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Research Article

The effectiveness of arthroscopic irrigation and debridement in the management of septic arthritis following anterior cruciate ligament reconstruction: A Systematic Review and Meta-Analysis

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ABSTRACT

Objective: This meta-analysis aimed to evaluate the effectiveness of arthroscopic irrigation and debridement in the management of septic arthritis following anterior cruciate ligament reconstruction (ACL-R), with a focus on graft retention rates, functional outcomes, and the microbiological profile of infections.

Methods: This meta-analysis adhered to PRISMA guidelines and was registered in PROSPERO (CRD42024562550). PubMed, Cochrane, ProQuest, and ScienceDirect databases were searched for studies published before July 2024 using predefined Medical Subject Headings terms and keywords related to ACL-R infections and arthroscopic irrigation and debridement. Inclusion criteria followed the PICO framework: Population (patients with septic arthritis following ACL-R), intervention (arthroscopic irrigation and debridement), comparator (none), and outcomes (graft retention rate, Lysholm Knee Score, International Knee Documentation Committee [IKD] score, and Tegner Activity Scale [TAS], and microbiology data). The risk of bias was assessed using the Cochrane Risk of Bias in Non-Randomized Studies–of Interventions. Meta-analyses were performed using R Studio, with results presented as pooled proportions or means with 95% confidence intervals (95% CI).

Results: A total of 20 studies involving 333 patients were analyzed, with follow-up periods ranging from 18 days to 67 months. The pooled graft retention rate was 92% (95% CI [88–94%]), confirmed by proportional meta-analysis with low heterogeneity (I^2=0%, P=2.0948). Functional knee outcomes showed pooled mean scores of 82.41 for Lysholm (95% CI [78.15–86.66], I^2=87.3%–92.7%), 79.37 for IKDC (95% CI [74.00–84.75], I^2=68.3%–82.2%), and 5.08 for TAS (95% CI [4.87–5.30], I^2=0%–52.6%), indicating moderate to satisfactory recovery. Coagulase-negative Staphylococcus (42.34%) and Staphylococcus aureus (23.12%) were the most frequently isolated pathogens, with 9.91% of cases involving antibiotic-resistant strains, including MRSA (4.50%) and MR-CNS (5.41%). Cephalosporin or vancomycin was the most commonly administered first-line antibiotic, often combined with other agents.

Conclusion: The findings suggest that arthroscopic irrigation and debridement, combined with appropriate antibiotic therapy, are effective in managing septic arthritis following ACL-R, achieving a high graft retention rate of 92% and moderate to satisfactory functional outcomes. However, the presence of antibiotic-resistant pathogens and challenges in returning to high-level sports highlight the importance of preventive measures to protect athlete performance and recovery.

Level of Evidence: Level IV, Therapeutic Study.

Introduction

Anterior cruciate ligament reconstruction (ACL-R) is a widely performed surgical procedure after an anterior cruciate ligament injury. The number of ACL-R has increased in recent years and is projected to rise further in the future, partly due to the changing nature of careers and lifestyles, particularly with the increase in professional and semi-professional athletes.[1] The aim of this procedure is to restore patients to their pre-injury activity levels, whether these activities are related to their occupation or, more commonly, to prior levels of sporting participation.[2] Despite significant advancements in this reconstruction technique, rare septic arthritis (SA) infections following ACL-R remain a serious challenge. Patients with SA typically exhibit symptoms such as knee pain and restricted movement, persistent joint swelling, local redness, and fever exceeding 38°C. In the majority of cases, symptom onset occurs between 10 and 25 days following the ACL reconstruction procedure.[3] Septic arthritis following ACL-R is reported as incidence rates ranging from 0.14% to 2.6%. This complication can result in delayed recovery and negatively affect both short-term and long-term outcomes. Graft failure, cartilage damage, and long-term joint dysfunction and degenerative changes are associated with untreated SA following ACL-R. Moreover, infections can significantly impact the patient's psychological and economic well-being. This is particularly critical for athletes, as it can adversely affect their professional careers.[4]

With an incidence of less than 1% in most cases, their impact can be severe.[5] Early recognition and aggressive treatment are crucial for successful outcomes. The treatment of SA following ACL-R often involves a combination of irrigation and debridement followed by prolonged antibiotic therapy.[6] Recent advances have highlighted the success of graft-retaining protocols through the combination therapy provided by orthopedic surgeons. Preserving the graft during the infection treatment process is essential to ensure that

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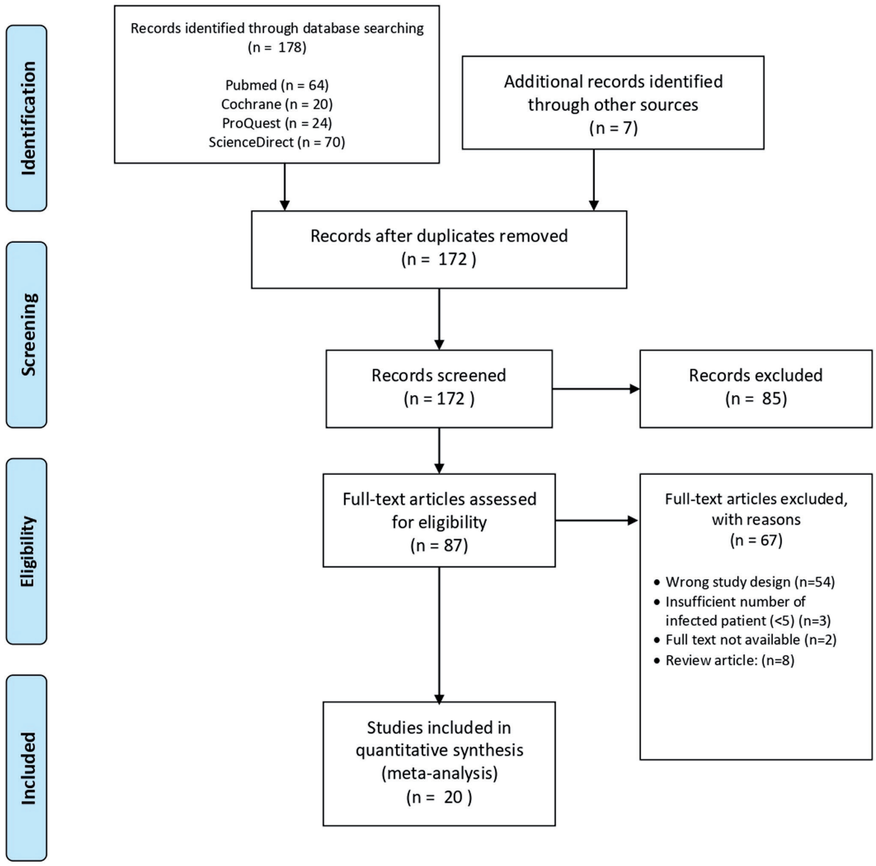

Figure 1. Flowchart of search results, article inclusion, and exclusion.

the initial ACL reconstruction is not compromised. By preserving it, we also ensure that the patient achieves a satisfactory functional outcome despite the occurrence of an infection.[1]

Given that patients affected by SA following ACL reconstruction are typically young and active, understanding the long-term impacts on postoperative activity levels and professional lives is crucial. This meta-analysis aims to provide a comprehensive review of the treatment of SA following ACL-R through irrigation and debridement. This review will primarily focus on the graft retention rate, functional knee outcomes following SA treatment, and the microbiological profiles of patients with infection complications.

Material and methods

Search strategy

This study followed the protocols outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement (PRISMA).[7] The study protocol was registered at the International Prospective Register of Systematic Reviews (CRD42024562550) prior to conducting this study. PubMed, Cochrane, ProQuest, and ScienceDirect were searched for relevant studies before July 2024. The search was conducted utilizing the Medical Subject Headings terms, combined with free words: (“ACL-R” or “ACL Reconstruction” or “Anterior cruciate ligament reconstruction”), (“SA” or “Postoperative infection” or “Joint infection” or “Knee Infection”), and (“Arthroscopic debridement” or “Irrigation and Debridement”). A flowchart summarizes the selection process details, as depicted in Figure 1.

HIGHLIGHTS

- The meta-analysis demonstrates a high graft retention rate of 92% (95% CI [88%-94%]) following arthroscopic irrigation and debridement for septic arthritis (SA) after anterior cruciate ligament reconstruction (ACL-R), confirming the effectiveness of graft-preserving techniques.
- Patients treated for SA after ACL-R achieved pooled mean scores of 82.41 on the Lysholm Knee Score, 79.37 on the IKDC score, and 4.08 on the TAS score, indicating generally moderate to satisfactory knee function post-treatment.
- Coagulase-negative Staphylococcus (42.34%) and Staphylococcus aureus (23.12%) were the most frequently isolated pathogens, with antibiotic-resistant strains found in 9.91% of cases.
- Despite successful graft retention and moderate functional recovery, returning to high-level sports remains challenging for many patients, particularly competitive athletes requiring exceptional knee function.

Inclusion and exclusion criteria

Relevant articles were manually screened using the Population, Intervention, Comparator, and Outcomes framework.

- Population: Patients with SA following ACL reconstruction.
- Intervention: Arthroscopic irrigation and debridement.
- Comparator: No comparator.
- Outcomes: Graft retention rate, functional outcome in Lysholm Knee Score, International Knee Documentation Committee (IKDC) score, and Tegner Activity Scale (TAS), and microbiology data.

Studies were included in the analysis with at least one of the clinical outcomes described above. Studies were excluded if they were:

- Articles published in languages other than English.
- Studies with insufficient data (fewer than 5 patients that reported SA)
- Included prophylactic measures for infection prevention rather than the treatment of established infections.

- Review articles, biomechanical research, cadaver studies, animal trials, case reports, editorials, reviews, guidelines, and conference abstracts.

Data extraction

Data were extracted independently by authors according to the inclusion and exclusion criteria explained above. Any disagreements during this step were resolved by team consensus. The extracted primary data are summarized in Table 1. Studies that report data without providing standard deviation (SD), but include standard error (SE) or range, will have their SD values calculated using the appropriate formulas.

Quality assessment and risk of bias

All studies were independently assessed for the risk of bias by 3 authors (E.M., A.P., and A.F.). This assessment was done according to the Cochrane Handbook for Systemic Intervention (v6.4). Cochrane Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) was used for non-RCT studies.[8] Cochrane Risk of Bias in Non-randomized Studies of Interventions evaluates bias from 7 possible sources of bias including: confounding, selection of participants into the study, classification of interventions, deviations from intended interventions, missing data, measurements of outcomes, and selection of the reported results. Judgement of each domain can be expressed as "low risk of bias," "moderate risk of bias," "serious risk of bias," or "critical risk of bias." Each result from ROBINS-I is inputted into the Robvis-Visualization tool to get the summary of the bias and risk of bias plot. All divergent views were resolved through team consensus.

Statistical analysis

R Studio was used to perform the meta-analysis. All analyses were presented as Forest plots. Proportional meta-analysis was used for evaluating graft retention rate after arthroscopic debridement of ACL-R infection. The logit-transformed proportion summary measure was used for evaluating these outcomes. Pooled estimates were calculated using the Generalized Linear Mixed Model method, and the results are presented as proportions with 95% CI. Functional outcome after arthroscopic irrigation and debridement using Lysholm Knee Score, IKDC score, and TAS were also evaluated using meta-mean analysis. This outcome is assessed by inputting sample size, mean, and SD across multiple studies. The results are presented as pooled means with 95% CI. In addition, sensitivity analysis was performed by excluding 1 study in each iteration to verify the robustness of the study results.

Results

Study selection and baseline study characteristics

Initially, 185 articles were identified as potentially relevant, and 172 remained after the duplicates were removed, 85 of which had been excluded by preliminary screening; the full text was carefully screened to exclude 67 articles, leaving a total of 20 studies that were published between 2004 and 2022 for detailed evaluation. All studies comprised a total of 333 patients with ACL-R SA with the follow-up period ranging from 18 days to 67 months. A complete overview of the studies is shown in Table 1).[9-28]

Risk of bias assessment

The methodological quality of all included RCTs and observational studies was assessed according to the Cochrane Handbook for Systematic Reviews of Interventions. For observational studies, most of the studies were judged to have a moderate risk of bias, with the exception of 8 studies with an overall serious risk of bias due to

Table 1. Overview of included studies[9-28]

No.	Author	Country	Inclusion period	Total ACL-R	Total patient with septic arthritis	% Male	Type of graft	Mean age	Follow-up
1	El-Kady et al, 2022	Egypt single center	2018-2021	836	12	67	Hamstring	43.6	20 days
2	Themessl et al, 2022	Germany single center	2006-2018	ND	38	76	Hamstring	36.2	60 months
3	Barbara et al, 2020	Croatia single center	2007-2017	1831	26	92	Hamstring	31.5	18 days
4	Georgeanu et al, 2019	Romania single center	2014-2017	262	6	83	Hamstring and BPTB	29.8	12 Months
5	Ascione et al, 2019	Italy single center	ND	ND	39	77	Hamstring and BPTB	25.0	36 months
6	Gupta et al, 2018	India single center	2010-2015	1468	17	92	Hamstring and BPTB	27.1	33.6 months
7	Bohu et al, 2018	French single center	2012-2016	1809	7	86	Hamstring and BPTB	36.4	33.6 months
8	Kim et al, 2017	Korea single center	2008-2009	ND	5	80	Hamstring	30.0	17.6 months
9	Schuster et al, 2015	Germany single center	2004-2014	7096	36	75	Hamstring	32.0	56.4 months
10	Boström Windhamre et al, 2014	Sweden single center	2001-2009	4384	27	48	Hamstring	27.0	60 months
11	Calvo et al, 2014	Chile single center	2000-2011	1564	7	100	Hamstring	28.3	63 months
12	Abdel-Aziz et al, 2014	Egypt single center	2004-2011	2560	24	100	Hamstring	26.0	59 months
13	Torres-Claramunt et al, 2012	Spain 2 center	2006-2009	810	15	76	Hamstring, BPTB	34.0	36 months
14	Demirağ et al, 2011	Türkiye single center	ND	ND	7	86	Hamstring, BPTB	29.0	46 months
15	Barker et al, 2009	United States single center	2002-2006	3126	18	78	Hamstring, BPTB, Achilles tendon allografts	34.1	ND
16	Wang et al, 2009	China single center	1997-2007	4068	15	87	Hamstring, BPTB, allograft	28.6	ND
17	Parada et al, 2009	USA single center	2002-2008	653	5	60	Hamstring	26.0	12 months
18	Van Tongel et al, 2007	Belgium single center	1996-2005	1736	11	91	Hamstring	33.0	67 months
19	Judd et al, 2006	USA single center	1999-2001	418	11	73	Hamstring	28.0	22 months
20	Fong et al, 2004	Singapore single center	1999-2002	472	7	100	Hamstring	23.0	11.7 months

ACL-R, anterior cruciate ligament reconstruction; BPTB, bone patellar tendon bone autograft; ND, not described.

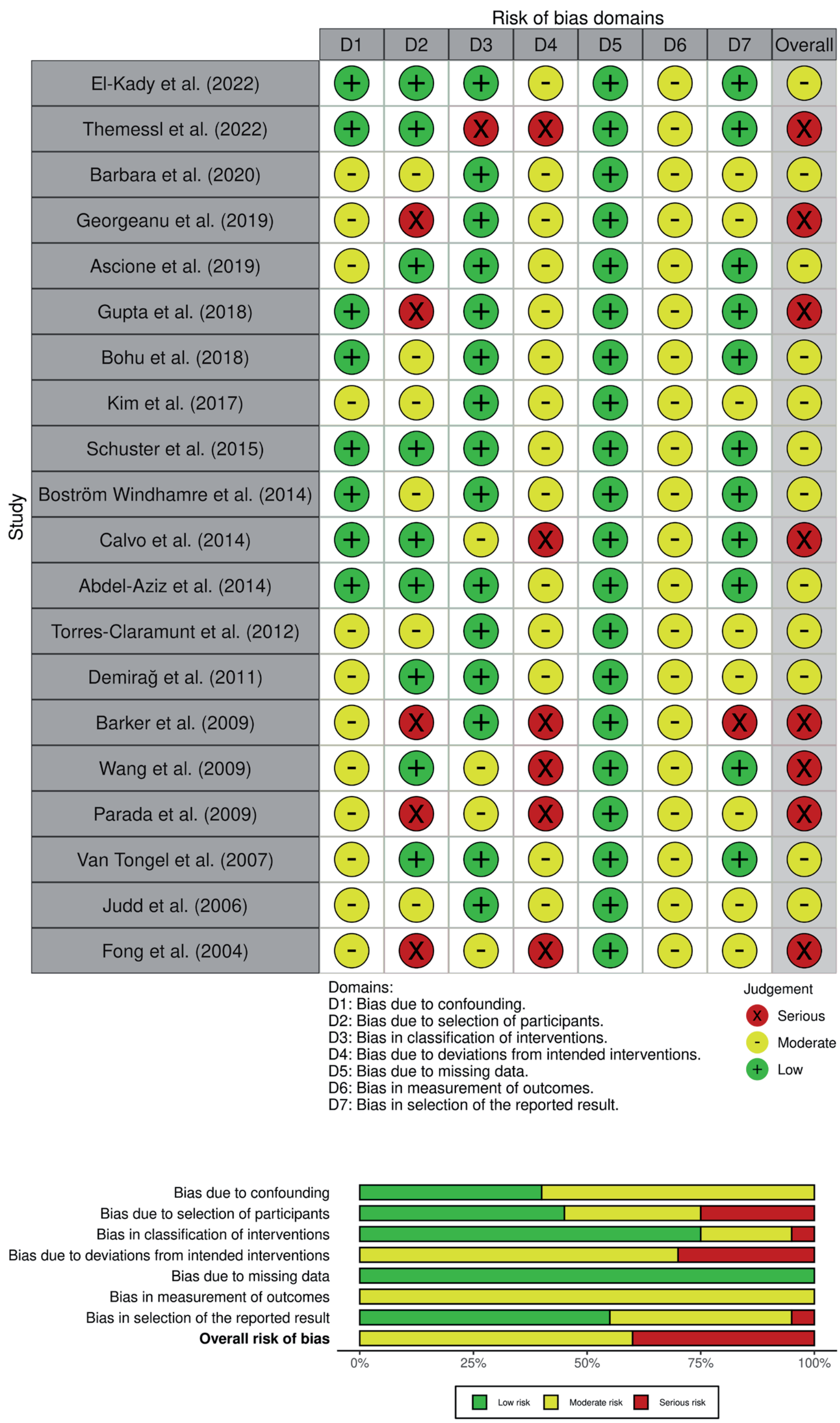

Figure 2. Risk of bias assessment of observational studies using ROBIN-1 criteria.

possible bias mainly on the selection of participants and deviations from intended intervention. The detailed risk of bias assessment for all studies is presented in Figure 2.

Graft retention rate

Graft retention rate was reported in 333 infection cases of 20 studies treated with arthroscopic irrigation and debridement. Proportional meta-analysis showed a graft salvage rate of 92%, with a 95% CI ranging from 88% to 94%. A common (fixed)-effects model was used due to a low level of heterogeneity (I^2 = 0%, and P = 2.0948).

The sensitivity analysis was conducted using the leave-one-out method, which systematically excludes each study one at a time to assess the impact of individual studies on the overall results. The analysis revealed that the overall pooled mean graft salvage rate remained robust and consistent across all exclusions, with the

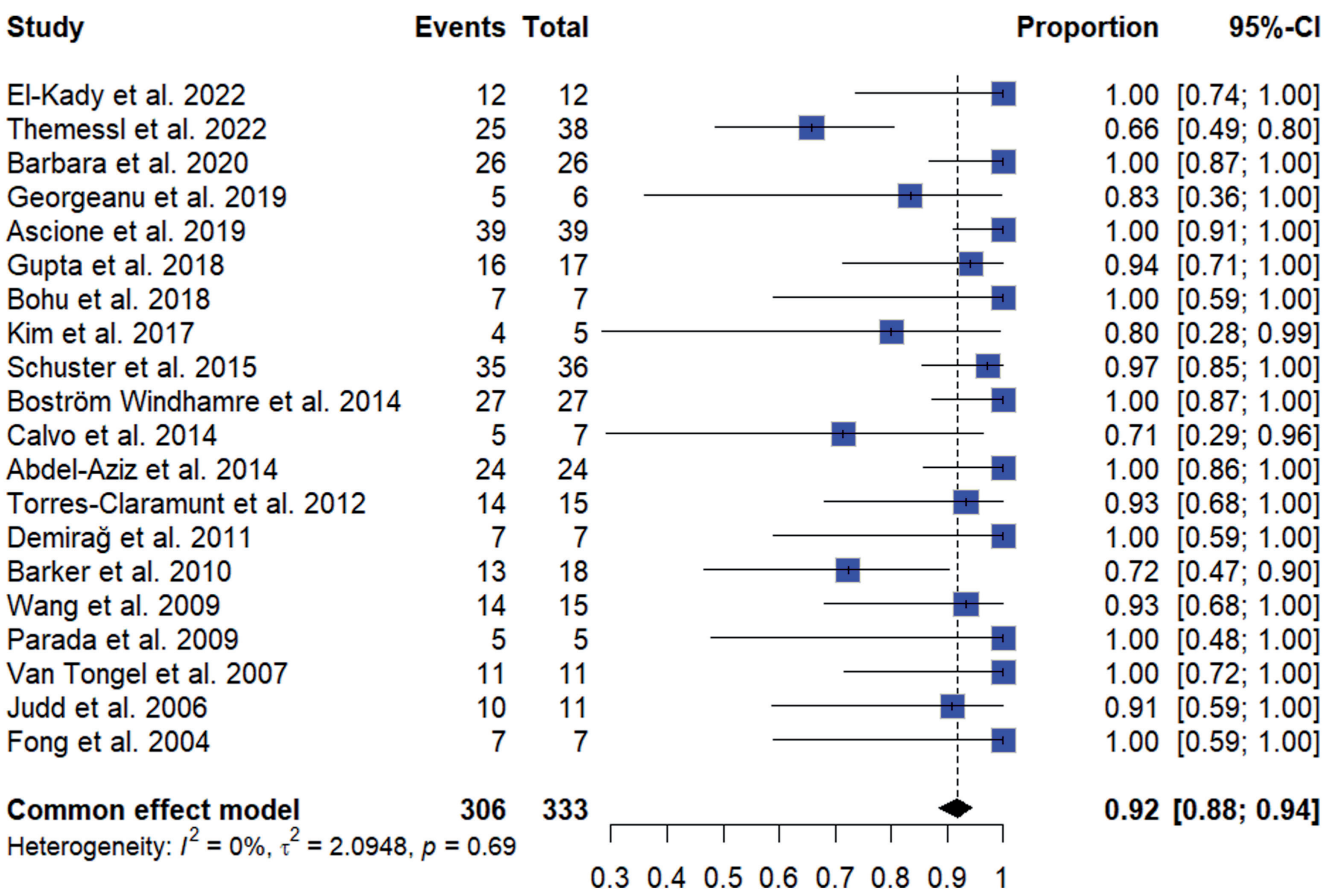

Figure 3. Forest plot of graft retention rate.

heterogeneity consistently remaining at 0%. This indicates that no single study unduly influenced the overall findings, thereby confirming the reliability and stability of the meta-analysis results.

Knee functional score

Lysholm score

Lysholm score was reported in 214 infection cases across 13 studies treated with arthroscopic irrigation and debridement. The pooled mean Lysholm score (MRAW) was 82.41, with a 95% CI ranging from 78.15 to 86.66. A random-effects model was used due to a high level of heterogeneity (I^2 = 92%, and P=<.01). Sensitivity analysis shows that the overall pooled mean Lysholm score remained consistent when individual studies were excluded, with mean scores ranging from 81.22 to 83.36. The heterogeneity (I^2) remained high, varying from 87.3% to 92.7% when different studies were excluded.

High heterogeneity of this study could be due to differences in patient populations, surgical techniques, postoperative care, and other factors. Despite this heterogeneity, the overall results indicate that patients generally achieve favorable knee function. Sensitivity analysis also showed the overall results are robust, with minimal variation and not overly influenced by any single study.

International knee documentation committee score

International knee documentation committee scores were reported in 108 infection cases across 6 studies. The pooled mean IKDC score (MRAW) was 79.37, with a 95% CI ranging from 74.00 to 84.75. A random-effects model was used due to a high level of heterogeneity (I^2 = 78%, and P=<.01). High heterogeneity of this study could be due to differences that have been explained similar to Lysholm Score.

Sensitivity analysis shows that the overall pooled mean IKDC score remained consistent with mean scores ranging from 77.71 to 81.51. However, the heterogeneity slightly varied when each study was omitted, ranging from 68.3% to 82.2%. Notably, excluding Bohu et al[15] and Kim et al[16] led to a reduction in heterogeneity to 68.3% and 69.6%, respectively. Despite these variations, the overall findings remain robust and are not significantly influenced by any single study.

Tegner activity scale

Tegner activity scale was reported in 143 infection cases of 9 studies. The pooled mean TAS (MRAW) was 5.08, with a 95% CI ranging from 4.87 to 5.30. A fixed-effects model was used due to a moderate level of heterogeneity (I^2 = 46%, and P=.1218).

Sensitivity analysis shows that the overall pooled mean TAS score remained consistent with mean scores ranging from 4.98 to 5.33. However, the heterogeneity varied highly when each study was omitted, ranging from 0% to 52.6%. Notably, excluding Kim et al[16] and Ascione et al[13] led to a reduction in heterogeneity to 0% and 52.6%, respectively. Despite these variations, the overall findings also remain robust.

Microbiology isolate

The microbiological analysis of SA following ACL reconstruction revealed a diverse spectrum of microorganisms. The most frequently

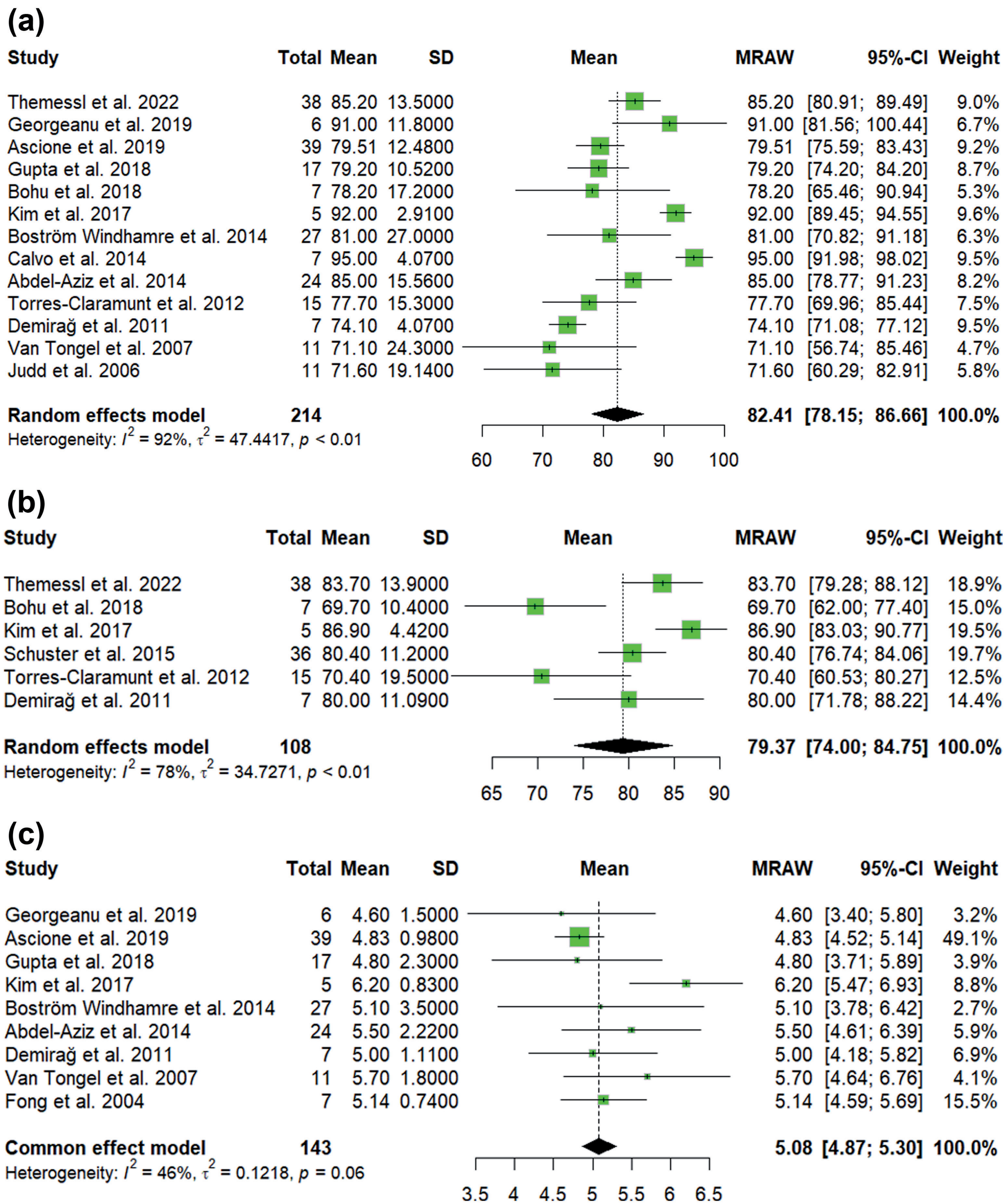

Figure 4. Forest plot of knee functional score. (A) Lysholm score; (B) IKDC score; and; (C) Tegner activity scale.

isolated pathogen was coagulase-negative *Staphylococcus* (CNS), accounting for 42.34% of the cases, followed by *Staphylococcus aureus* as the second most common pathogen, found in 23.12% of cases. Other bacteria (including *Enterococcus faecalis*, *Propionibacterium acnes*, *Streptococcus*, *Pseudomonas aeruginosa*, *Enterobacter*, *Peptostreptococcus*, *Escherichia coli*, *Klebsiella* sp., and *Corynebacterium*) contributed to 13.51% of the cases. Mixed infections were also observed in 2.70% of cases, highlighting the diverse microbiological landscape of SA. Interestingly, in 18.32% of cases, no microorganisms were detected. The presence of antibiotic-resistant organisms is also significant in this study, with a total of 33 isolates identified as resistant strains, representing 9.91% of the cases. This

Table 2. Microorganisms cultured in septic arthritis after ACL reconstruction

Microorganisms	Number of isolate	Percentage
Coagulase negative *Staphylococcus*	141	42.34
• MR-CNS	18	5.41
Staphylococcus aureus	77	23.12
• MRSA	15	4.50
Enterococcus faecalis	11	3.30
Propionibacterium acnes	10	3.00
Streptococcus	7	2.10
Pseudomonas aeruginosa	4	1.20
Enterobacter	4	1.20
Peptostreptococcus	3	0.90
E. coli	2	0.60
klebsiella sp.	2	0.60
Corynebacterium	2	0.60
Mixed	9	2.70
Negative	61	18.32

includes methicillin-resistant *S. aureus* (MRSA) and methicillin-resistant coagulase-negative *Staphylococcus* (MR-CNS), accounting for 4.50% and 5.41% of the cases, respectively. Detailed information on the microorganisms causing SA following ACL-R can be found in Table 2.

Antibiotic and irrigation and debridement treatment

Treatment of SA after ACL-R consists of a combination of surgical and antimicrobial therapy. Table 3 describes the summary of antibiotic treatment as a prophylactic approach of ACL-R and the empiric antibiotic of SA after ACL-R. Prophylactic antibiotics to prevent infection after ACL reconstruction frequently include intravenous cephalosporins. For patients with a cephalosporin allergy, clindamycin or vancomycin is provided as an alternative. Curative empiric antibiotic treatments exhibited a greater variety of antibiotic usage. For most studies, cephalosporin or vancomycin is frequently used as the first-line treatment. They are often combined with each other or with other antibiotics such as penicillin, gentamicin, or clindamycin. However, some studies employed combinations of different antibiotic classes. For instance, Barbara et al[11] utilized a regimen of ciprofloxacin combined with gentamicin, clindamycin, or rifampin. Gupta et al[14] used a combination of amoxicillin/clavulanic acid and gentamicin. Another approach, seen in Boström Windhamre et al[18] and Van Tongel et al[26] , involved the use of other penicillin drugs, such as cloxacillin and flucloxacillin, respectively.

The number of debridements reported varied across studies. Most studies reported an average of 1-2 debridements. Boström Windhamre et al[18] reported the highest average debridements with 3.7 (ranging from 1 to 11 debridements), while Ascione et al[13] reported the lowest average number of debridements at 0.53 (ranging from 0 to 1 debridement). For irrigation, most studies reported using volumes in the range of 8-18 L of saline solution. There is some variability in the reported number of debridements and irrigation volumes, likely reflecting different clinical protocols and practices.

Discussion

Septic arthritis following ACL-R is a rare but serious complication. The literature reports varying incidence rates of SA following ACL-R, ranging from 0.4% to 2.6%.[9-28] A study was conducted to evaluate the adverse outcomes of ACL-R performed in a large national hospital system in England over 20 years, involving 104 255 procedures. This study found that approximately 4 knee infections occur per 850 ACL-Rs (around 0.47%). Specifically, ACL-R in arthroscopic knee procedures showed a higher reoperation rate for infections at 0.47% (95% CI, 0.43-0.52) compared to other arthroscopic procedures like partial meniscectomy (0.14%, 95% CI, 0.13-0.14).[36] Similarly, another large national sample reported a comparable postoperative infection rate of 0.8%, with 1779 cases among 217 541 patients who underwent ACL-R. This study also identified significant independent risk factors for infection following ACL-R, including male sex, obesity, tobacco use, and older age.[37] Although the overall occurrence is low, the implications of SA are significant as an orthopedic emergency, necessitating urgent medical intervention to prevent long-term consequences. The presence of the ACL graft post-treatment is crucial for the patient's recovery, particularly for those aiming to return to sports at both for professionals or non-professional levels. Graft retention not only preserves knee stability but also facilitates quicker rehabilitation and a return to pre-injury activity levels.[10] Our meta-analysis demonstrated a high graft salvage rate of 92% following arthroscopic irrigation and debridement. This high rate of retention can be attributed to aggressive treatment protocols which include arthroscopic irrigation and debridement combined with the prompt administration of antibiotics, which will be discussed later. Graft removal is generally considered only in specific scenarios, such as when the graft is non-functional, covered in thick purulent exudate, or when the infection persists despite repeated debridement.[12,13]

Functional recovery is a critical outcome for patients that undergo ACL-R, especially for athletes or those whose lifestyles or careers depend on maintaining high levels of physical activity.[29] Septic arthritis following ACL-R poses a significant challenge in terms of knee function and the ability to return to pre-injury activity levels. In this meta-analysis, we collectively pooled several knee functional scores, including the Lysholm Knee Scoring Scale, the IKDC score, and the TAS.

Despite the high heterogeneity observed in some scores, the overall results indicate that patients who underwent arthroscopic irrigation and debridement for SA following ACL-R achieved satisfactory knee function, enabling them to resume moderate physical activities. The presence of an intact graft, as described above, was a significant factor that contributed to the overall good knee function. However, despite these encouraging results, the return to high-level sports remains a challenge for many patients. Competitive athletes often require exceptional knee function and stability to perform at peak levels, which may not be fully attainable with moderate activity levels.[30] According to Themessl et al,[10] the highest return to sport rates were observed in typical endurance and low-demand activities with minimal risk of re-injury, such as swimming, running, and cycling. In contrast, for high-demand activities like pivoting sports, the return to full activity was more limited. Among patients who participated in pivoting sports prior to their injury, 23 (62.2%) were able to return to at least 1 pivoting sport postoperatively, but only 10 patients (26.3%) returned to all their previous sports at their prior frequency.[10] A dilemma arises when considering the needs of competitive athletes who require higher functional knee scores to return to their pre-infection levels of activity.[3] In line with previous literature, the TAS scores in this meta-analysis are satisfactory for non-competitive individuals but may fall short for those aspiring to compete at higher levels.

Our meta-analysis shows the overall graft function remained good in most of the patients. However, patients with infected ACL-Rs generally exhibited inferior clinical outcomes compared to those without complications,[14,15,18,20,21] The lower functional scores observed in most

Table 3. Summary of prophylactic and empiric antibiotic of septic arthritis after ACL-R[9-28]

No	Author	Prophylactic antibiotic	Empiric antibiotic of septic arthritis	Irrigation and debridement
1	El-Kady et al, 2022	Single dose 2 g IV first generation cephalosporin (Cefazolin) pre-op; Post-op: 2 g IV Cefazolin every 8 hours (5 doses); Oral: 500 mg PO Cefuroxime BID for 7 days	IV first gen cephalosporin (Cefazolin)	• Number of debridement: 1.3 (1-2); • 8 L of saline irrigation
2	Themessl et al, 2022	ND	IV antibiotics for 10-14 days; Oral antibiotics for at least 4 weeks	• Number of debridement: ND
3	Barbara et al, 2020	Single dose Cephalosporins or Clindamycin (in case of allergy)	Fluoroquinolone (Ciprofloxacin) 2 × 400 mg IV + Aminoglycoside (Gentamicin) 3 × 80 mg IV or Lincosamide (Clindamycin) 3 × 600 mg IV or Rifamycin (Rifampin) 2 × 600 mg IV until CRP is in normal range	• Number of debridement: 1.23 (1-3); • 8-15 L of saline irrigation
4	Georgeanu et al, 2019	Single dose 2 g IV third generation cephalosporin (Ceftriaxone) 60 minutes pre-op	Third generation cephalosporin (Ceftriaxone) IV + Glycopeptide (Vancomycin) IV 3-4 weeks, continued to oral for total duration of 6 weeks	• Number of debridement: 1.16 (1-2); • 8-10 L of saline irrigation
5	Ascione et al, 2019	ND	Third generation cephalosporin + Glycopeptide IV 2 weeks, continued to oral for at least 6 weeks	• Number of debridement: 0.53 (0-1);
6	Gupta et al, 2018	ND	Penicillin (Amoxicillin + Clavulanic acid) 1.2 g IV + Aminoglycoside (Gentamicin) 80 mg IV BID	• Number of debridement: 1.05 (1-2); • 18 L of saline irrigation
7	Bohu et al, 2018	Single dose 2 g IV Cephalosporin (Cephalothin) pre-op; or 1 g IV Glycopeptide (Vancomycin) pre-op (in case of allergy)	Glycopeptide (Vancomycin) IV (15 mg/kg for 1 hour 30 minutes and then 500-1000 mg for 60 to 90 minutes every 6 hours to 15-25 mg/L of residual vancomycin dosed every 48 hours) + Penicillin (Tazocillin) IV (3-4 g every 6 hours for 60 to 90 minutes). Antibiotics were administered for 6 weeks, 10 days intravenously and then orally.	• Number of debridement: 1.4 (1-2)
8	Kim et al, 2017	First generation cephalosporin IV from shortly before surgery to post-op day 2	First generation cephalosporin IV. Duration of administration of intravenous antibiotics was 29.4 days (range, 19 to 45 days)	• Number of debridement: 1.2 (1-2);
9	Schuster et al, 2015	Single dose: Cephalosporins (Group I or II) or Lincosamide (Clindamycin) (in case of allergy) 30 minutes pre-op	Cephalosporin (Group I or II) + Aminoglycoside or Lincosamide (Clindamycin) or Rifamycin (Rifampicin) IV. The length of antibiotic therapy is based on the individual course of each patient, and when CRP levels are within normal range	• Number of debridement: 2.25 (1-6); • 10-15 L of saline irrigation
10	Boström Windhamre et al, 2014	Single dose: 2 g IV Penicillinase-resistant penicillin (Cloxacillin) pre-op; or 600 mg IV Lincosamide (Clindamycin) pre-op (penicillin allergy)	Penicillinase-resistant penicillin (Cloxacillin) IV 2 g 3 times daily, or Lincosamide (Clindamycin) 600 mg 3 times daily (penicillin allergy), continued to oral for a mean of 7.6 weeks	• Number of debridement: 3.7 (1-11); • 9 L of saline irrigation
11	Calvo et al, 2014	Single dose: 2 g IV first generation cephalosporin (Cefazolin); or 600 mg IV Lincosamide (Clindamycin) (penicillin allergy)	IV antibiotics continued for 4 weeks; Oral antibiotics for 2 weeks	• Number of debridement: 1.57 (1-3)
12	Abdel-Aziz et al, 2014	ND	IV Cephalosporin or Vancomycin; continued to oral for a median of 28 (range 21-42) days;	• Number of debridement: 3 (1-6); • 9-15 L of saline irrigation
13	Torres-Claramunt et al, 2012	Single dose: 2 g IV first generation cephalosporin (Cefazolin) or 500 mg IV Glycopeptide (Vancomycin) (penicillin allergy) pre-op	IV third generation cephalosporin (Ceftazidime) 2 g/8 h + Glycopeptide (Vancomycin) 1 g/12h; Oral antibiotics post 2-3 weeks	• Number of debridement: 1.3 (1-3); • 10-15 L of saline irrigation
14	Demirağ et al, 2011	ND	IV Cefazolin sodium + Gentamicin sulfate for 3-4 weeks; Continued to Oral Amoxicillin and Clavulanate for total of 6 weeks	• Number of debridement: 1.14 (1-2)
15	Barker et al, 2010	Single dose: 2 g IV first generation cephalosporin (Cefazolin); or 500 mg IV Glycopeptide (Vancomycin) (penicillin allergy) pre-op	IV Cefazolin or Vancomycin; Oral antibiotics post 2-3 weeks	• Number of debridement: 1.5 (1-3)
16	Wang et al, 2009	Perioperative: Second generation cephalosporin or Quinolones; Post-op: 3-5 days	IV second generation cephalosporin or Vancomycin; Continued to Oral antibiotics for mean period 19.4 days (13-38 days)	• ND
17	Parada et al, 2009	Single dose IV first generation cephalosporin (pre-op)	IV antibiotics for gram-positive; Continued to Oral antibiotics for 4.8 weeks	• Number of debridement: 2.4 (1-4)
18	Van Tongel et al, 2007	Perioperative: First generation cephalosporin; No post-op antibiotics	IV Flucloxacillin (6 × 1 g/day) + Gentamicin (320 mg/day); Oral antibiotics for an average of 24.6 days	• Number of debridement: 1.8 (1-4)
19	Judd et al. 2006	Pre-op and 24 hours post-op antibiotics	IV Cefazolin or Vancomycin, continued to Oral antibiotics for 4-6 weeks	• Number of debridement: 2.4 (1-4); 9 L of saline irrigation
20	Fong et al, 2004	ND	IV broad spectrum antibiotic; continued to Oral antibiotics post 4-6 weeks	• Number of debridement: 1.4 (1-3)

of the studies could be attributed to complications such as arthrofibrosis or cartilage damage caused by the infection.[13] This damage can delay or even prevent the return to pre-injury activity levels. Another factor to consider is psychological factors that also play a critical role in the recovery process. Lack of motivation, fear of re-injury, and a shift in interests can significantly impact a patient's ability to return to activity postoperatively.[10]

Septic arthritis following ACL-R involves a complex microbiological profile that shows significant variation across different regions. The most frequently isolated pathogen overall was coagulase-negative *Staphylococcus* (CNS) (42.34%), with *S. aureus* being the second most common pathogen (23.12%). There are about 38 recognized species of coagulase-negative staphylococci (CoNS), 13 of which are known to colonize humans, including *Staphylococcus* *epidermidis*, *Staphylococcus haemolyticus*, *Staphylococcus hominis*, *Staphylococcus lugdunensis*, and others. Among these, *S. epidermidis* is the most commonly isolated species in clinical settings and is often noted for its virulence and pathogenicity.[32]

In our subgroup analysis based on geographic regions, we found that both Europe and the Americas reflected the overall microbiological findings, with CNS being the most common pathogen, occurring in 44.81% and 34.15% of cases, respectively. However, *S. aureus*, the second most common pathogen overall, exhibited a different pattern, being most prevalent in Asia, where it accounted for 30.00% of the cases. The clinical significance of these differences in pathogen prevalence is considerable. *Staphylococcus aureus* is known for its aggressive virulence factors, including toxins and enzymes that can lead to more severe infections and rapid joint destruction.[32] In contrast, CNS, which is more prevalent in Europe and the Americas, typically causes more indolent or chronic infections. Coagulase-negative *Staphylococcus* is often associated with biofilm formation, which can result in persistent, low-grade infections that are more difficult to eradicate.[33] This can also influence clinical decision-making, such as considering the removal of infected grafts when biofilm formation is suspected.

In assessing the sources of infection, our analysis suggests that accidental autograft contamination during handling, the use of contaminated inflow cannulas, or drainage systems could be significant contributors. Additionally, contaminated surgical incisions or arthroscopic portals during ACL-R might predispose patients to infection. The preparation of hamstring tendon autografts, which may take longer than bone-patellar tendon-bone (BPTB) autografts, could increase the risk of contamination, though it remains unclear whether contamination primarily occurs during graft harvest or preparation.[9,14]

A notable finding in our meta-analysis is that, in many cases, the causative pathogen was not identified (around 18.32%). This may be due to incorrect sampling, inadequate conservation of specimens, or low microbial concentrations in the samples. Recent evidence suggests that molecular techniques like polymerase chain reaction have better sensitivity for detecting bacterial DNA than standard microbiological analysis, indicating a need for improved diagnostic methods in future clinical practice.[11] Additionally, our findings highlight the presence of antibiotic-resistant strains in 9.91% of cases, which is a significant concern. The distribution of resistant strains remained relatively consistent across regions, with Asia at 6.25%, the Americas at 9.76%, and Europe at 11.33%. These resistant strains included both MRSA and MR-CNS. Methicillin resistance, depicted by the presence of the mecA gene in *S. aureus* and CoNS, varies between different studies. This gene encodes a penicillin-binding protein with decreased affinity for β-lactam antibiotics, leading to significant treatment challenge.[34]

The main public health problem associated with these resistant strains is their contribution to higher mortality rates, longer hospital stays, and exorbitant treatment costs. The increased healthcare costs are compounded by the limited treatment options available due to multiple drug resistance. Moreover, studies have shown that infections caused by MRSA are associated with increased mortality and morbidity compared to methicillin-sensitive *Staphylococcus aureus*. This can significantly impact the quality of life, which requires optimal health and function. For athletes, in particular, addressing these infections promptly is crucial to maintaining their ability to compete and perform at high levels.[35]

The treatment of infections following ACL-R typically involves a combination of surgical debridement and antimicrobial therapy, tailored to the specific pathogen identified.[11] Prophylactic antibiotics, commonly intravenous cephalosporins, are standard to prevent infection after ACL-R, with clindamycin or vancomycin used as alternatives for patients with cephalosporin allergies. Once an infection is suspected, immediate arthroscopic debridement and empirical antibiotics are the treatment of choice and should be performed even before microbiological results are available, as prompt intervention is crucial for preventing joint damage and preserving graft function.

For most studies, cephalosporin or vancomycin is frequently used as the first-line empirical treatment, often in combination with other antibiotics such as penicillin, gentamicin, or clindamycin. Antibiotic treatment is maintained for a minimum of 4-6 weeks, beginning with intravenous administration.[15] As soon as the pathogen is identified and sensitivity analysis is completed, the antibiotic regimen is transitioned to more specific culture-sensitive oral antibiotics until clinical and laboratory parameters normalize. This approach is consistent across most studies, with the transition to oral antibiotics being contingent on an adequate clinical response and a decrease in C-reactive protein (CRP) levels.

A previous meta-analysis conducted by Kuršumović et al[35] also explored the treatment outcomes of SA following ACL-R, providing valuable insights into graft salvage rates and microbiological profiles. However, there are notable differences between the previous study and our current meta-analysis. While their analysis included 16 studies, our meta-analysis expanded the scope by including 20 studies, thereby increasing the robustness of our findings. Importantly, our study set a threshold of more than 5 infection cases per study, excluding studies with fewer cases to enhance the sensitivity and generalizability of the results. Moreover, our study evaluated both BPTB and hamstring grafts, whereas the previous study focused solely on hamstring grafts. Over the years, the management of ACL-R infections has significantly improved, leading to an increase in graft retention rates from 85% in the previous study to 92% in our analysis. This improvement reflects advancements in surgical techniques, infection control practices, and a deeper understanding of the factors contributing to successful graft retention.

In terms of microbiological findings, both meta-analyses identified CNS and *S. aureus* as the primary pathogens involved in SA post-ACL-R.[35] Additionally, our meta-analysis offers a significant advantage in that it includes a comprehensive assessment of knee functional outcomes, an aspect less thoroughly covered in the previous meta-analysis. By evaluating functional scores, our study provides a more comprehensive view of patient recovery, linking graft retention success with overall knee function and the potential for athletes to return to their pre-injury levels of activity.

While the effectiveness of arthroscopic irrigation, debridement, and tailored antibiotic therapy in managing SA after ACL-R has been observed, it is important not to oversimplify these findings as universally applicable solutions. The diversity of infections, variability in resistance patterns, and the individual patient's clinical picture all suggest that a more tailored approach is essential. Moreover, prevention remains the most crucial strategy in minimizing the risk of infection and ensuring better outcomes for patients.

Limitations

This meta-analysis has several limitations that should be acknowledged. First, SA following ACL-R is a relatively rare complication, which means the sample sizes in individual studies were often small. This rarity may limit the generalizability of the findings. Second, the majority of the included studies are observational in nature, which inherently limits the ability to establish causality and may introduce confounding factors that could affect the outcomes. Third, many of the studies included in this analysis were found to have a moderate to serious risk of bias. This variability in study quality may influence the reliability of the pooled results. However, despite these limitations, this study offers a thorough overview of the management strategies for SA following ACL-R infections, providing valuable insights into effective treatment protocols and highlighting key areas for future research.

This meta-analysis demonstrates the effectiveness of arthroscopic irrigation, debridement, and antibiotic therapy in managing SA after ACL-R, achieving a high graft retention rate of 92%. Even though the incidence of ACL-R SA is quite rare, preventive measures must be taken seriously to support the professional level of the athlete. While functional outcomes are generally satisfactory, competitive athletes may face challenges in returning to peak performance. Comprehensive measures not only enhances recovery outcomes but also help maintain the high functional standards required for competitive athletes.

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