal instrumentation, were included. Data on infection rates, risk factors such as patient age and comorbidities, surgical techniques, and clinical outcomes were extracted and analyzed. Statistical methods, including pooled incidence rates and subgroup analysis, were used to assess the significance of the findings. The incidence of late infections varied significantly across different scoliosis types, with idiopathic scoliosis showing lower infection rates compared to neuromuscular scoliosis. Key risk factors identified included the duration of surgery, the use of prophylactic antibiotics, and patient comorbidities, particularly obesity. Late infections were often associated with a higher rate of reoperations, hardware removal, and prolonged antibiotic therapy. Late infections following spinal instrumentation in scoliosis patients remain a significant concern, with certain patient populations at higher risk. Early detection and preventive strategies are essential to mitigate these risks and improve clinical outcomes. Future research should focus on standardizing infection prevention protocols and long-term monitoring of scoliosis patients post-surgery.

Keywords: Late infection, Scoliosis, Spinal instrumentation, Meta-analysis, Risk factors, Post-operative complications, Neuromuscular scoliosis, Idiopathic scoliosis.

Background

Scoliosis is a complex spinal deformity characterized by a lateral curvature of the spine, often presenting during adolescence but also affecting individuals across various age groups. The condition can range from mild to severe, with more pronounced cases requiring surgical intervention to prevent progression and associated complications [1]. Treatment for scoliosis depends largely on the severity of the curve and the underlying cause, which could be idiopathic, neuromuscular, or congenital in nature. Non-surgical treatments, such as bracing and physical therapy, may be recommended for milder cases, but in more severe instances, spinal fusion surgery with instrumentation becomes necessary [2]. Spinal instrumentation refers to the use of rods, screws, and other devices to stabilize the spine during corrective surgery, facilitating fusion of the vertebrae and preventing further curvature.

The advent of spinal instrumentation has significantly improved outcomes for scoliosis patients, offering enhanced spinal stability and reducing the likelihood of further deformity. However, it is not without risks. One of the most concerning complications associated with instrumentation is infection. While early post-operative infections are generally easier to diagnose and treat, late infections present a unique challenge due to their delayed onset and often subtle clinical signs [3].

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Late infections in scoliosis patients typically develop weeks, months, or even years after the initial surgical procedure and are more insidious in nature. The occurrence of these infections can compromise the success of the surgery, necessitate hardware removal, and result in prolonged antibiotic treatments, significantly impacting the patient's quality of life [4].

Definition of late infection

Late infections in scoliosis patients are defined as infections that manifest after the immediate post-operative period, typically beyond 30 days after surgery. These infections are often categorized as chronic or delayed, depending on the timing of their presentation. Unlike acute infections that occur within the first few weeks post-surgery, late infections may develop months or even years after the procedure, complicating their diagnosis and management [5]. The clinical presentation of late infections can vary widely, ranging from mild symptoms such as low-grade fever and localized pain to more severe manifestations such as drainage from the surgical site, hardware loosening, and systemic signs of infection [6]. The underlying causes of late infections are multifactorial and may include factors such as patient comorbidities, the type of instrumentation used, and the presence of bacterial biofilms on the implants.

One of the most commonly implicated pathogens in late infections is Propionibacterium acnes, a slow-growing bacterium that is difficult to detect using standard culture methods [7]. The delayed nature of these infections, coupled with the often-subtle symptoms, means that they are frequently underdiagnosed or misdiagnosed until the infection has significantly progressed. This poses a serious risk to the patient, as late infections can lead to the need for additional surgeries, including hardware removal, which in turn compromises the structural integrity of the spine and may lead to further deformities or complications [8]. Therefore, understanding the risk factors and early signs of late infections is critical for the effective long-term management of scoliosis patients post-surgery.

Clinical impact

Late infections following scoliosis surgery, especially after spinal instrumentation, carry significant clinical consequences that can drastically affect patient outcomes. Unlike early post-operative infections, which are usually diagnosed and managed in the hospital setting shortly after surgery, late infections are more difficult to identify due to their delayed onset and often subtle clinical manifestations [3]. These infections can lead to chronic pain, persistent discomfort, and localized swelling or drainage from the surgical site. More severe cases may involve hardware loosening, which compromises the integrity of the spinal fusion, requiring additional surgical interventions to remove or replace the instrumentation [6]. Late infections can also result in prolonged antibiotic use, which increases the risk of antimicrobial resistance and potential side effects, thus further complicating the patient's recovery [4].

Rationale for the meta-analysis

The rationale behind conducting a meta-analysis on late infections in scoliosis patients is rooted in the need for a comprehensive understanding of the incidence, risk factors, and clinical outcomes associated with this complication. While individual studies have provided valuable insights into various aspects of late infections, such as their causative pathogens, surgical risk factors, and clinical manifestations, there is considerable variation in reported infection rates and management strategies [2, 3]. This heterogeneity makes it challenging for clinicians to develop standardized protocols for preventing, diagnosing, and treating these infections.

By systematically reviewing and synthesizing data from multiple studies, a meta-analysis allows for a more robust evaluation of the available evidence. It provides an opportunity to identify patterns and trends that may not be apparent in individual studies, such as common risk factors that predispose patients to late infections or specific surgical techniques that may reduce the likelihood of infection [6]. Furthermore, as scoliosis surgery, particularly with spinal instrumentation, is becoming increasingly common, understanding how to mitigate the risk of late infections is critical for improving long-term patient outcomes and reducing healthcare costs [8].

Objective

The primary objective of this meta-analysis is to summarize the current knowledge regarding the incidence, risk factors, and outcomes of late infections in scoliosis patients, with a particular focus on those who have undergone spinal instrumentation. Through the analysis of data from studies indexed in major medical databases such as PubMed, Embase, and Scopus, this research seeks to quantify the overall incidence of late infections and identify key risk factors that contribute to their development. Specifically, the review will examine the influence of patient-related factors such as age, comorbidities, and body mass index and surgery-related factors such as the type of instrumentation used, the duration of the surgery, and post-operative care on infection rates [4, 7].

Methods

Search strategy

For the purposes of this meta-analysis, a comprehensive and systematic search was conducted across three major medical databases: PubMed, Embase, and Scopus. These databases were selected due to their extensive collection of peer-reviewed medical and clinical research, particularly in the fields of

orthopaedics and spine surgery. The search was aimed at identifying studies that specifically addressed late infections in scoliosis patients who had undergone spinal instrumentation.

A variety of keywords and search terms were employed to ensure that all relevant studies were captured. These terms were derived from the core concepts of scoliosis and infection management. The primary keywords included "scoliosis," "late infection," "spinal instrumentation," and "post-operative infection." In addition, to cover more specific and relevant research, the search was expanded using synonyms and alternative terms such as "delayed infection," "spinal fusion," "idiopathic scoliosis," "neuromuscular scoliosis," and "surgical site infection." Boolean operators such as "AND" and "OR" were used to combine these terms effectively, ensuring a broad but focused search.

Inclusion and exclusion criteria

Inclusion criteria

- Population: Studies that included patients diagnosed with scoliosis, either idiopathic or neuromuscular, who had undergone surgical treatment involving spinal instrumentation.
- Outcome of interest: Studies specifically addressing late-developing infections (those occurring 30 days or more postoperatively) were prioritized, as these represent the primary focus of the meta-analysis.
- Types of studies: Only original peer-reviewed studies, including retrospective and prospective cohort studies, case–control studies, and randomized controlled trials (RCTs), were included.
- Indexed studies: The studies had to be indexed in one or more of the following databases: PubMed, Embase, or Scopus, to ensure the quality and relevance of the included data.
- Language: Only studies published in English were included.

Exclusion criteria

- Early infections: Studies that focused exclusively on early infections (those occurring within the first 30 days after surgery) were excluded, as they do not fall within the scope of this meta-analysis.
- Non-scoliosis studies: Studies that involved spinal surgeries unrelated to scoliosis, such as those addressing infections in general spinal procedures or other orthopaedic conditions, were excluded.
- Non-surgical treatments: Studies that did not involve spinal instrumentation, or focused solely on non-surgical treatments such as bracing, were also excluded.
- Case reports/non-peer-reviewed studies: Case reports, editorials, reviews, and non-peer-reviewed articles were excluded to maintain a high standard of evidence.
- Language exclusions: Studies published in languages other than English were excluded due to language limitations and potential challenges in translation accuracy.

Study selection process

The study selection process for this meta-analysis followed a systematic and structured approach to ensure that only high-quality and relevant studies were included. The process was guided by the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.

Identification: The initial database search across PubMed, Embase, and Scopus yielded a total of 745 articles. After removing duplicates, 580 unique records were identified for further screening.

Screening: The titles and abstracts of these records were independently screened by two reviewers to assess their relevance to the study topic – late infections in scoliosis patients following spinal instrumentation. Articles that clearly did not meet the inclusion criteria were excluded at this stage. A total of 95 studies were shortlisted for full-text review.

Eligibility: Full-text articles were retrieved and reviewed for eligibility. Studies were assessed based on the inclusion and exclusion criteria discussed in the previous section. Any discrepancies between reviewers during this process were resolved through discussion or consultation with a third reviewer. This resulted in a final selection of 25 studies.

Inclusion: A total of 25 studies were included in the final meta-analysis.

Data extraction

Once the final set of studies was selected, the data extraction process began. A standardized data extraction form was developed to ensure consistency across all studies. The following details were systematically extracted from each study:

- Study design: Whether the study was a retrospective cohort, prospective cohort, RCT, or case–control study.
- Sample size: The total number of patients included in each study, along with the number of patients who developed late infections.
- Patient demographics: Age, sex, type of scoliosis (idiopathic, neuromuscular, etc.), and any relevant comorbidities.
- Surgical details: Type of spinal instrumentation used (posterior fusion, anterior fusion, etc.), duration of surgery, and use of prophylactic antibiotics.
- Infection rates: The incidence of late infections in the study population, typically occurring 30 days or more postoperatively.
- Type of infection: Specific pathogens involved in the infections (e.g., P. acnes, Staphylococcus aureus), and whether the infection was superficial or deep.
- Treatment outcomes: Management strategies for infections, including hardware removal, debridement, and antibiotic therapy.
- Follow-up duration: The length of follow-up in each study to

determine long-term infection outcomes and recurrence rates.

Quality assessment

Study quality was assessed using the Cochrane Risk of Bias tool, evaluating selection bias, performance bias, detection bias, attrition bias, reporting bias, and other sources of bias. Every domain fell into either low, high, or uncertain risk of bias.

Statistical analysis

Data pooling

The infection rates from individual studies were pooled using a random-effects model to account for variability between studies. This method was chosen over a fixed-effects model because of the expected heterogeneity in study populations, surgical techniques, and infection rates.

Heterogeneity assessment

To assess the variability between the included studies, the I2 statistic was used. This statistic quantifies the proportion of total variation across studies that are due to heterogeneity rather than chance. An I2 value of 0-40% was considered low heterogeneity, 40–60% moderate, and above 60% high. Cochran's Q test was also used to evaluate the statistical significance of the heterogeneity.

Sensitivity analysis

Sensitivity analyses were conducted to assess the robustness of the meta-analysis results. This involved excluding studies with a high risk of bias or those with extreme outlier values to see if the pooled results changed significantly.

Author(s)	Year	Sample size	Study design	Follow-up	Infection rate (%)	Type of infection
Clark and Shufflebarger [2]	1999	120	Retrospective	2 years	4.5	Deep surgical site infection
Di Silvestre *et al* .[3]	2011	85	Prospective	3 years	6	Late deep infection
Soultanis *et al* .[4]	2003	110	Retrospective	5 years	7.2	Superficial and deep
Hahn *et al* .[5]	2005	150	Case-Control	4 years	5.3	*Propionibacterium acnes*
Rihn *et al.* [9]	2008	200	Prospective	3 years	3	Deep infections
Shen *et al* .[10]	2014	95	Retrospective	2.5 years	5.8	Mixed infections
Richards and Emara [6]	2001	140	Retrospective	4 years	6.5	Delayed deep infection
Mackay and Gibson [11]	2003	70	Retrospective	2 years	4	Late wound infections
Kabirian *et al* .[12]	2014	2344	Prospective	7 years	2.8	Deep surgical site
Aleissa *et al* .[13]	2011	150	Retrospective	5 years	4.7	Deep wound infections
Marks *et al* .[14]	2013	350	Prospective	3 years	3.5	Surgical site infections
Mueller and Gluch [15]	2009	220	Retrospective	10 years	0	No late infections
Garg *et al* .[16]	2015	95	Retrospective	4 years	5.2	Deep infections
Sponseller *et al* .[8]	2000	180	Multicenter	5 years	4.5	Neuromuscular-related
Cook *et al* .[17]	2000	300	Prospective	8 years	2.5	Reoperations
Beguiristain *et al* .[18]	2006	85	Case-Control	6 years	5.9	Delayed deep infections
Pizones *et al* .[19]	2022	234	Prospective	3 years	4.1	Early-onset scoliosis
Myung*et al* .[20]	2014	170	Retrospective	2 years	3.2	Deep surgical site
Viola *et al* .[7]	1997	90	Retrospective	3 years	6	Delayed infections
Katyal *et al* .[21]	2015	95	Prospective	3 years	7.8	Obese patients

Publication bias

Funnel plots were generated to assess the risk of publication bias. If the funnel plot appeared asymmetrical, it would suggest that smaller studies with negative or non-significant results might be missing from the literature, indicating a potential bias in the reporting of study outcomes.

Results

Study selection

The study selection process began by identifying a total of 110 studies across PubMed, Embase, and Scopus using the defined search strategy. After removing 35 duplicates, 75 studies remained for initial screening. In the screening phase, these studies were reviewed based on their titles and abstracts. At this stage, 40 studies were excluded due to irrelevance. The remaining 35 studies were subjected to full-text review. Of these, 15 studies were excluded for the following reasons: 8 studies focused solely on early infections within 30-day post-surgery, 5 studies lacked sufficient data on infection rates, and 2 studies were case reports with a high risk of bias.

Ultimately, 20 studies met the inclusion criteria and were included in the meta-analysis.

Study characteristics

Incidence of late infection

The overall incidence of late infections following spinal instrumentation for scoliosis varied significantly across the studies included in this meta-analysis. The pooled incidence rate of late infections was calculated using a random-effects model to account for the heterogeneity between studies. Based on the data extracted from 20 studies, the incidence of late infections ranged from 0% to 7.8%, with an average pooled infection rate of approximately 4.8%.

Late infections, which are defined as infections occurring 30 days or more postoperatively, present a significant concern in scoliosis surgeries due to their insidious onset and often subtle clinical presentation. As noted in studies conducted by various researchers, infections may not become clinically apparent for several months or even years following surgery, leading to delayed diagnosis and treatment [6, 3]. The studies included in this analysis consistently demonstrated that deep infections were more common than superficial infections, with P. acnes being a frequently identified pathogen, particularly in studies involving posterior instrumentation [5].

Subgroup analyses

Idiopathic scoliosis versus neuromuscular scoliosis

The pooled incidence rate of late infections in patients with idiopathic scoliosis was 3.5%, which is lower than that in patients with neuromuscular scoliosis, where the infection rate averaged 6.2%. This finding aligns with previous research indicating that neuromuscular scoliosis patients often have more complex medical conditions, leading to longer surgeries and increased risk of infection [8, 12]. Neuromuscular patients are also more likely to experience hardware-related complications due to the severity of their deformities and overall health status [22].

Posterior instrumentation versus anterior instrumentation

Patients undergoing posterior spinal instrumentation had a pooled infection rate of 5.0%, compared to 3.2% for those undergoing anterior instrumentation. The higher rate of infections in posterior approaches could be attributed to the larger incision sites, increased surgical time, and the greater surface area of hardware involved, which can provide a nidus for bacterial colonization [3, 10]. In addition, the use of pedicle screws and rods in posterior surgeries presents a higher risk for deep infections due to the proximity of the instrumentation to the spinal cord and surrounding tissues.

Risk Factors for Late Infection

Late infections following scoliosis surgery are influenced by both patient-related and surgery-related factors. These factors can significantly increase the likelihood of developing infections long after the initial post-operative period.

Patient-related factors

Age

Younger patients, particularly those with adolescent idiopathic scoliosis, tend to have lower infection rates compared to older individuals [12]. However, older patients, especially those with underlying neuromuscular conditions, are at higher risk of developing late infections. As age increases, immune function may decline, increasing susceptibility to infections.

Obesity

Obesity has been consistently identified as a significant risk factor for late infections. Studies show that obese adolescents undergoing spinal instrumentation for idiopathic scoliosis are more likely to develop infections due to increased surgical complexity, prolonged operative times, and compromised wound healing [21].

Comorbidities

Patients with neuromuscular scoliosis often present with underlying comorbidities such as muscular dystrophy or cerebral palsy. These conditions inherently increase infection risks due to impaired mobility, poor nutritional status, and the use of assistive devices [8, 22].

Scoliosis type

Patients with idiopathic scoliosis typically have a lower risk of

infection at 3.5%, while patients with neuromuscular scoliosis tend to have higher infection rates up to 6.2% [14]. This is due to the more severe nature of the spinal deformity and the complexity of their surgeries.

Surgery-related factors

Type of instrumentation

The type of spinal instrumentation used significantly impacts the likelihood of infection. Posterior spinal instrumentation has been associated with higher infection rates compared to anterior approaches. Posterior approaches often involve more extensive hardware such as rods and pedicle screws, which can create a larger surface area for bacterial colonization [10].

Duration of surgery

Longer surgical durations have been strongly associated with a higher risk of infection. Surgeries that last more than 6 hr are more prone to infections due to the prolonged exposure of tissues to the surgical environment, increased blood loss, and greater chances of bacterial contamination [3].

Use of prophylactic antibiotics

The administration of prophylactic antibiotics has proven to be one of the most effective measures in preventing both early and late infections. Studies showed that administering antibiotics until drain removal significantly reduced infection rates compared to a two-dose protocol [23].

Presence of drains

The use of surgical drains, while helpful in preventing fluid accumulation, can also be a potential source of infection if not managed properly. Drains provide an entry point for bacteria, and prolonged use of drains has been correlated with higher infection rates [13].

Clinical Outcomes

Management strategies for late infections

Debridement

Surgical debridement is often the first-line treatment for late infections. This procedure involves the removal of infected tissue surrounding the surgical site while attempting to preserve the spinal instrumentation, if feasible [16]. Early and aggressive debridement can help control the infection without requiring immediate hardware removal.

Hardware removal

In cases where debridement is ineffective, hardware removal becomes necessary. This step is particularly critical when the infection is resistant to antibiotics or continues to recur despite treatment [6]. Hardware removal is often followed by a long course of antibiotic therapy to clear any residual infection and prevent recurrence.

Antibiotic therapy

Long-term antibiotic therapy plays a pivotal role in managing late infections, particularly after debridement or hardware removal. In most cases, patients are prescribed intravenous antibiotics for several weeks, followed by oral antibiotics for an extended period [5]. P. acnes, a common pathogen in late infections, requires specific antibiotic regimens due to its slow-growing nature and biofilm formation on hardware [23].

Impact of late infections on long-term outcomes

Reoperation rates

Late infections often lead to higher reoperation rates, either to remove infected hardware, perform debridement, or stabilize the spine after hardware removal. Studies found that the incidence of reoperations due to late infections ranged between 20 and 35%, depending on the severity and timing of the infection [3, 10].

Functional outcomes

Late infections can significantly compromise functional outcomes, including spinal stability and mobility. When hardware removal is required, patients may experience a loss of spinal correction, leading to increased pain, reduced mobility, or a return of spinal deformities [8].

Patient satisfaction

The psychological and emotional toll of dealing with late infections can significantly impact patient satisfaction. The need for multiple surgeries, extended antibiotic therapy, and potential deformity recurrence often leaves patients dissatisfied with their treatment outcomes [14].

Discussion

Incidence

The pooled data revealed that the overall incidence of late infections across the included studies ranged from 0% to 7.8%, with a mean pooled infection rate of 4.8%. This variability can be attributed to differences in patient populations, surgical techniques, and post-operative care protocols across the studies.

Patients with idiopathic scoliosis generally had lower infection rates (around 3.5%) compared to those with neuromuscular scoliosis (around 6.2%), a trend that aligns with the more complex medical conditions and surgeries associated with neuromuscular scoliosis. Furthermore, posterior spinal instrumentation showed a higher infection rate (5.0%) than anterior instrumentation (3.2%), likely due to the increased hardware surface area and longer surgery times associated with posterior approaches [3, 6].

Risk factors

A variety of patient-related and surgery-related factors were identified as contributing to the risk of late infections. Patient-related factors such as older age, obesity, and underlying comorbidities, especially in patients with neuromuscular scoliosis, significantly increased the likelihood of infection. Obesity, in particular, was highlighted as a major risk factor due to poor wound healing and the added complexity of surgical procedures in overweight individuals [21].

Surgery-related factors, including the type of instrumentation, longer operative durations, and the use of prophylactic antibiotics, also played a substantial role in infection outcomes. Prolonged surgeries and the use of complex posterior instrumentation were associated with higher infection rates, while extended antibiotic protocols administered until drain removal were shown to reduce infection risk [23].

Clinical outcomes

Late infections often resulted in serious clinical consequences, including increased reoperation rates, compromised functional outcomes, and reduced patient satisfaction. The need for hardware removal in cases where infections could not be controlled by antibiotics or debridement frequently led to mechanical instability, requiring further surgical interventions [6]. Patients who experienced late infections typically faced longer recovery periods, restricted mobility, and in some cases, a return of spinal deformities [14].

Comparison with existing literature

Alignment with previous studies

The incidence rates of late infections found in this meta-analysis (mean 4.8%) are consistent with the ranges reported in previous studies, which have identified infection rates between 2% and 8% for various forms of scoliosis surgery [3, 10]. The trend of higher infection rates in patients with neuromuscular scoliosis compared to idiopathic scoliosis is also well-documented in the literature [8, 22].

Differences from previous reviews

While many previous studies focus primarily on early post-operative infections, this meta-analysis specifically highlights late infections (those occurring 30 days or more postoperatively), which are often more difficult to diagnose and treat. The longer follow-up durations in the studies included in this analysis (up to 10 years in some cases) allowed for a more thorough examination of late-developing infections [15].

Clinical implications

Early detection

One of the most significant takeaways from this study is the importance of early detection of late infections. The insidious nature of these infections – sometimes developing months or even years after surgery – makes early clinical recognition crucial [10]. Clinicians should maintain a high index of suspicion, particularly in patients who present with unexplained pain, swelling, or low-grade fevers long after their surgery. Regular follow-ups and a thorough evaluation of any subtle post-operative changes, including the use of advanced imaging techniques, may help in the timely identification of infections before they cause significant harm.

Prevention

Prevention strategies should focus on addressing both patient-related and surgery-related factors that increase the risk of late infections. For high-risk patients – such as those with neuromuscular scoliosis, obesity, or underlying comorbidities – pre-operative planning should include optimizing the patient's overall health and carefully selecting the surgical approach [21]. Measures like preoperative weight management for obese patients or pre-surgical infection screening for those with compromised immune systems can reduce the likelihood of post-operative complications.

Intraoperative practices such as limiting surgery duration and ensuring sterile conditions are also critical for minimizing infection risk. Furthermore, extended prophylactic antibiotic regimens, such as continuing antibiotics until drain removal, should be considered standard practice in high-risk cases to reduce bacterial colonization on the hardware [23].

Treatment

Once a late infection is diagnosed, the treatment strategy should be tailored to the severity and type of infection. Early and aggressive debridement may be sufficient for controlling superficial infections without the need for hardware removal [16]. However, deep infections often require a more invasive approach, including hardware removal followed by long-term antibiotic therapy.

This analysis reinforces the importance of comprehensive infection management, combining surgical intervention with targeted antibiotic regimens, particularly when dealing with slow-growing bacteria like P. acnes [5]. The findings emphasize that while hardware preservation is ideal, ensuring the complete eradication of infection takes precedence in preventing further complications.

Strengths and Limitations

Strengths

Comprehensive review: One of the key strengths of this meta-analysis is its broad search strategy, which included data from three major databases – PubMed, Embase, and Scopus. This

comprehensive approach ensured that relevant studies from a wide range of clinical and geographical settings were included.

Rigorous selection process: The study selection process was highly rigorous, following the PRISMA guidelines. Using strict inclusion and exclusion criteria, the analysis focused exclusively on studies that provided detailed data on late infections following spinal instrumentation for scoliosis [2, 6].

Limitations

Heterogeneity among studies

Despite the strengths of the review, heterogeneity remains a notable limitation. The included studies varied widely in terms of patient populations, surgical techniques, and follow-up durations, which may influence the pooled incidence rates of late infections [8]. The I2 statistic indicated moderate heterogeneity (I2 = 55%).

Potential biases

Another limitation is the potential for publication bias. Studies with negative or non-significant results may be underrepresented in the literature, which could skew the overall infection rates reported in this meta-analysis. Funnel plot analysis suggested some asymmetry, indicating a possible publication bias [13].

Limited data on certain subgroups

Data limitations exist for certain subgroups, particularly patients undergoing anterior instrumentation or those with less common types of scoliosis [14]. Most studies focused on posterior instrumentation, but fewer data were available on patients treated with anterior approaches.

Conclusion

Incidence

The pooled data from the studies revealed a mean incidence rate of 4.8% for late infections, with infection rates varying significantly depending on patient factors and surgical techniques. The incidence was notably higher in patients with neuromuscular scoliosis (around 6.2%) compared to those with idiopathic scoliosis (3.5%) [8]. Furthermore, posterior instrumentation was associated with a higher infection rate (5.0%) compared to anterior approaches (3.2%) [3].

Risk factors

Several patient-related and surgery-related risk factors were consistently identified across studies. Patient-related factors included age, with older patients and those with comorbid conditions at higher risk for infections. Obesity was a major contributing factor, as patients with higher body mass indexes experienced more wound complications and prolonged healing times [21]. On the surgical side, factors such as longer operative times, type of instrumentation used, and duration of prophylactic antibiotic use were strongly linked to infection outcomes [10].

Clinical management

The management of late infections typically involves a combination of surgical intervention and antibiotic therapy. In less severe cases, debridement may suffice to control the infection, but deep infections often necessitate hardware removal, which can compromise spinal stability and increase the risk of further complications. Following hardware removal, patients usually require prolonged courses of antibiotics, tailored to the specific pathogen identified, to fully eradicate the infection and prevent recurrence [6].

Recommendations for future research

Standardization of surgical protocols: There is a need for more standardized surgical protocols regarding the use of prophylactic antibiotics and post-operative care [23].

Long-term outcomes in anterior instrumentation: Future studies should investigate the long-term outcomes and infection rates associated with anterior approaches [14].

Focus on less studied scoliosis subtypes: Research on congenital or syndromic scoliosis is scarce and warrants further investigation [19].

Quality of life and psychological impact: The psychological and emotional impacts of late infections are underexplored in the current literature [14].

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his consent for his images and other clinical information to be reported in the Journal. The patient understands that his name and initials will not be published, and due efforts will be made to conceal his identity, but anonymity cannot be guaranteed.

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