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MAJOR ARTICLE

Two-Year Outcomes of Postoperative Spine Infection: Implant Retention and Predictors of Treatment Failure

P. J. Davis,[1,2] I. Hassan,[1] T. P. W. Jones,[1,2] R. Kaiser,[3,4,5] E. Stirling,[3] M. Scarborough,[1,2] and M. I. Andersson[1,6]

[1]Department of Microbiology, Oxford University Hospitals NHS Trust, Oxford, UK, [2]Nuffield Department of Medicine, University of Oxford, Oxford, UK, [3]Department of Spinal Surgery, Oxford University Hospitals NHS Trust, Oxford, UK, [4]Nuffield Department of Clinical Neurosciences, University of Oxford, Oxford, UK, [5]Department of Anatomy, Second Faculty of Medicine, Charles University, Prague, Czech Republic, and [6]Nuffield Division of Clinical Laboratory Science, Radcliffe Department of Medicine, University of Oxford, Oxford, UK

Background. Postoperative spine infection (PSI) after surgery occurs in approximately 1%–2% of cases and is associated with significant morbidity. High-quality evidence to guide optimal prevention and management of PSI is limited.

Methods. We retrospectively identified all adult patients over a 3-year period (2020–2023) who required reoperation for deep PSI. Clinical, microbiological therapy, and 24-month outcome data were collected. Treatment failure was defined as unplanned return to the operating room secondary to persistent infection or infection-related implant failure requiring removal. Descriptive statistics and univariate logistic regression were used to identify factors associated with failure.

Results. Sixty-three deep PSI cases were identified (range 18–91 years, median 59 years, 56% female). Onset of infection ranged from 4 days to 30 weeks postoperatively (median 20 days). *Staphylococcus aureus* and Enterobacterales were the most common pathogens, followed by coagulase-negative staphylococci and *Cutibacterium acnes*. Treatment failure occurred in 13 cases (21%). In cases where implants were present (81% of total cohort), planned antibiotic durations of either 12 weeks or 24 weeks demonstrated similar success rates ($P = .76$). Infections involving *Cutibacterium acnes* were more likely associated with implant removal ($P = .04$). No other significant risk factors for failure were identified.

Conclusions. Most PSIs were effectively managed in this cohort with surgical debridement and targeted antibiotics, allowing implant retention in most patients with instrumentation.

Keywords. antibiotics; implant-associated infection; spinal surgery; surgical site infection.

Postoperative spine infections (PSIs) are serious complications of spinal surgery, associated with significant morbidity and substantial healthcare costs [1, 2]. Although overall postoperative infection rates range from 2% to 10% of cases, deep PSIs have been reported in 1.7% of cases in a recent meta-analysis [3]. In instrumented procedures, these infections a particularly complex, often necessitating prolonged hospitalization, multiple reoperations, and extended antibiotic therapy. Despite substantial efforts to implement preventive measures, PSIs remain a leading cause of unplanned readmissions after spinal surgery [4].

Several patient-related risk factors for PSI have been described including advanced age, male sex, obesity, smoking, diabetes, and corticosteroid use [5]. However, it remains unclear how these variables influence the likelihood of successful PSI management. Microbiologically, *Staphylococcus aureus* is the dominant pathogen with gram-negative bacilli accounting for 13–25% of cases [3, 6]. *Cutibacterium acnes* has been highlighted as a problematic organism in spinal infections [7, 8].

Effective management of PSIs typically requires both surgical intervention and antimicrobial therapy. However, universal treatment guidelines are lacking, and clinical practice varies significantly between centers [9]. Although implant removal may facilitate source control, it often mandates prolonged recumbency. This is also associated with mechanical instability with the potential consequences of intractable pain, deformity, or neurological compromise and is therefore frequently avoided. Consequently, implant retention after aggressive debridement is considered an acceptable treatment strategy when implants are stable in early infection [10]. However, the optimal duration of antibiotics after surgical debridement with retained implants remains uncertain, with reported durations ranging from 6 weeks to lifelong suppressive therapy [11, 12].

Current strategies are often extrapolated from prosthetic joint infection (PJI) data [13, 14]. However, research into bone and joint infection involving metalwork typically focusses on hip, knee and shoulder arthroplasty rather than the spine. Although both clinical problems are implant-associated and involve biofilm, peri-spinal implant infection differs from

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Correspondence: Peter Davis, MBBS, Nuffield Department of Medicine, Old Road Campus Research Build, Roosevelt Dr, Headington, Oxford, Oxfordshire OX3 7DQ, UK (peter.davis@paediatrics.ox.ac.uk).

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hip/knee PJI in anatomy [15], timing of presentation, microbiology (including higher prominence and interpretive challenges of *C acnes*), diagnostic pathways, and surgical feasibility of implant exchange or removal. These differences can make direct extrapolation of treatment strategies from arthroplasty to the spine problematic.

Definitions of success and failure may also vary because treatment strategies are often based on small series or adopted from appendicular prosthetic joint infection. Consequently, key questions remain unanswered—including optimal route and duration of antibiotics, whether infected spinal hardware can be safely retained and how is "treatment success" defined. We set out to define the epidemiology of cases with deep PSI, describe the microbiology and clinical management to highlight those factors associated with implant retention and treatment success.

METHODS

We conducted a retrospective observational cohort study at the Oxford University Hospitals NHS Foundation Trust (OUHFT), a tertiary referral center with a specialized adult spinal surgery unit. The study period spanned from 1 January 1 to 1 January 2023.

For this study, we defined a deep PSI case as any adult patient (aged ≥18 years) who had undergone a spinal surgical procedure (with or without prosthesis insertion) and subsequently returned to the operating room for suspected surgical site infection involving deep tissues. A "deep" PSI was defined as an infection involving the deep incision, fascia, muscle, or implant (if present). To be included as a confirmed deep PSI, the surgical wound exploration had to yield ≥1 positive microbiological culture from deep tissue or implant specimens and the patient must have received a course of organism targeted antibiotic therapy of greater than 2 weeks.

Exclusion criteria included infections presenting more than 1 year from prior surgical procedure (per UK Health Security Agency guidance [16]) and cases managed without a surgical debridement. If a patient underwent multiple reoperations for the same infection episode, these were analyzed as a single composite case.

Potential PSI cases were identified through a combination of surgical log review and electronic medical records. We searched the electronic surgical logbook (ORBIT) for all spinal surgeries during the study period. Procedure descriptions were manually reviewed to identify entries suggestive of surgical debridement for infection. If a procedure appeared to indicate a possible PSI, the case was then reviewed in the electronic patient record (EPR) to confirm it met inclusion criteria and to complete data collection. We collected data on patient comorbidities, surgical details, microbiological results, and management using a standardized electronic case report form.

Treatment and Outcomes

We noted any additional return-to-surgery operations for infection, including return to the operating room for repeat debridements or eventual implant removal. For antimicrobial therapy, we recorded the total planned duration of antibiotic treatment (in weeks) as determined by the treating infection team, as well as the specific agents used once culture-directed therapy was finalized. Total antibiotic prescribing initiated or continued in primary care was incompletely documented in hospital records; however, when duration was specified in discharge summaries or antibiotic therapy was documented as extended by infection or spinal teams at follow-up, these data were included in the analysis.

Each patient was followed up for 24 months from the index infection surgery through review of clinic notes on EPR. We defined outcomes, adapted from previously published definitions [17]:

- Treatment success: completion of the intended antibiotic course with no requirement for additional unplanned surgical interventions and no evidence of infection recurrence at follow up
- Treatment failure encompassing several scenarios:
  - Primary failure—the infection was not controlled by the initial therapy, necessitating an unplanned reoperation while on the initial course of antibiotics (after at least 2 weeks of therapy, to distinguish from immediate second-look operations)
  - Relapse—infection recurred after completion of the full antibiotic course, with the same organism identified
  - New PSI—a new postoperative infection at the same surgical site but with a different causative organism, occurring after resolution of the initial infection
  - Infection-related death—death of a patient where the cause was directly related to the spinal infection or its complications (as documented by death certificate when recorded on EPR)
- Other outcomes: cases that did not clearly fall into success or failure (eg, death from unrelated causes or loss of follow-up) were recorded but excluded from risk factor analyses.

For the purposes of risk factor analysis, only cases classified as "success" or "failure" were compared as per our study design.

Statistical Analysis

We used descriptive statistics to summarize the cohort. Continuous variables are presented as mean and standard deviation or as median with range/interquartile range (IQR), as appropriate to their distribution. Categorical variables are presented as counts and percentages. To explore associations

between potential risk factors and outcomes, we performed univariate analyses. Categorical factors were compared using Fisher's exact test. Continuous variables were compared using the Wilcoxon rank-sum test for medians. We also conducted univariable logistic regression for each factor to estimate odds ratios (ORs) with 95% confidence intervals (CIs), using treatment failure and prosthesis retention as the outcome of interest. Given the limited number of failures, multivariable modeling was restricted to avoid overfitting; therefore, univariate results are reported unless otherwise specified as exploratory multivariable analyses. A 2-tailed $P < .05$ was considered statistically significant. Statistical analyses were performed using R statistical software (version 4.3.2), with results cross-verified by manual calculation where necessary.

Ethics

This project was registered as a clinical service evaluation with the OUHFT (Quality Improvement Ulysses No. 9617). In line with Health Research Authority guidance in the United Kingdom, formal ethics committee approval was not required for this service evaluation of routinely collected data.

RESULTS

A total of 1957 adult spinal surgeries were performed at OUHFT between 1 January 2020 and 1 January 2023, as identified by the ORBIT operating room log. Case notes were reviewed to determine eligibility; the process has been summarized in Figure 1. Ultimately, 63 unique deep PSI cases met the inclusion criteria. All surgery was performed by or under supervision of a consultant spinal surgeon.

The median age of patients was 59 years (range 18–91), and 56% were female. The index spinal surgeries leading to infection were most frequently performed for degenerative spine disease (25/63, 39.7%). The majority of infections (51/63, 81%) occurred after instrumented surgery. There were no significant differences in baseline demographics or comorbid conditions between patients who ultimately had successful outcomes and those who developed infections (see Table 1).

Treatment Outcome

Treatment success was achieved in 77% of cases where an outcome was attributed, 2 cases lost to follow up were excluded from this analysis and a further 4 cases who died without surgery referenced on their death certificate were excluded (3 of these deaths were in patients with metastatic malignancy).

We further analyzed whether timing of surgical debridement onset affected outcomes. We compared early presentation (defined as surgical debridement ≤30 days postsurgery) to late presentation (>30 days). Neither the likelihood of clinical success ($P = .25$) nor the rate of implant removal ($P = .39$) differed significantly between early versus late presentations. Receiver operating characteristic analysis did not identify a useful threshold for time-to-presentation from index surgery in predicting treatment success or failure (area under curve = 0.42).

We also examined the influence of instrumented spinal level as a predictor of treatment failure. In a multivariable logistic regression adjusting for the number of instrumented levels, no specific spinal region was significantly associated with treatment failure or implant removal. Lumbar surgery showed a trend toward higher odds of failure (OR 5.87; 95% CI, .93–72.1; $P = .097$) but this did not reach statistical significance.

Microbiology From Surgical Sampling

S aureus was the single most common causative organism, identified in 24/63 (38%) of cases (see Figure 2). Notably, Gram-negative bacilli were prominent—when combining Enterobacterales and *Pseudomonas aeruginosa*, Gram-negative organisms were found in 41% of infections. Polymicrobial infections occurred in 33% of cases.

Enterobacterales were associated with the earliest onset of infection after index surgery (median 17.5, IQR 11.2–19) and were statistically more likely to present within 30 days postoperatively ($P = .001$). In an exploratory multivariate analysis allowing for polymicrobial infections, no significant differences in time to presentation were observed between organism groups after correcting for multiple comparisons (all adjusted $P > .1$; pairwise Wilcoxon tests, Benjamini-Hochberg correction). The lowest P value (.13) was observed between *C acnes* and Enterobacterales, suggesting a trend toward later presentation in *C acnes* infections. No other organisms showed a clear early versus late presentation pattern. *S aureus* infections occurred up to 209 days postsurgery (median 20.5, IQR 16.5–43.7), whereas *C acnes* cases tended to present later (median 50.5, IQR 15.2–127.7).

Antimicrobial resistance was relatively uncommon in this data set, 2/24 cases of *S aureus* were identified as methicillin resistant, and no rifampicin resistance was recorded for any of the staphylococci isolates. Strikingly, a high proportion of the Gram-negative isolates in our series possessed inducible AmpC β-lactamases (*Enterobacter cloacae* complex was most frequently found); 14 of 24 Enterobacterales isolates (58%) were intrinsic AmpC producers. No extended spectrum β-lactamases or carbapenemase-producing Enterobacterales were identified.

Associations Between Organisms at Location or Severity of Infection

To explore the relationship between causative organism and the level of spinal instrumentation, we mapped the infecting bacteria for each case against the vertebral levels instrumented in the index procedure with results summarized in Figure 3. *Enterococcus faecalis* infections had a median instrumented level of L3 and were more likely to be involved in more caudal infections than *S aureus* ($P = .049$). In contrast, *C acnes* infections were associated with more cranial spinal levels (median T8) than *S aureus* ($P = .042$). Interestingly, Enterobacterales

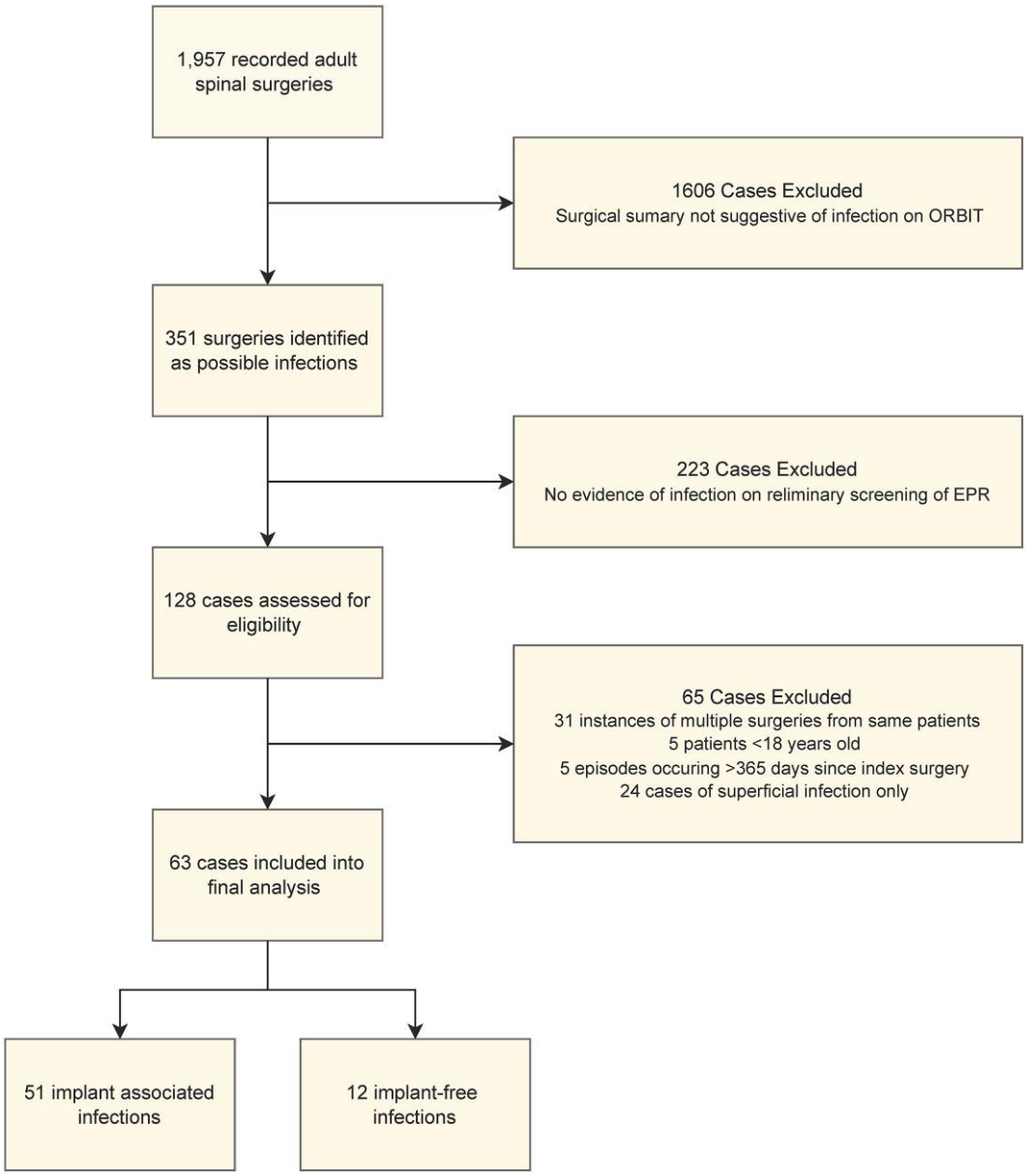

Figure 1. Schematic of process for case identification. We initially identified 351 surgeries that involved a revision debridement procedure; of these, 223 (63.5%) were excluded on preliminary review. The remaining 128 cases underwent detailed assessment of the relevant EPR: 5 were excluded because the index surgery occurred when the patient was <18 years old, 5 were excluded because presentation was >365 days from the index surgery, 24 were deemed superficial (incisional) PSIs, and 31 cases were repeat operations for the same infection episode.

infections had a distribution similar to *S aureus*, occurring at significantly more cranial levels than *E faecalis* ($P = .049$), despite both being enteric flora.

Our analysis identified infections involving *C acnes* were associated with a higher risk of eventual implant removal (when present). In a univariate analysis, *C acnes* infection was associated with a lower odd of implant retention (OR = 0.19; 95% CI, .03–.91; $P = .04$) at 24 months' follow up (see Figure 4). In practical terms, 4 of 12 infections involving *C acnes* in our series ultimately required implant removal to achieve cure within 24 months of the initial debridement. No other organism was significantly associated with clinical failure or implant removal. The indications for implant removal are shown in Table 2.

Antibiotic Prescribing

Administration of intravenous antibiotics immediately before sampling was unusual; 3/63 patients received antibiotics in the 24 hours before surgical debridement, 2 of whom had an *S aureus* bacteremia, whereas another patient received amoxicillin/clavulanic acid in the context of a *Citrobacter* spp

Table 1. Patient and Surgical Characteristics by Outcome (Treatment Success vs Failure) Baseline Characteristics of Patients Stratified by 24-month Outcome

Patient Characteristic	Success (n = 44)	Failure (n = 13)	Odds Ratio (95% CI)	*P* Value
Demographics				
Male sex, n (%)	22 (50.0)	6 (46.2)	0.86 (0.24–2.98)	.81
Age, median (IQR), y	61 (23.7–67.2)	61 (51–71.5)	1.02 (0.99–1.05)	.24
Charlson Comorbidity Index, mean ± SD	2.2 ± 2.4	2.2 ± 1.7	1.01 (0.75–1.31)	.97
Risk factors for infection				
Diabetes, n (%)	4 (9.1)	2 (15.4)	1.82 (0.23–10.68)	.52
Active malignancy, n (%)	8 (18.2)	2 (15.4)	0.82 (.11–3.89)	.82
Steroid use ≤ 2 wks of surgery, n (%)	2 (4.5)	2 (15.4)	3.82 (0.42–34.90)	.20
BMI >30, n (%)	14 (31.8)	3 (23.1)	0.64 (0.13–2.50)	.55
Indication for surgery				
Degenerative spinal disease, n (%)	18 (40.9)	6 (46.2)	Reference	—
Spinal deformity, n (%)	11 (25.0)	2 (15.4)	1.50 (0.29–11.40)	.65
Trauma, n (%)	8 (18.2)	4 (30.8)	2.75 (0.43–23.60)	.30
Malignancy, n (%)	7 (15.9)	1 (7.7)	1.83 (0.07–27.20)	.66
Surgical factors				
First spinal operation, n (%)	28 (63.6)	9 (69.2)	—	0.87
Insertion of implant, n (%)	35 (79.5)	10 (76.9)	0.86 (0.21–4.40)	.84
Number of instrumented vertebrae, mean (SD)	5.3 (3.5)	5.5 (4.2)	1.01 (0.84–1.19)	.88
Polymicrobial infection, n (%)	14 (31.8)	4 (30.8)	0.95 (0.23–3.49)	.94
D from index surgery to surgical debridement, median (IQR)	19.5 (12–34.5)	27 (17.5–45.5)	1.01 (0.99–1.02)	.26
Number of surgical samples, mean	5.1	4.1	—	0.13
Number of positive cultures, mean	4.2	3.5	—	.26

Abbreviations: BMI, body mass index; CI, confidence interval; IQR, interquartile range; SD, standard deviation.

Six patients were excluded from this analysis, yielding n = 57 (44 successes, 13 failures). Univariable logistic regression was used (failure = outcome of interest); an OR > 1 indicates higher odds of failure.

bacteremia. There were no suspected cases of hematogenous seeding. A limited range of antibiotics was used for targeted therapy postoperatively. The most common regimen was ciprofloxacin plus rifampicin, which was prescribed in 15 of 38 staphylococcal infections. Overall, rifampicin was used in combination with a second agent in 26/38 (68%) of infections involving *Staphylococci* and in 6/12 (50%) of *C acnes*–associated infections. In our study, rifampicin use was not associated with higher success rates (OR = 1.67; 95% CI, .58–5.07; $P = .35$) or implant retention (OR = 2.52; 95% CI, .54–15.28; $P = .24$). In subgroup analyses of *S aureus*, coagulase-negative staphylococci, and *C acnes* cases, rifampicin use showed no significant impact on outcomes (with wide CIs reflecting limited sample size). The same was true when these 3 organisms were combined as a composite "gram-positive" group.

Implant-associated PSI

Of the 63 cases included in this cohort, 51 involved spinal implants (81%). In all cases, spinal implants were at least partially retained on initial surgical debridement when infection was suspected. Table 3 summarizes baseline case characteristics and outcome for patients with spinal implants. The total planned duration of antibiotics after surgical debridement varied, but in nearly all cases involving retained prosthetic material it fell into 1 of 2 regimens: 12 weeks or 24 weeks of therapy. The 24-month treatment success was statistically similar between the 2 planned antibiotic duration groups ($P = .76$), with antibiotics only extended beyond the planned duration in a small minority of cases. Surgical debridement techniques were individualized on a case-by-case basis, but generally included lavage, debridement, and revision of broken or loose implants. Partial implant exchanges were not recorded in this cohort; complete removal or exchange procedures are reported in Table 2.

Only 6 cases of implant-associated infection presented more than 90 days after their index operation, none was considered to be hematogenous seeding to the spine. Prostheses were eventually removed in 2 (33%) of these cases.

Notably, infections involving Enterobacterales were significantly more likely to have been a planned 24-week antibiotic course ($P = .002$). Patients in the 24-week group were also more likely to have had prior spinal surgeries ($P = .04$).

DISCUSSION

In this retrospective cohort, combined surgical and antimicrobial management yielded favorable outcomes for most patients with retained infected spinal implants. After excluding patients lost to follow-up and those whose deaths were unrelated to spinal infection, 76% met our definition of treatment success

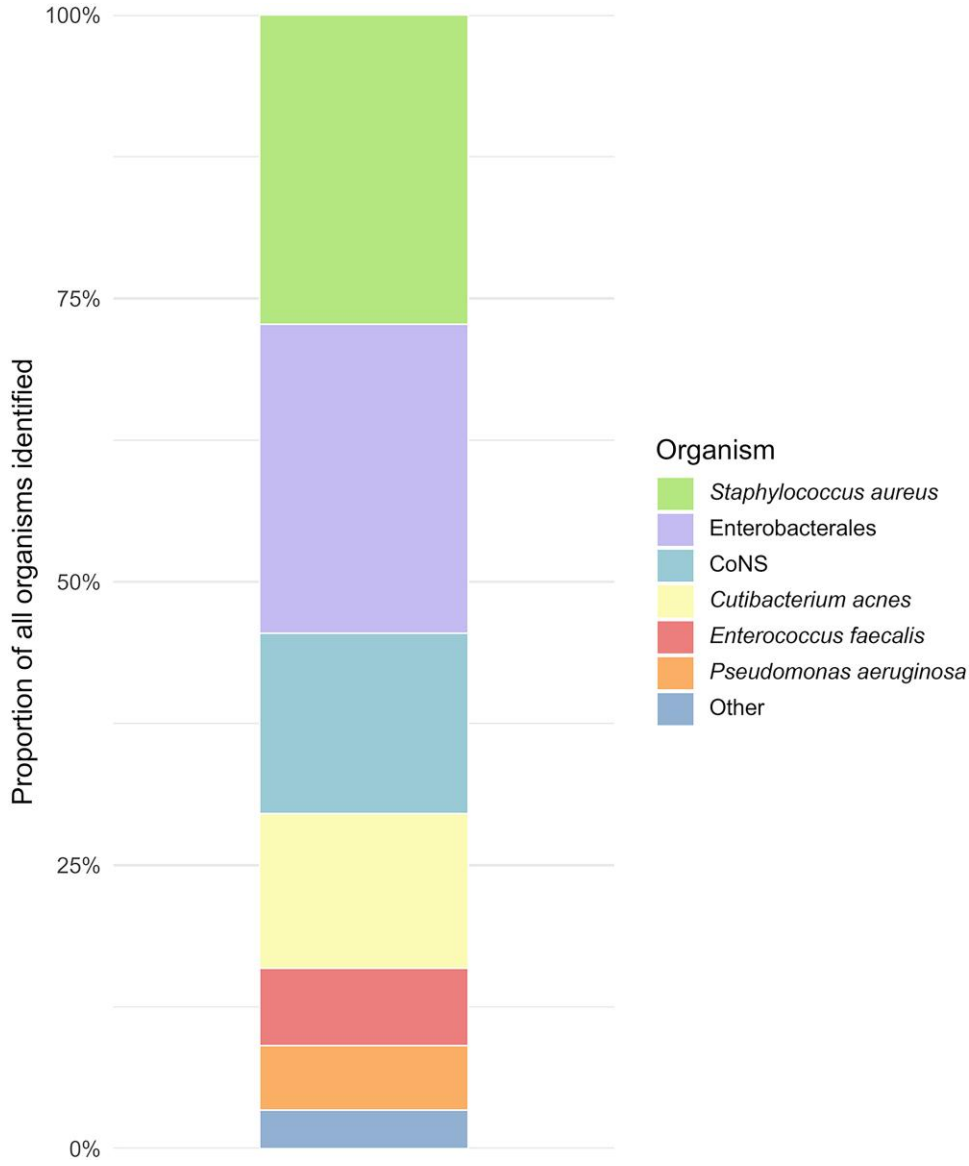

Figure 2. Plot of relative frequency of organisms isolated from deep surgical site infection cultures. *Staphylococcus aureus* was found in 24 cases, Enterobacterales in 22, Coagulase-negative staphylococci (CoNS) in 14 cases, *Cutibacterium acnes* in 12 cases, *Enterococcus faecalis* in 6 cases, and *Pseudomonas aeruginosa* in 4 cases. Infrequently isolated organisms (each in 1 case) included β-hemolytic streptococci, *Corynebacterium* spp., *Finegoldia magna*, and *Peptostreptococcus* were recorded as "other."

without requiring indefinite suppressive antibiotics, and 88% retained their spinal implants at 24 months of follow-up. These outcomes are reassuring and compare favorably to published results for debridement, antibiotics, and implant retention (DAIR) success rates reported in the hip [18] and knee [19, 20] PJI studies (34%–74%). However, there is no standardized approach of DAIR as applied to spinal implant infections, and the debridement techniques used in this cohort were individualized on a case-by-case basis. Our findings are consistent with other PSI studies reporting success rates of 80%–94% when implants are retained [21–23], further suggesting that hip and knee PJI management approaches may not directly apply to instrumented PSI. We did not identify any specific patient factors, such as age or comorbidities, that predicted failure. This may suggest that most patients can initially be managed with debridement with implant retention unless there is a clear indication for removal.

Consistent with prior literature, *S aureus* was a leading cause of infection [24]. However, an unexpected finding was that gram-negative bacilli (Enterobacterales and *Pseudomonas*) represented a larger proportion of infections than the 12%–21% reported elsewhere [6, 12, 22, 25]. We initially

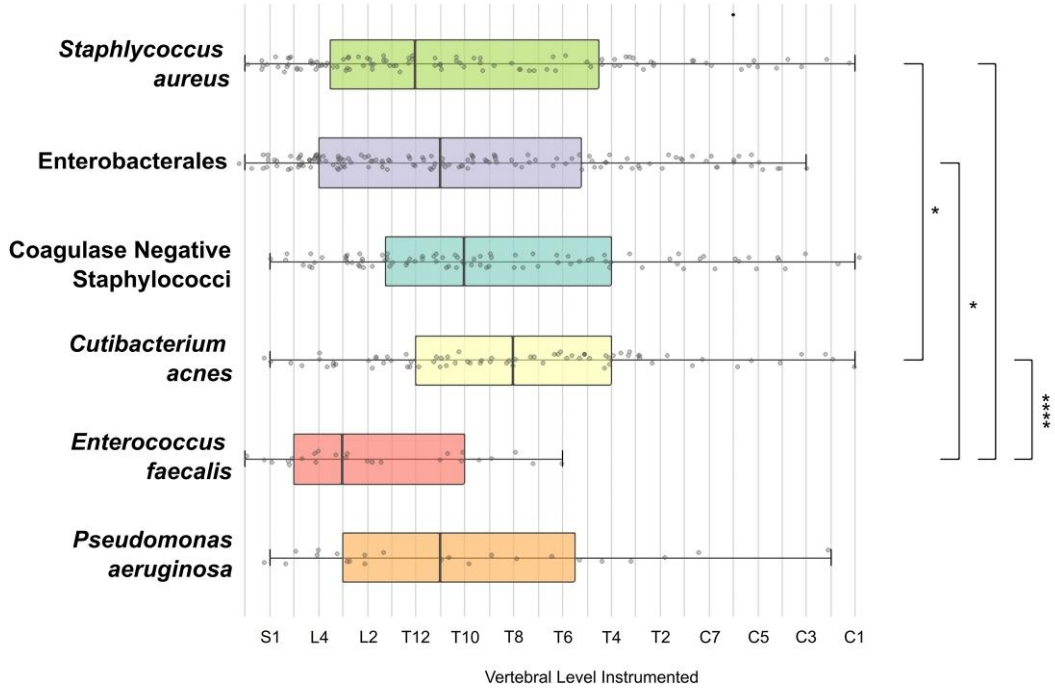

Figure 3. Association of infecting organism with level of spinal instrumentation. Boxplot showing distribution of instrumented vertebral levels by pathogen. *P* values from Wilcoxon rank-sum tests. $^{*}P < .05$, $^{****}P < .0001$.

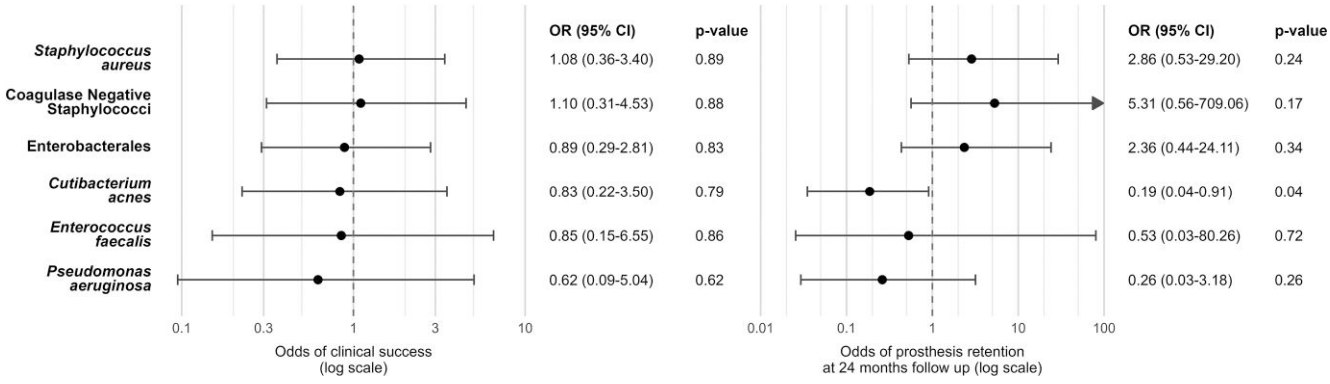

Figure 4. Forest plot demonstrating the association of infecting organism with clinical success and implant retention at 24 months. Odds ratios and 95% confidence interals were calculated using Firth's penalized logistic regression to account for small-sample bias.

hypothesized that gram-negative infections would be more frequent in lumbar and sacral cases because of proximity to the perianal region where enteric organisms are more abundant on the skin [26]. However, we found that Enterobacterales infections were distributed across spinal levels similarly to *S aureus* and were recovered from surgeries instrumenting vertebral levels statistically more cranial than that of infections involving *E faecalis* (another enteric organism). The reason for this distribution is unclear. One possibility is that many gram-negative infections in our series were environmental in origin, as has been hypothesized in other studies evaluating PSIs [27, 28], rather than stemming from the patient's native flora. Supporting this, we observed a high proportion of AmpC-producing gram-negatives, which are frequently associated with hospital-acquired infections [29–31]. This is plausible given many gram-negative infections in our cohort presented early (median 17.5 days after index surgery), suggesting infection is established in the early postoperative period.

Previous studies evaluating spinal implant infections have highlighted onset of infection as a key determinant for management decisions, with delayed onset (typically >3 months) after

Table 2. Clinical Details of Cases Requiring Implant Removal

Age And Sex	Comorbidities	Number of Previous Spinal Operations	Index Surgery	D From Index Surgery to Surgical Debridement	Bacteria From Surgical Sampling (Resistance Pattern)	Targeted Antibiotic Therapy	Planned Antibiotic Duration	Total Antibiotic Duration Prior to Revision Surgery	D From First Surgical Debridement to Removal of Prosthesis	Indication for Prosthesis Removal and Subsequent Culture Result
51F	Scoliosis, obesity, thoracic giant cell tumour, concurrent corticosteroids	0	T6 Giant cell tumor resection and reconstruction	13	*Cutibacterium acnes* (wild-type)	Amoxicillin 1 g TDS	12 wks	19 d	19	Persistent discharging wound despite 2 debridements. Removal of bone graft and cage replacement undertaken. Sterile culture from explanted prosthetic material
81M	Hypertension, dyslipidemia,	0	Posterior thoraco-lumbar fixation and decompression	25	*Staphylococcus aureus* (penicillin resistant, otherwise fully susceptible)	Ciprofloxacin 500 mg BD and rifampicin 450 mg BD	12 wks	69 d	69	Persistent pain, positive sagittal balance postsurgery. Implant exchanged. Uncertainty if related to infection. Sterile culture of explanted prosthetic material
39M	Smoker	0	Posterior thoraco-lumbar T5-L1 fixation	207	*Cutibacterium acnes* (wild-type)	Amoxicillin 1 g TDS	12 wks	12 wks	373	Persistent pain, collection on MRI. Thought to be related to chronic infection. *Cutibacterium acnes* cultured from explanted prosthetic material (remained susceptible to penicillin)
70M	None	0	L5/S1 Transforaminal Interbody fusion	42	*Cutibacterium acnes* (wild-type)	Doxycycline 100 mg BD and rifampicin 450 mg BD	12 wks	24 wks with brief interruption (~3 wks)	536	Persistent pain, leaking serous fluid from wound. Radiology not suggestive of worsening infection or issues with metalwork. Coagulase-negative staphylococci cultured from explanted prosthetic material
74M	Prostatectomy	1	Laminectomy L2/3 and L3/4 with existing metalwork	19	*Citrobacter sp.* (Wild type)	Amoxicillin/clavulanic acid 1.2 g IV (remained hospitalized)	12 wks	53 d	53	Severe L3/4 discitis with loose L3 screws and L3/4 pseudoarthosis—thought to be a consequence of infection. Implant exchanged. *Citrobacter* spp. cultured from explanted prosthetic material (remained susceptible to amoxicillin/clavulanic acid)
52F	Progressive kyphosis of whole spine, Chronic pressure sores	≥2	Extension of fusion to C2 and to L3	206	*Pseudomonas aeruginosa* (wild-type), *Cutibacterium acnes*, (wild-type), *Finegoldia magna* (wild-type)	Ciprofloxacin 750 mg BD	12 wks	133 d	133	Exposed prosthesis, metalwork removed with primary closure. *Escherichia coli* cultured from explanted prosthetic material (ESBL)

Abbreviations: BD, twice daily; IV, intravenous; MRI, magnetic resonance imaging; TDS, three times a day.

Table 3. Comparison of Clinical Characteristics and Outcomes in Patients Planned to Receive ≤12 Weeks vs ≥24 Weeks of Antibiotic Therapy With Retained Prosthetic Material

Characteristic	Overall (N = 51)	≤12 Wks (N = 31)	24 Wks (N = 20)	*P* Value
Age, median (IQR), y	58 (30.5–67)	58 (33–68.5)	56 (19.7–66)	.48
Charlson Comorbidity Index, mean ± SD	2.7 ± 2.8	2.7 ± 2.6	2.7 ± 3.2	.94
No. of vertebrae instrumented, mean ± SD	5.5 ± 3.4	5.2 ± 3.3	6.1 ± 3.6	.35
First spinal surgery, n (%)	41 (80)	28 (90)	13 (65)	.04
Indication for surgery				
Degenerative spine, n (%)	16 (31)	11 (35)	5 (25)	
Malignant cord compression, n (%)	3 (6)	0 (0)	3 (15)	
Pathological fracture, n (%)	5 (10)	4 (13)	1 (5)	
Primary tumour, n (%)	4 (8)	2 (6)	2 (10)	
Spinal deformity, n (%)	11 (22)	5 (16)	6 (30)	
Traumatic fracture, n (%)	12 (24)	9 (29)	3 (15)	
Antibiotic duration extended, n (%)	5 (10)	2 (6)	3 (15)	.56
Return to surgery, n (%)	14 (27)	9 (29)	5 (25)	.99
Readmission, n (%)	10 (20)	5 (16)	5 (25)	.49
Treatment success, n (%)	35 (69)	21 (68)	14 (70)	.76
Treatment failures				
Died—PSI-related, n (%)	2 (4)	1 (3)	1 (5)	
New PSI, n (%)	2 (4)	2 (6)	0 (0)	
Primary failure, n (%)	5 (10)	4 (13)	1 (5)	
Relapse failure, n (%)	1 (2)	1 (3)	0 (0)	
Lifelong suppressive antibiotics, n (%)	1 (2)	0 (0)	1 (5)	
Died—unrelated, n (%)	4 (8)	1 (3)	3 (15)	
Unknown/lost to follow-up, n (%)	1 (2)	1 (3)	0 (0)	
D from index surgery to surgical debridement, median (IQR)	19 (12.5–50.5)	20 (15–47.5)	18 (10.7–49.7)	.95
Organisms identified				
Staphylococcus aureus, n (%)	17 (33)	12 (39)	5 (25)	.37
Coagulase-negative Staphylococci, n (%)	13 (25)	9 (29)	4 (20)	.53
Enterobacterales, n (%)	19 (37)	6 (19)	13 (65)	.002
Cutibacterium acnes, n (%)	12 (24)	9 (29)	3 (15)	.32
Enterococcus faecalis, n (%)	3 (6)	0 (0)	3 (15)	.06
Pseudomonas aeruginosa, n (%)	4 (8)	2 (6)	2 (10)	.64
Polymicrobial infection, n (%)	17 (33)	8 (26)	9 (45)	.22

Abbreviations: IQR, interquartile range; PSI, postoperative spine infection; SD, standard deviation.

Statistical comparisons used Wilcoxon rank-sum tests for continuous variables and Fisher's exact test for categorical variables.

index surgery being associated with poorer outcomes or rates of implant retention [32–34]. Although cases that met criteria for treatment success presented on average earlier than those with treatment failure (median of 19.5 days vs 27 days), comparison did not meet statistical significance, which may reflect a lack of power in our relatively modest data set.

C acnes infections were associated with a statistically higher likelihood of implant removal in our cohort. *C acnes* (formerly *Propionibacterium acnes*) is a low-virulence anaerobic skin commensal organism, particularly associated with spinal and shoulder PJI, but has also been associated with chronic back pain and native vertebral osteomyelitis [35]. Our finding aligns with a recent multicenter study by Núñez-Pereira et al., which reported that spinal infections resulting from *C acnes* had significantly higher implant removal rates compared to non–*C acnes* infections (30% vs 13%) [36]. The need for removal may relate to *C acnes*' capacity to form biofilm and the difficulty of eradicating a well-established, chronic infection on implants. Future research might clarify whether adjunctive rifampicin or prolonged suppression improves retention rates. We also suggest closer follow-up when *C acnes* is identified, as its indolent presentation may delay recognition and allow biofilm formation, potentially increasing the risk of implant failure.

In our cohort, we found those cases where 24 weeks of antimicrobials were planned conferred no clear advantage in preventing treatment failure compared to a 12-week regimen. It should be noted that the decision of 12 weeks versus 24 weeks of antimicrobial therapy may have reflected the treating clinicians' judgment of the complexity of the infection, particularly given those treated for 24 weeks were more likely to have had multiple spinal procedures and gram-negative infection. It is difficult to infer optimal durations of treatment from these results given a number of confounding factors that we have not been able to adequately adjust for in a limited data set.

However, our findings add to the limited evidence suggesting that routine extension of curative antimicrobial therapy beyond 12 weeks may not be necessary. Supporting this, a recent prospective observational study reported reassuring outcomes with a 6-week course of systemic antibiotic therapy after PSI, most cases of which involved prosthetic material, with clinical failure occurring in 8.2% of patients [17]. In addition, a prospective randomized study comparing 6 versus 12 weeks of therapy has been undertaken [37]. Although full results remain unpublished, the ethical and clinical equipoise underpinning such a trial would suggest that indications for much longer treatment durations, such as 24 weeks, are unlikely to be beneficial. Although rifampicin is frequently given in combination therapy for instrumented deep PSI involving gram-positive organisms and has been associated with reduced deep PSI recurrence in an observational study [38], our data did not clearly demonstrate a benefit.

Our study has several limitations. In this single-center retrospective cohort, the limited number of failure events restricts the statistical power to explore risk factors for treatment failure. We recognize that the spinal procedures in our cohort were heterogeneous, and we did not attempt to control for many specific surgical factors given the limitations of retrospective data. Additionally, no formal distinction was made between surgical debridement without implant exchange and partial implant exchange. Treatment approaches (such as antibiotic duration or local antibiotic use) were not standardized but rather based on individual clinical judgment, introducing potential bias and confounders. We were unable to determine exact antibiotic durations or regimen changes in a significant number of cases (particularly when care was continued in another hospital), so these data could not be reliably analyzed. Additionally, we did not systematically assess functional outcomes or long-term quality of life. Our definition of treatment success was relatively narrow; we acknowledge that chronic pain or disability resulting from the infection and its treatment are important considerations for patients and could be incorporated within the definition of treatment failure.

Despite these limitations, our study has several strengths. The definitions of treatment success and failure were pragmatic, enabling clear classification of outcomes in the vast majority of cases. We also employed a 2-year follow-up, which is important given the potential for late-presenting failures in spinal infections.

In conclusion, deep surgical site infections following spinal procedures remain a challenging complication that requires coordinated surgical and medical management. Our cohort study suggests that the majority of these infections can be treated successfully while retaining spinal hardware. Standardized terminology for DAIR procedures in spinal surgery would also improve consistency across future studies. Our data suggests that extending antibiotic treatment courses beyond 3 months did not confer obvious added benefit. We also highlight that *C acnes* infections often require eventual hardware removal and may require particular vigilance in follow-up. Prospective, multicenter trials are needed to determine the minimum effective duration of antibiotic therapy after surgical debridement for deep PSI, particularly where implants are retained, and to identify factors associated with treatment failure and implant removal.

Notes

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References

1. Lupo BD, Jameson WP, Quinones CJ, et al. Risk factors and outcomes of surgical site infections of the spine: a retrospective multi-center analysis. J Clin Med **2025**; 14:3520.
2. Parchi PD, Evangelisti G, Andreani L, et al. Postoperative spine infections. Orthop Rev (Pavia) **2015**; 7:5900.
3. Zhou J, Wang R, Huo X, Xiong W, Kang L, Xue Y. Incidence of surgical site infection after spine surgery: a systematic review and meta-analysis. Spine (Phila Pa 1976) **2020**; 45:208–16.
4. Avinash M, Renjith KR, Shetty AP, Sharma V, Kanna RM, Rajasekaran S. Unplanned readmissions after spine surgery: a single-center prospective analysis of a 90-day model in 2,860 cases. Asian Spine J **2020**; 14:43–50.
5. Alfin DJ, Shilong DJ, Bot GM, Dengunu Salun W. Surgical site infection rate in spine surgery, incidence, and risk factors: a ten-year retrospective cohort review in a developing neurosurgical centre. BMC Surg **2025**; 25:127.
6. Kalfas F, Severi P, Scudieri C. Infection with spinal instrumentation: a 20-year, single-institution experience with review of pathogenesis, diagnosis, prevention, and management. Asian J Neurosurg **2019**; 14:1181–9.
7. Tai DBG, Lahr B, Suh GA, Berbari EF, Huddleston PM, Tande AJ. Defeating the hidden foe: antibiotic therapy and clinical outcomes of Cutibacterium acnes spinal implant infections. Open Forum Infect Dis **2023**; 10:ofad403.
8. Baroudi M, Daher M, Parks RD, et al. Cutibacterium acnes in spine surgery: pathophysiology, diagnosis, and treatment. Spine J **2024**; 24:1545–52.
9. Tai DBG, Patel R, Lovecchio F, Kwee T, Wouthuyzen-Bakker M. State-of-the-art review: diagnosis and management of spinal implant infections. Clin Infect Dis **2024**; 79:e65–71.
10. Divi SN, Kepler CK, Boody BS, et al. Consensus on implants in infections after spine surgery. Clin Spine Surg **2020**; 33:163–71.
11. Kasliwal MK, Tan LA, Traynelis VC. Infection with spinal instrumentation: review of pathogenesis, diagnosis, prevention, and management. Surg Neurol Int **2013**; 4(Suppl 5):S392–403.
12. Kowalski TJ, Berbari EF, Huddleston PM, Steckelberg JM, Mandrekar JN, Osmon DR. The management and outcome of spinal implant infections: contemporary retrospective cohort study. Clin Infect Dis **2007**; 44:913–20.
13. Li C, Ojeda-Thies C, Xu C, Trampuz A. Meta-analysis in periprosthetic joint infection: a global bibliometric analysis. J Orthop Surg Res **2020**; 15:251.
14. Karczewski D, Pumberger M, Muller M, Andronic O, Perka C, Winkler T. Implications for diagnosis and treatment of peri-spinal implant infections from experiences in periprosthetic joint infections-a literature comparison and review. J Spine Surg **2020**; 6:800–13.

15. Puri T, Frost ML, Curran KM, et al. Differences in regional bone metabolism at the spine and hip: a quantitative study using (18)F-fluoride positron emission tomography. Osteoporos Int **2013**; 24:633–9.
16. England PH. Protocol for the Surveillance of Surgical Site Infection. London: Public Health England, **2019**.
17. Fernandez-Gerlinger MP, Arvieu R, Lebeaux D, et al. Successful 6-week antibiotic treatment for early surgical-site infections in spinal surgery. Clin Infect Dis **2019**; 68:1856–61.
18. Tsang STJ, Ting J, Simpson AHRW, Gaston P. Outcomes following debridement, antibiotics and implant retention in the management of periprosthetic infections of the hip: a review of cohort studies. Bone Joint J **2017**; 99-B:1458–66.
19. Abbaszadeh A, Yilmaz MK, Izadi N, et al. Efficacy of DAIR (debridement, antibiotics, and implant retention) in total hip and knee arthroplasty: a systematic review and meta-analysis. J Arthroplasty **2026**; 41:19–38.
20. Salman LA, Altahtamouni SB, Khatkar H, Al-Ani A, Ahmed G. Success rate of single versus multiple debridement, antibiotics, and implant retention (DAIR) in hip and knee periprosthetic joint infection: a systematic review and meta-analysis. Eur J Orthop Surg Traumatol **2024**; 34:3859–72.
21. Hickmann AK, Bratelj D, Pirvu T, et al. Management and outcome of spinal implant-associated surgical site infections in patients with posterior instrumentation: analysis of 176 cases. Eur Spine J **2022**; 31:489–99.
22. Wille H, Dauchy FA, Desclaux A, et al. Efficacy of debridement, antibiotic therapy and implant retention within three months during postoperative instrumented spine infections. Infect Dis **2017**; 49:261–7.
23. Billieres J, Uckay I, Faundez A, et al. Variables associated with remission in spinal surgical site infections. J Spine Surg **2016**; 2:128–34.
24. Palmowski Y, Burger J, Kienzle A, Trampuz A. Antibiotic treatment of postoperative spinal implant infections. J Spine Surg **2020**; 6:785–92.
25. Margaryan D, Renz N, Bervar M, et al. Spinal implant-associated infections: a prospective multicentre cohort study. Int J Antimicrob Agents **2020**; 56:106116.
26. Long DR, Bryson-Cahn C, Waalkes A, et al. Contribution of the patient microbiome to surgical site infection and antibiotic prophylaxis failure in spine surgery. Sci Transl Med **2024**; 16:eadk8222.
27. Rosendorf LL, Daicoff G, Baer H. Sources of gram-negative infection after open-heart surgery. J Thorac Cardiovasc Surg **1974**; 67:195–201.
28. Ali KM, Al-Jaff BMA. Source and antibiotic susceptibility of gram-negative bacteria causing superficial incisional surgical site infections. Int J Surg Open **2021**; 30:100318.
29. Zerr DM, Miles-Jay A, Kronman MP, et al. Previous antibiotic exposure increases risk of infection with extended-spectrum-beta-lactamase- and AmpC-producing Escherichia coli and Klebsiella pneumoniae in pediatric patients. Antimicrob Agents Chemother **2016**; 60:4237–43.
30. Muller A, Lopez-Lozano JM, Bertrand X, Talon D. Relationship between ceftriaxone use and resistance to third-generation cephalosporins among clinical strains of Enterobacter cloacae. J Antimicrob Chemother **2004**; 54:173–7.
31. Rodriguez-Bano J, Miro E, Villar M, et al. Colonisation and infection due to Enterobacteriaceae producing plasmid-mediated AmpC beta-lactamases. J Infect **2012**; 64:176–83.
32. Hanmer OJ, Houlsby WT, Thom H, Ross IS, Lloyd DJ, Russell G. Fat as an energy supplement for preterm infants. Arch Dis Child **1982**; 57:503–6.
33. Chen SH, Lee CH, Huang KC, Hsieh PH, Tsai SY. Postoperative wound infection after posterior spinal instrumentation: analysis of long-term treatment outcomes. Eur Spine J **2015**; 24:561–70.
34. Aydinli U, Karaeminogullari O, Tiskaya K. Postoperative deep wound infection in instrumented spinal surgery. Acta Orthop Belg **1999**; 65:182–7.
35. Passerini M, Maamari J, Geno Tai DB, et al. Cutibacterium acnes in spine tissue: characteristics and outcomes of non-hardware-associated vertebral osteomyelitis. J Bone Jt Infect **2023**; 8:143–9.
36. Nunez-Pereira S, Benavent E, Ulldemolins M, et al. Cutibacterium spp. Infections after instrumented spine surgery have a good prognosis regardless of rifampin use: a cross-sectional study. Antibiotics **2023**; 12:518.
37. Betz M, Uckay I, Schupbach R, et al. Short postsurgical antibiotic therapy for spinal infections: protocol of prospective, randomized, unblinded, noninferiority trials (SASI trials). Trials **2020**; 21:144.
38. Cho OH, Bae IG, Moon SM, et al. Therapeutic outcome of spinal implant infections caused by Staphylococcus aureus: a retrospective observational study. Medicine (Baltimore) **2018**; 97:e12629.