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Original Article

Analysis of Risk Factors and Development of a Predictive Model for Post-Spinal Surgery Infections in Older Patients

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SUMMARY

Background: Post-operative infection hampers recovery in older adults after spinal surgery. We analyzed infection patterns and risk factors for deep/organ-space infection.
Methods: A retrospective review of 317 patients ≥ 65 years (January 2019–October 2024) identified superficial versus deep/organ-space infections. Baseline, laboratory and operative variables were compared; independent predictors were determined with multivariable logistic regression. Model performance was gauged with the area under the receiver-operating-characteristic curve (AUC) and calibration tests.
Results: Superficial infection occurred in 200 patients (63.1%) and deep/organ-space infection in 117 (36.9%). Compared with superficial cases, deep infections were linked to greater age, higher body-mass index (BMI), diabetes, frailty, hypoalbuminemia, longer operative time and procedures involving ≥ 3 spinal levels. Multivariable analysis confirmed age, BMI, diabetes, frailty, albumin < 35 g/L, operative time, ≥ 3 levels, and intra-operative transfusion as independent predictors. The model demonstrated good discrimination (AUC = 0.82) and acceptable calibration. Deep/organ space infection was associated with longer hospitalization (16.7 ± 5.9 vs. 12.3 ± 4.1 days, $p < 0.001$), higher re-operation rates (16.2% vs. 3.5%, $p < 0.001$), and greater ICU utilization (18.8% vs. 7.0%, $p = 0.002$). Infection related mortality remained low overall (4.3%).
Conclusion: Advanced age, metabolic comorbidity, frailty and complex, prolonged surgery independently predicts deep/organ-space infection after spinal procedures in older adults. Early identification of these factors can guide targeted prevention and improve outcomes.

1. Introduction

The rising volume of spinal procedures worldwide, particularly in aging populations, underscores the increasing burden of post-operative spinal infections. These infections are categorized based on the depth of tissue involvement: superficial, deep incisional, or organ/space infections, and can be related to implants.[1,2] These infections often lead to prolonged hospital stays, reoperations, functional decline, increased healthcare costs, and even mortality.[3–5] The incidence of surgical site infections (SSIs) in spinal surgery ranges from 1% to 20%.[3,5,6] Older adults are particularly vulnerable to these infections due to age-related physiological changes such as immune senescence, sarcopenia, and frailty.[7] Additionally, the higher prevalence of multimorbidity, including conditions like diabetes, cardiovascular disease, and renal impairment, along with polypharmacy, further complicates their perioperative management.[7] Unique challenges in geriatric spine surgery include addressing nutritional deficits, poor bone quality, and reduced wound healing capacity.[7] Effective management of these infections requires a comprehensive approach, including the use of advanced diagnostic techniques, appropriate antibiotic therapy, and sometimes surgical intervention to prevent complications such as spinal instability and chronic pain.[2,8] Understanding and mitigating the risk factors associated with SSIs, particularly in older adults, is crucial for improving surgical outcomes and reducing the burden on healthcare systems.[9,10]

Current evidence identifies several perioperative and patient-related determinants influencing SSI in spinal surgery, including diabetes, operative time, and instrumentation. Established risk factors encompass age, frailty, nutritional status, and comorbidities such as obesity and smoking.[10–12] However, previous studies often suffer from limitations, including mixed-age cohorts lacking geriatric granularity, predominantly retrospective designs, and insufficient models distinguishing between superficial and deep infections.[10,13] The need for predictive modeling in the geriatric spine population is underscored by the advantages of individualized risk prediction, which can enhance targeted prophylaxis, optimize resource allocation, and facilitate shared decision-making.[13,14]

Our study focused on a pure geriatric cohort from a large tertiary facility in China and deliberately incorporates geriatric-specific indices, such as frailty and serum albumin, alongside operative complexity measures. Our primary objective is to identify independent risk factors for deep/organ-space postoperative spinal infections among older adults, while secondary goals include constructing a

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robust multivariable model and comprehensively characterizing infection timing, microbiology, and outcomes.

2. Methods

2.1. Study design and setting

This retrospective cohort examined postoperative spinal infections in adults ≥65 treated at Guangzhou Hospital of Integrated Traditional and Western Medicine (Jan 2019–Oct 2024). Hospital databases and electronic charts were screened for any spine surgical-site infection (SSI) recorded within 90 days of surgery. SSIs were classified by CDC/NHSN depth: superficial (skin/subcutaneous) or deep/organ-space (fascia, muscle, disc, epidural, etc.); cases showing both depths were categorized as deep/organ-space. The Institutional Review Board approved the study, waived informed consent because data were de-identified, and confirmed compliance with the Declaration of Helsinki and national regulations. Patient confidentiality was strictly maintained throughout.

2.2. Study population

2.2.1. Inclusion criteria

1) Age ≥ 65 years at the time of the index spinal operation; 2) Underwent any elective or urgent cervical, thoracic, or lumbar spinal surgery (decompression, fusion, or combined procedures) at Guangzhou Hospital of Integrated Traditional and Western Medicine between January 2019 and October 2024; 3) Developed a postoperative spinal infection that satisfied CDC/NHSN surveillance definitions for surgical-site infection within 90 days of the index procedure; 4) Had complete peri-operative, microbiological, and follow-up documentation sufficient to assign infection depth, comorbidities, and outcome variables; 5) Maintained at least 90 days of postoperative follow-up at our institution or through validated outpatient records to capture late-manifesting infections and clinical outcomes.

2.2.2. Exclusion criteria

1) Active spinal or systemic infection before the index operation or revision surgery performed specifically for an existing infection; 2) Simultaneous non-spinal procedures through the same incision that could confound attribution of infection origin; 3) Incomplete or missing key data elements; 4) Loss to follow-up, transfer of care, or death from non-infectious causes within 90 days post-surgery; 5) Immunocompromised states unrelated to age or typical comorbidity profiles.

2.3. Data collection and variables

Patient information was abstracted from institutional databases and charts with a standardized form. Four variable domains were captured as detailed below:

2.3.1. Demographic and preoperative factors

Recorded items were age, sex, body-mass index, and smoking status (current/former vs. never). Major comorbidities — diabetes, hypertension, coronary artery disease, and chronic kidney disease — were transcribed from the medical history. Nutritional status by the most recent pre-op serum albumin (g/L). Global physiologic risk was coded with the American Society of Anesthesiologists (ASA) Physical Status class I–VI.

2.3.2. Frailty Index

Frailty was quantified with the 11-item Modified Frailty Index (mFI-11). The index sums 11 predefined comorbidities/functional deficits (Supplementary Table S1) and is expressed as the proportion of deficits present (score 0–1). For descriptive purposes patients were classified as robust (mFI-11 = 0), prefrail ($0.09 \leq$ mFI-11 < 0.27) or frail (mFI-11 ≥ 0.27). In multivariable models the mFI-11 was analyzed as a continuous variable.

2.3.3. Surgical characteristics

Operative reports supplied the spinal region, procedure category, approach (minimally invasive vs. open), and number of levels treated. Intra-operative metrics included total operative time, estimated blood loss, and use of blood transfusion (intra- or peri-operative). Peri-operative antibiotic data covered guideline adherence to prophylaxis and any postoperative courses administered before infection diagnosis.

2.3.4. Infection details

Time to infection was calculated as days from index surgery to first clinical diagnosis of a surgical-site infection (SSI). Depth was classified per CDC/NHSN criteria as superficial-incisional or deep/organ-space. Causative pathogens were extracted from culture reports. In addition, any SSI in which instrumentation was demonstrably colonized (purulence on hardware, positive implant culture, radiographic loosening or surgeon-judged device involvement) was coded as an implant-related infection (IRI). IRIs necessarily fulfil deep-incisional or organ/space criteria and were analyzed as a prespecified subset of the deep/organ-space group.

2.3.5. Post-infection outcomes

Follow-up records provided: (1) need for reoperation to manage the infection; (2) intensive-care-unit admission attributable to the SSI or its sequelae; (3) total length of stay, defined as days from original surgical admission through all subsequent infection-related hospitalizations; (4) 30-day readmission; and (5) all-cause mortality within 90 days of surgery. Reoperation was defined as any return to the operating room after the index infection-control procedure (debridement ± hardware removal) during the 90-day postoperative window.

2.3.6. Data quality control

Two independent reviewers cross-checked every data field. Discrepancies were reconciled by consensus using the original records to ensure accuracy and completeness.

2.4. Statistical analysis

Baseline and peri-operative variables were compared between superficial and deep/organ-space SSI groups. Distribution of continuous data was checked by Shapiro–Wilk; means ± SD or medians (IQR) were reported, while categorical data were expressed as frequencies and percentages. Student's t, Mann-Whitney U, and χ^2/Fisher tests identified factors ($p < 0.10$) entered, with clinically important covariates, into a multivariable logistic regression. Backward elimination retained predictors with $p < 0.05$; odds ratios (95% CI) are presented. Multicollinearity was excluded by variance-inflation factors. Discrimination (ROC-AUC) and calibration (Hosmer–Lemeshow) were evaluated, with 10-fold cross-validation to check over-fitting. Analyses used R 4.2.2 (pROC, caret); two-tailed $p < 0.05$ denoted significance.

3. Results

Table 1 presents the demographic and clinical profile of the 317

infected patients. The cohort was predominantly in the early 70s (71.0 ± 5.8 years), with women comprising 52.1%. Common cardiometabolic comorbidities included hypertension (54.3%) and diabetes mellitus (30.0%), while the mean BMI was 25.1 ± 3.2 kg/m^2. In this cohort, 20.5% participants were current smokers, and pre-operative hypo-albuminemia (< 35 g/L) was documented in 27.8% of cases. The median frailty index was 0.22 (IQR 0.15–0.29), indicating a largely prefrail-to-frail population.

Table 2 details operative variables, with Lumbar fusion was the most frequent procedure (56.2%), followed by cervical fusion (22.4%) and thoracic fusion (11.0%); decompression without fusion accounted for the remaining 10.4%. A minimally invasive approach was employed in 25.6% of cases. The average operative time was 180 ± 50 minutes, estimated blood loss 300 ± 110 mL, and 24.6% of patients required intra-operative transfusion. Multi-level surgery (≥ 3 levels) was performed in 25.2% of the cohort (Table 2).

The overall median time to infection onset was 12 days (IQR 7–19) (Table 3). Superficial surgical-site infection predominated (200/317; 63.1%), whereas deep or organ-space infection accounted for 117/317 (36.9%), of whom 27 (8.5%) met our definition of implant-related infection (Table 3). *Staphylococcus aureus* was the leading pathogen (40.4% of positive cultures), followed by *Escherichia coli* (15.8%) and coagulase-negative staphylococci (12.3%) (Table 3). Nearly one-third of episodes (29.7%) required surgical debridement and/or hardware removal in addition to antimicrobial therapy (Table 3).

Mean length of hospital stay for infected patients was 14.1 ± 5.2 days (Table 3). Re-admission for infection-related issues occurred in 24.6%, while 11.4% required intensive-care support (Table 3). Reoperation was necessary in 8.5%, and the infection-specific 90-day mortality was low at 1.6% (Table 3). Functional status at discharge, assessed by the Barthel Index, averaged 80.2 ± 10.5, indicating moderate independence, yet was significantly lower in the deep/organ-space subgroup (data not shown).

In the univariable logistic analysis, deep/organ-space infections occurred in older (72.1 ± 5.3 vs. 70.2 ± 6.0 yr, p = 0.008) and heavier patients (BMI 25.9 ± 3.3 vs. 24.6 ± 3.1 kg/m^2, p = 0.002) (Table 4). Diabetes (39.3% vs. 24.5%, p = 0.006), greater frailty (0.25 ± 0.10 vs.

Table 1
Baseline demographics and clinical characteristics of infected patients.

Characteristic	Infected (n = 317)
Age (years)	71.0 ± 5.8
Gener	
Male	152 (47.9%)
Female	165 (52.1%)
BMI (kg/m^2)	25.1 ± 3.2
Smoking history	
Current smoker	65 (20.5%)
Ever smoker	37 (11.67%)
Never smoker	205 (64.67%)
Diabetes mellitus	95 (30.0%)
Hypertension	172 (54.3%)
Coronary artery disease	46 (14.5%)
Chronic kidney disease	22 (6.9%)
Steroid use	18 (5.7%)
Frailty index	0.22 ± 0.10
Preoperative albumin (g/L)	36.5 ± 5.0
Hypo-albuminemia	88 (27.8%)
ASA classification	
I	15 (4.7%)
II	190 (59.9%)
III	102 (32.2%)
IV	10 (3.2%)

Table 2
Surgical and perioperative details among infected patients.

Variable	Infected (N = 317)
Type of surgery	
Lumbar fusion	178 (56.2%)
Cervical fusion	71 (22.4%)
Thoracic fusion	35 (11.0%)
Decompression only	33 (10.4%)
Minimally invasive approach	81 (25.6%)
Operative time (minutes)	180 ± 50
Estimated blood loss (mL)	300 ± 110
Number of levels operated	
1 level	140 (44.2%)
2 levels	97 (30.6%)
≥ 3 levels	80 (25.2%)
Intraoperative blood transfusion	78 (24.6%)
Prophylactic antibiotic regimen	
1st generation cephalosporin	240 (75.7%)
Others	77 (24.3%)
Hospital stay (days)	14.1 ± 5.2

Table 3
Infection characteristics and outcomes among infected patients.

Infection characteristic	Value
Time to infection (median days, IQR)	12 (7–19)
Superficial infection	200 (63.1%)
Deep infection	117 (36.9%)
Hardware not involved	90 (28.4%)
Implant-related infection	27 (8.5%)
Most common pathogens	
Staphylococcus aureus	40.4%
Escherichia coli	15.8%
Coagulase-negative staphylococci	12.3%
Pseudomonas aeruginosa	7.6%
Other or polymicrobial	23.9%
Additional Interventions	
Antibiotic therapy only	223 (70.3%)
Surgical debridement ± hardware removal	94 (29.7%)
Readmission for infection	78 (24.6%)
ICU admission	36 (11.4%)
Length of hospital stay (days)	14.1 ± 5.2
Prolonged wound drainage (> 7 days)	85 (26.8%)
Reoperation	27 (8.5%)
Infection-related mortality (within 90 days)	5 (1.6%)
Overall mortality (within 90 days)	13 (4.1%)
Functional status at discharge (Barthel Index)	80.2 ± 10.5

Table 4
Univariate analysis of superficial vs. deep/organ-space infections among the infected cohort.

Variable	Superficial (n = 200)	Deep/ organ-space (n = 117)	p-value
Age (years), mean ± SD	70.2 ± 6.0	72.1 ± 5.3	0.008
Female sex, n (%)	110 (55.0%)	55 (47.0%)	0.167
BMI (kg/m^2), mean ± SD	24.6 ± 3.1	25.9 ± 3.3	0.002
Diabetes mellitus, n (%)	49 (24.5%)	46 (39.3%)	0.006
Hypertension, n (%)	105 (52.5%)	67 (57.3%)	0.402
Coronary artery disease, n (%)	24 (12.0%)	22 (18.8%)	0.079
Frailty index, mean ± SD	0.20 ± 0.09	0.25 ± 0.10	< 0.001
Albumin (g/L), mean ± SD	37.0 ± 4.9	35.6 ± 5.1	0.003
Operative time (minutes)	168 ± 48	198 ± 55	< 0.001
≥ 3 levels operated, n (%)	34 (17.0%)	46 (39.3%)	< 0.001
Intraoperative transfusion, n (%)	37 (18.5%)	41 (35.0%)	0.001
Minimally invasive approach, n (%)	59 (29.5%)	22 (18.8%)	0.043
Time to onset (days), median (IQR)	9 (6–14)	15 (9–22)	< 0.001

0.20 ± 0.09, p < 0.001), and hypoalbuminemia (35.6 vs. 37.0 g/L, p = 0.003) were more common (Table 4). Deep cases also had longer operations (+30 min, p < 0.001), more multilevel constructs (39.3% vs. 17.0%, p < 0.001), and higher transfusion rates (35.0% vs. 18.5%, p = 0.001) (Table 4). Median onset was later (15 vs. 9 days, p < 0.001) (Table 4). Sex and cardiovascular comorbidity did not differ (Table 4).

Multivariable logistic regression (Table 5) identified eight independent determinants of deep/organ-space infection. No significant interaction terms were observed, and collinearity diagnostics were satisfactory (all variance-inflation factors < 2.5).

The final model demonstrated good discrimination, with an AUC of 0.82 (95% CI: 0.78–0.86) (Table 6). At the optimal probability threshold (Youden index), sensitivity for detecting deep/organ-space infection was 0.75, specificity 0.77, positive predictive value 0.65, and negative predictive value 0.85 (Table 6). Calibration was acceptable (Hosmer–Lemeshow $p = 0.38$), and mean AUC on 10-fold cross-validation was 0.80 ± 0.02, indicating stable internal validity (Table 6).

Deep/organ-space infection was associated with longer hospitalization (16.7 ± 5.9 vs. 12.3 ± 4.1 days, p < 0.001), higher re-operation rates (16.2% vs. 3.5%, p < 0.001), and greater ICU utilization (18.8% vs. 7.0%, $p = 0.002$) (Supplementary Table S2). Infection-related mortality remained low overall (4.3%) but was confined to the deep/organ-space group (Supplementary Table S2).

4. Discussion

Among 317 geriatric patients with postoperative spinal infections, deep/organ-space infections comprised 37%. A eight-variable multivariable model discriminated well between deep/organ-space and superficial infections (AUC ≈ 0.82). Focusing on an elderly cohort from a high-volume Chinese center and stratifying by infection depth addresses prior studies' mixed age ranges and depth-agnostic designs. This depth-specific risk profile sharpens understanding of infection in older adults and underscores the urgent need for targeted prophylactic and therapeutic strategies in geriatric spine surgery.

In line with prior mixed-age spine studies, our findings underscore the importance of age and BMI as significant contributors to postoperative infection risk in older patients. Notably, both variables exhibited robust effect sizes, consistent with evidence suggesting a linear increase in infection severity with advancing age and a 21% rise in SSI risk per 5-unit increment in BMI.[15,16] In our cohort, patients presenting with a higher BMI and advanced age had a particularly high likelihood of deep infections, which aligns with the concept of immunosenescence in older adults.[15] Diabetes mellitus further heightened susceptibility, consistent with established pathophysiological links between hyperglycemia, impaired neutrophil function, and microvascular compromise.[17,18] Frailty and hypoalbuminemia emerged as key predictors — paralleling geriatric orthopedic studies that identify these markers as essential indicators of postoperative complications.[19] The interplay of operative complexity factors was similarly corroborated by prior work highlighting tissue devitalization and increased bacterial inoculation risks.[20–22] Moreover, the depth-specific stratification in our study demonstrated that deep/organ-space infections correlated more strongly with these systemic and procedural burdens than superficial SSIs, corroborating reports that non-superficial infections often engender poorer clinical outcomes.[20,23]

Mechanistically, the confluence of frailty, malnutrition, and extended surgical durations can compromise host defenses, rendering older adults especially prone to infections. Our data revealed *S. aureus* as the predominant pathogen (40.4%), reflecting its recognized affinity for hardware-associated infections and capacity for biofilm formation.[24,25] These biofilms, which are complex, three-dimensional bacterial communities, protect pathogens from the host immune response and antibiotic penetration.[26,27] Coupled with the genetic diversity and virulence factors of *S. aureus*, including those that enable antibiotic resistance, such infections can require combined surgical and antimicrobial strategies, as advocated by the DAIR (Debridement, Antibiotics, and Implant Retention) approach.[28,29] Consequently, addressing both patient-specific risk factors and pathogen-related challenges is critical for reducing morbidity in geriatric spinal surgery.

Clinically, our findings suggest that comprehensive preoperative optimization — such as improving glycemic control, correcting malnutrition, and instituting frailty screening programs — may lower infection rates and facilitate recovery.[30–34] During the operative phase, adopting team briefings, standardized protocols, and blood-sparing measures can shorten surgical duration and minimize potential contamination.[35] Postoperative pathways that incorporate early wound surveillance, rigorous antibiotic stewardship, and geriatric rehabilitation have likewise shown promise in mitigating complications and expediting functional recovery.[33,36] Lastly, our eight-factor predictive model could be integrated into electronic medical records for real-time stratification and personalized resource allocation.[37] By tailoring interventions at each stage of the surgical continuum, this model facilitates evidence-based decision-making to improve outcomes and reduce the burden of postoperative spinal infections in older adults.

Strengths aside, this retrospective single-center study risks selection bias, lacks non-infected controls, and may not generalize beyond high-volume Chinese centers.

In conclusion, age, high BMI, diabetes, frailty, hypoalbuminemia, prolonged surgery, and multi-level procedures independently predict deep/organ-space SSIs in elderly spine patients. Our accurate model supports geriatric-focused perioperative strategies. Multicenter validation across diverse settings is needed to advance evidence-based, patient-centered spine care.

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Table 5
Multivariable logistic regression for deep/organ-space infection vs. superficial infection.

Predictor	Adjusted OR	95% CI	p-value
Age (per 1-year increase)	1.04	1.01–1.07	0.016
BMI (per 1 kg/m^2)	1.09	1.03–1.15	0.003
Diabetes mellitus (yes vs. no)	1.85	1.14–3.00	0.012
Frailty index	2.30	1.44–3.66	< 0.001
Albumin < 35 g/L	1.62	1.03–2.54	0.037
Operative time (per 30 min)	1.20	1.11–1.30	< 0.001
≥ 3 levels operated	2.24	1.37–3.66	0.001
Intraoperative transfusion	1.78	1.07–2.96	0.026

Table 6
Model performance indices (predicting deep/organ-space vs. superficial infection).

Metric	Value
AUC (95% CI)	0.82 (0.78–0.86)
Sensitivity (for deep infection)	0.75
Specificity (for superficial)	0.77
Positive predictive value (PPV)	0.65
Negative predictive value (NPV)	0.85
Hosmer–Lemeshow Test (p-value)	0.38
10-fold cross-validation mean AUC	0.80 ± 0.02

Ethical approval

The study was approved by the Ethics Committee of Guangzhou Hospital of Integrated Traditional and Western Medicine.

Conflict of interest

The authors have no conflicts of interest to declare.

Supplementary materials

Supplementary materials for this article can be found at http://www.sgecm.org.tw/ijge/journal/view.asp?id=37.

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