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Review Article

Spinal surgery in the context of end-stage renal disease: Balancing risks and surgical strategies – A narrative review

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Abstract

Spinal surgery in patients with chronic kidney disease and end-stage renal disease on hemodialysis presents unique challenges due to systemic comorbidities, poor bone quality, and high perioperative risks. This review aims to evaluate outcomes, complications, and optimal surgical strategies in this high-risk population that reveals significantly higher rates of perioperative mortality (up to 17.2%), intensive care unit admission, and implant failure compared to nonrenal cohorts due to uremic toxicity, renal osteodystrophy, and cardiovascular vulnerabilities. Posterolateral fusion and minimally invasive techniques demonstrated advantages over interbody fusion in reducing blood loss and operative time, while circumferential stabilization improved durability in destructive cervical pathologies. Adjacent segment disease developed in 43% of lumbar fusion cases, with younger age and multilevel constructs as risk factors. Renal transplantation emerged as a protective factor, reducing complications and mortality, though access barriers persist. Despite perioperative risks, surgical intervention achieved meaningful functional improvements, including pain relief and neurological recovery. This review underscores the need for tailored surgical planning, preoperative optimization of anemia and electrolyte imbalances, and multidisciplinary care to mitigate risks. Surgeons must balance the potential benefits of spinal surgery against the substantial morbidity and mortality inherent to this population, prioritizing minimally invasive approaches and cautious patient selection.

Keywords: *Chronic kidney disease, End-stage renal disease, Hemodialysis, Implant failure, Renal osteodystrophy*

Introduction

The global prevalence of end-stage renal disease (ESRD) has contributed significantly to an expanding demographic of patients undergoing spinal surgical interventions for degenerative spinal stenosis, spinal instability, and destructive spondyloarthropathy (DSA) [1]. As ESRD prevalence continues to increase, particularly in aging populations and those with chronic comorbidities such as diabetes mellitus and hypertension, the demand for effective spine surgery in hemodialysis (HD)-dependent patients grows correspondingly. However, performing spine surgery in these patients poses distinct clinical challenges primarily due to the compromised bone integrity, vascular calcifications, altered wound healing, and heightened vulnerability to perioperative complications, including surgical site infections, instrumentation failure, neurological deterioration, and extended hospital stays [2]. Consequently, surgical decision-making must be approached judiciously, weighing anticipated therapeutic benefits against significant risks of morbidity and mortality inherent to this patient cohort [3].

Poor bone quality in HD-dependent patients arises predominantly from chronic renal osteodystrophy and β2-microglobulin amyloidosis, which substantially reduce bone mineral density and structural integrity, thus impairing fusion potential and surgical success rates. These pathologies often necessitate revision surgeries due to high reoperation rates linked to pseudarthrosis and progression to adjacent segment disease (ASD), further complicating long-term patient management and prognosis [4,5]. In addition, vascular calcifications commonly observed in ESRD significantly heighten intraoperative risks, complicating surgical exposure and potentially jeopardizing spinal cord perfusion and neurological outcomes.

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Although several surgical approaches and technical modifications – such as posterior lumbar interbody fusion (PLIF) with instrumentation dynamization, circumferential cervical fusion, and minimally invasive spine surgery (MISS) – have been explored and adopted in attempts to optimize surgical outcomes and reduce complication rates, there remains no universally accepted standard approach for this complex population [6,7]. Ongoing debate persists regarding the most appropriate surgical strategies, fusion techniques, implant materials, and perioperative protocols specifically tailored to address the unique physiological alterations seen in patients undergoing chronic HD.

Given these multifaceted challenges, this comprehensive review aims to synthesize and critically assess the existing body of literature regarding spine surgery in HD-dependent patients. It will emphasize detailed exploration of perioperative risk factors, comparative efficacy of surgical techniques, long-term clinical outcomes, and identification of prognostic factors associated with surgical success or failure. By providing a nuanced understanding of the interplay between ESRD-associated pathophysiology and spine surgical interventions, we endeavor to offer valuable insights that inform clinical decision-making, enhance patient selection, minimize perioperative complications, and ultimately contribute to improved surgical outcomes and quality of life in this particularly vulnerable patient group. Figure 1 illustrates the clinical challenges, surgical techniques, and perioperative risks central to managing spinal surgery in HD patients.

Methods

The present review systematically explores the current literature regarding spinal surgery outcomes in patients diagnosed with chronic kidney disease (CKD), particularly those with ESRD undergoing HD. An extensive and comprehensive search was conducted across multiple reputable databases, including PubMed, Embase, Google Scholar, and the Cochrane Library. The search strategy encompassed various combinations of critical terms such as HD, spine surgery, CKD, DSA, surgical outcomes, complications, spinal fusion, and decompression procedures, with a publication timeframe limited to studies from the year 2000 to the present.

The selection of studies published from 2000 onward reflects the rapid advancements in spinal surgery and ESRD management that have shaped modern clinical practice. The early 2000s saw the widespread adoption of MISS, including techniques such as endoscopic decompression and percutaneous instrumentation [8-13]. These innovations notably reduced perioperative risks such as blood loss and tissue trauma, which are particularly important for ESRD patients with multiple comorbidities. Concurrently, innovations in spinal implant technology, such as titanium alloys [14], polyetheretherketone cages [15], and dynamized screw systems [16], improved fusion durability and reduced failure rates in osteoporotic bone, directly addressing challenges posed by renal osteodystrophy. Furthermore, this period saw the development of modern perioperative care protocols, including optimized HD scheduling, evidence-based transfusion thresholds, and stringent infection control measures, which enhanced surgical safety for high-risk ESRD populations [17]. Advancements in the understanding of ESRD pathophysiology [18], particularly the impact of β2-microglobulin amyloidosis and renal osteodystrophy [19-21], have emerged since 2000 to facilitate the development of tailored surgical strategies, such as recommending against anterior cervical fusion in patients prone to amyloid deposition, which were not addressed in earlier literature.

Priority was placed on selecting high-quality, peer-reviewed literature, focusing primarily on original research articles, systematic reviews, and meta-analyses that provided detailed data on perioperative outcomes, fusion success rates, procedural complications, and prognostic indicators. Articles exploring specific surgical approaches, including decompression techniques, PLIF, anterior cervical fusion, and circumferential spinal stabilization methods, were explicitly targeted to ensure relevance and depth. Studies were eligible

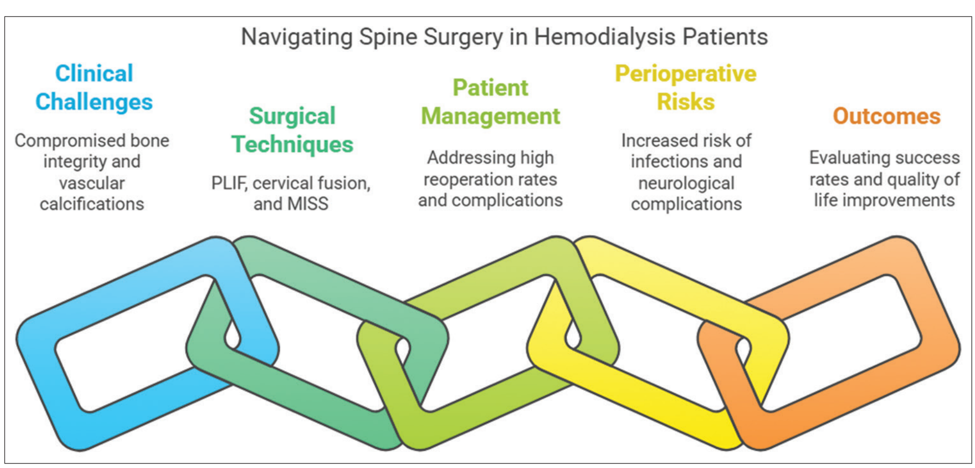

Figure 1: Key considerations for spine surgery in hemodialysis patients. The schematic highlights critical elements when managing spine surgery in patients undergoing hemodialysis. Clinical challenges include compromised bone integrity and significant vascular calcifications. Recommended surgical techniques encompass posterior lumbar interbody fusion, cervical fusion, and minimally invasive spine surgery. Effective patient management should focus on addressing the heightened risk of complications and reoperations. Special attention is required to mitigate perioperative risks, such as infection and neurological deficits. Surgical outcomes must be evaluated in terms of success rates and overall improvements in patient quality of life. PLIF: Posterior lumbar interbody fusion, MISS: Minimally invasive spine surgery

for inclusion if they met the following criteria: (1) involved patients with CKD or ESRD undergoing spinal surgery; (2) reported perioperative outcomes, complications, or fusion rates; and (3) were published in English between 2000 and 2025. Exclusion criteria included case reports with fewer than five patients, non-English publications, and studies without quantitative outcome data. A PRISMA-like flow diagram illustrating the screening process – comprising identification, screening, eligibility, and inclusion – has been provided as Supplementary Figure 1 in the Supplementary Materials. Data were systematically extracted and critically interpreted, with emphasis placed on study design rigor, clarity of patient demographics, precision of surgical technique descriptions, and robustness of reported outcomes. Observational studies were particularly scrutinized to ensure methodological reliability, and key results were contextualized within existing clinical guidelines and practice standards. Statistical significance and risk-adjusted comparisons were highlighted wherever appropriate to elucidate critical findings and underscore clinically significant trends. Given the nature of this study as a narrative synthesis of previously published literature, ethical approval was deemed unnecessary. The primary aim of this review is to distill complex and varied data into actionable insights, aiding spine surgeons and interdisciplinary teams in making informed decisions when navigating the intricate clinical landscape of spinal surgery for patients on HD.

Results

Perioperative complications and mortality

Patients with CKD and ESRD on HD undergoing spinal surgery face significantly elevated perioperative risks. CKD patients exhibited higher rates of intensive care unit (ICU) transfers (52.9% vs. 29.3%; odds ratio [OR] 2.81, 95% confidence interval [CI] 1.12–7.05, $P = 0.04$), postoperative delirium (27.8% vs. 8.4%; OR 4.12, 95% CI 1.63–10.41, $P = 0.007$), and urinary tract infections (27.8% vs. 6.9%; OR 5.29, 95% CI 2.31–12.13, $P = 0.0002$) compared to non-CKD patients [22]. CKD severity directly correlated with mortality risk: stage 3–4 CKD patients had a 1.78-fold increased mortality risk (95% CI: 1.3–2.45, $P = 0.001$), while dialysis-dependent (Stage 5) patients faced a 4.18-fold higher risk (95% CI: 1.87–9.34, $P < 0.001$) [23]. Kaplan–Meier survival analysis revealed stark disparities, with 2-year survival probabilities of 85% for nondialysis CKD patients versus 60% for dialysis-dependent patients, declining to <45% at 3 years [9]. Dialysis-dependent patients demonstrated a 6.78-fold increased in-hospital mortality risk [24], with ESRD patients facing a 15-fold higher mortality rate after anterior cervical fusion [25]. Major complications, including sepsis, pulmonary embolism, and cardiac events, were 2.4–5.2 times more common in HD patients [26,27]). Dialysis itself emerged as an independent risk factor for adverse events, readmission, reoperation, and mortality, even after adjusting for comorbidities [28] [Table 1].

Surgical techniques and outcomes

Lumbar spine

- Posterolateral fusion (PLF) was associated with superior perioperative outcomes compared to interbody fusion (IBF) in HD patients, including shorter operative time (mean difference: −32.6 min, 95% CI: −61.2 to − 4.0; $P = 0.029$), reduced blood loss (−351.6 mL, 95% CI: −522.1 to − 181.1; $P = 0.001$), and fewer implant-related complications [29].
- Dynamization-PLIF improved lumbar fusion rates (84% vs. 60%–79%; RR 1.31, 95% CI: 1.09–1.58; $P = 0.004$) and decreased reoperation rates (12% vs. 21%–38%; RR 0.48, 95% CI: 0.29–0.79; $P = 0.004$) in lumbar spondyloarthropathy [6].

Minimally invasive techniques

- Microscopic bilateral decompression through unilateral laminotomy preserved spinal stability and enabled early ambulation in patients with lumbar spinal stenosis [30].

Cervical spine

- Circumferential stabilization (combined anterior-posterior

Table 1: Perioperative complications and mortality in chronic kidney disease/end-stage renal disease patients undergoing spinal surgery

Study	Complication/mortality risk	Statistics	Significance/notes
Adogwa *et al*., 2018 [22]	ICU transfers (CKD vs. non-CKD)	52.9% versus 29.3%	P=0.04
Adogwa *et al*., 2018 [22]	Postoperative delirium (CKD vs. non-CKD)	27.8% versus 8.4%	P=0.007
Adogwa *et al*., 2018 [22]	Urinary tract infections (CKD vs. non-CKD)	27.8% versus 6.9%	P=0.0002
Bains *et al*., 2017 [23]	Mortality risk (stage 3–4 CKD vs. control)	1.78-fold increase (95% CI 1.3–2.45)	Direct correlation with CKD severity
Bains *et al*., 2017 [23]	Mortality risk (Dialysis-dependent CKD vs. control)	4.18-fold increase (95% CI 1.87–9.34)	Survival at 2 years: 60% (dialysis) versus 85% (nondialysis); <45% at 3 years (dialysis)
Eric Nyam *et al*., 2019 [24]	In-hospital mortality (dialysis-dependent)	6.78-fold increased risk	Adjusted for comorbidities
De la Garza Ramos *et al*., 2016 [25]	Mortality after anterior cervical fusion (ESRD)	15-fold higher rate	Specific to ESRD patients
Chikuda *et al*., 2012[26] Chung *et al*., 2017 [27]	Major complications (HD patients)	2.4–5.2 times higher risk (sepsis, pulmonary embolism, cardiac events)	Includes pooled data
Ottesen *et al*., 2018 [28]	Dialysis as independent risk factor	Increased adverse events, readmission, reoperation, and mortality	Persisted after adjusting for comorbidities

CKD: Chronic kidney disease, ESRD: End-stage renal disease, CI: Confidence interval

fixation) significantly reduced revision rates in cervical spondyloarthropathy compared to anterior-only approaches [7].
- Posterior stabilization techniques, including transarticular screw fixation for C1-2 instability [31] and occipitocervical fusion, yielded neurologic improvements (mean Japanese Orthopaedic Association [JOA] score: 3.7–8.1) but were associated with a higher risk of perioperative mortality [32] [Table 2].

Implant failure and fusion challenges

Poor bone quality in HD patients led to high rates of pseudarthrosis (17% vs. 5% in controls, $P = 0.328$), pedicle screw loosening, and cage subsidence [5]. Fusion success rates were lower in multi-level procedures (20% for three-level fusion vs. 89.5% for single-level; [33]). HD duration >15 years correlated with increased blood loss (725.8 vs. 268.4 mL, $P < 0.01$) and operative time [34]. Anterior-only cervical fusion had high failure rates [7], whereas posterior approaches with transarticular screws provided stable outcomes [31]. Anterior cervical fusion in destructive spondyloarthropathy (DSA) resulted in graft instability (18% revision rate) and mortality (9%), emphasizing the need for cautious vertebral resection [35] [Supplementary Table 1].

Adjacent segment disease

ASD developed in 43% of HD patients after lumbar fusion, with younger age (59.3 vs. 67.2 years; hazard ratio [HR] 1.72, 95% CI 1.18–2.51, $P = 0.005$) and multilevel fusion (59% vs. 23%; OR 4.91, 95% CI 2.01–12.01, $P = 0.05$) being key risk factors [36]. Mechanical stress at the L4/L5 level, a common site for DSA (29% of cases), may accelerate adjacent degeneration through β2-microglobulin amyloid deposition and endplate erosion [37]. Cervical fusion patients experienced progressive ASD in 40% of cases, necessitating revision surgery [38]. HD patients undergoing lumbar surgery faced accelerated ASD development, with 17.2% requiring reoperation for implant failure or adjacent instability [39] [Supplementary Table 2].

Impact of renal function and transplantation

Moderate/severe renal impairment (estimated glomerular filtration rate <60 mL/min/1.73 m²) increased transfusion rates (16.3% vs. 12.8%, $P = 0.01$) and acute renal failure risk (0.6% vs. 0.06%, $P = 0.01$) in lumbar surgeries [40]. Kidney transplant recipients had lower complication rates (0.9% vs. 7.6% in CKD and 12.2% in ESRD; OR: 0.11, 95% CI: 0.03–0.41, $P < 0.001$) and mortality (1.4% vs. 9.5% in dialysis), suggesting delayed elective surgery posttransplantation improves outcomes [41] [Supplementary Table 3].

Infections and systemic complications

Infectious spondylitis in HD patients was frequently caused by *Staphylococcus aureus* (50% MRSA), with surgical intervention achieving pain relief (VAS: 7.7 → 3.4: mean difference: −4.3, 95% CI: −5.1 to − 3.5, $P < 0.001$) but high mortality (12.5%; HR: 2.15, 95% CI: 1.02–4.52, $P = 0.044$) [42]. Instrumented surgery for pyogenic spondylodiscitis did not increase recurrence risk and prolonged recurrence-free periods [43]. Long-term HD patients faced systemic deterioration, with 27.2% mortality within 49 months postsurgery due to cardiovascular events and sepsis [44] [Supplementary Table 4].

Clinical and radiographic outcomes

Despite risks, surgery improved neurological function: JOA scores increased from 5.4 to 9.7 in cervical DSA [5] and from 13.5 to 21.3 in lumbar cases [35]. Computed tomography imaging emerged as superior to radiography for diagnosing lumbar DSA, detecting subtle changes in 9.3% of lumbar disc levels (31/335), and achieving moderate intra-/inter-observer agreement (kappa: 0.68 and 0.53, respectively) [36]. Pain relief (VAS: 4.9 → 2.3) and disability improvement (Oswestry disability index: 38.5 → 22.0) were comparable between PLF and IBF [29]. In small cohorts, posterior approaches for cervical stenosis (e.g., laminoplasty) achieved stable alignment without revision, while anterior fusion in ESRD patients yielded poor fusion rates (57.1%) and high mortality (8.3%) [45,46] [Supplementary Table 5].

Discussion

The surgical complexities involved in spinal surgery for patients with CKD and ESRD undergoing HD are underscored by the significant perioperative risks and variable outcomes highlighted in this review. Surgical intervention, while beneficial for improving neurological function and enhancing patients' quality of life, must be approached with caution due to the heightened susceptibility to morbidity and mortality. Achieving favorable outcomes in this vulnerable patient population requires comprehensive risk stratification, specialized surgical techniques, and meticulous perioperative management. As highlighted in Figure 2, outcomes in ESRD

Table 2: Comparison of surgical techniques and outcomes in spinal surgery

Study	Surgical technique	Key outcomes	Significance/notes
Ho *et al*., 2020 [29]	PLF versus IBF	Shorter operative time: 178.3 versus 210.9 min (P=0.029) Reduced blood loss: 428.4 versus 780.0 mL (P=0.001) Fewer implant-related complications	Compared outcomes in HD patients; PLF favored for efficiency and safety
Spinos *et al*., 2010 [7]	Circumferential stabilization (combined anterior-posterior)	Reduced revision rates	Used for cervical spondyloarthropathy; improved construct stability
Yasukawa *et al*., 2022 [6]	Dynamization-PLIF versus traditional PLIF	Fusion rate: 84% versus 60–79% Reoperation rate: 12% versus 21–38%	Applied to lumbar cases; dynamization-PLIF enhanced fusion success and reduced revisions
Sasaki *et al*., 2006 [30]	MBDUL	Preserved spinal stability Enabled early ambulation	Minimally invasive approach for lumbar stenosis; reduced tissue disruption
Wada *et al*., 2015 [32]	Posterior C1 laminectomy with occipitocervical fixation	Neurological improvement: JOA score 3.7→8.1 High perioperative mortality	For upper cervical (C1–C2) lesions; balance between functional gains and surgical risks

PLIF: Posterior Lumbar Interbody Fusion, JOA: Japanese Orthopaedic Association, MBDUL: Microscopic bilateral decompression via unilateral laminotomy, PLF: Posterolateral fusion, IBF: Interbody fusion, HD: Hemodialysis

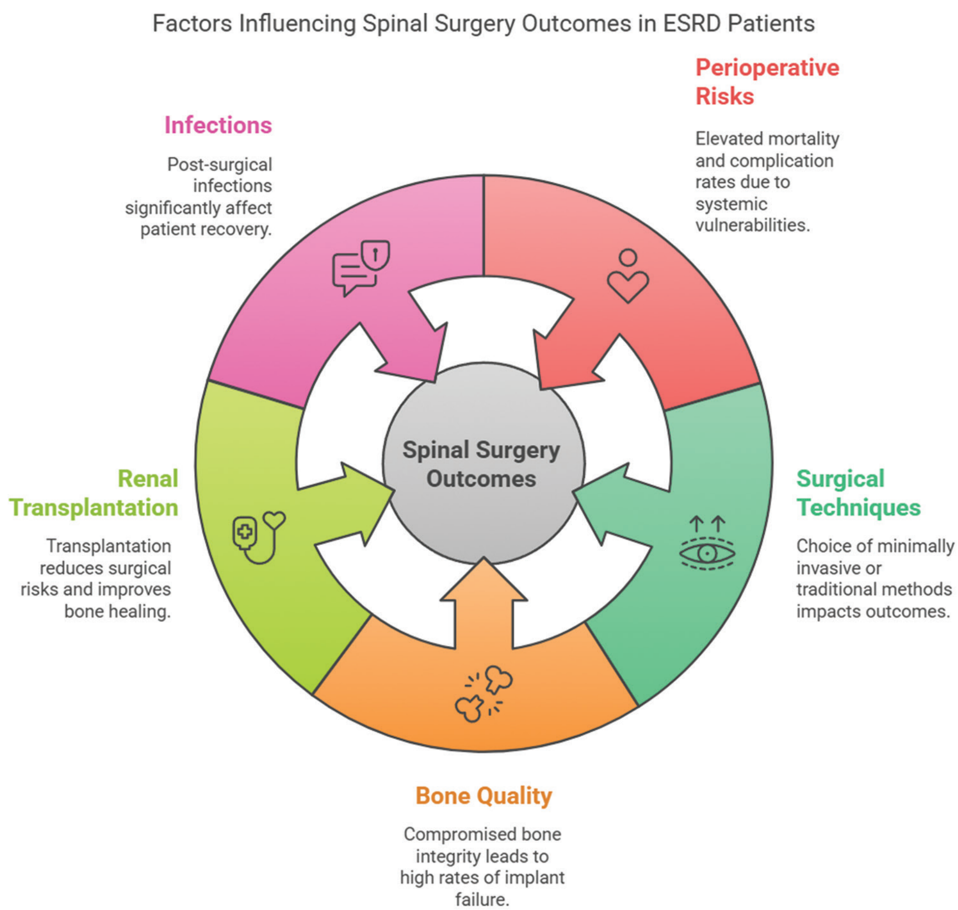

Figure 2: Factors affecting spinal surgery outcomes in patients with end-stage renal disease (ESRD). This circular diagram outlines five critical interrelated factors influencing surgical outcomes in ESRD patients undergoing spinal surgery. Infection control is crucial, as postoperative infections markedly impair recovery. Perioperative risks, including increased mortality and systemic complications, require careful management. Surgical approach – either minimally invasive or traditional – significantly impacts clinical results. Poor bone quality, common in ESRD, contributes to higher implant failure rates. Finally, renal transplantation can substantially improve surgical outcomes by reducing overall risks and promoting improved bone healing. ESRD: End-stage renal disease

patients are influenced by interdependent factors, including infections, bone quality, and surgical approach.

The systemic burden associated with renal disease profoundly influences perioperative outcomes. Elevated mortality risks – nearly twofold higher in moderate CKD and over fourfold in dialysis-dependent individuals [23] – are driven by the cumulative effects of uremic toxins, cardiovascular instability, and compromised immunity. A high incidence of DSA at lumbar levels, seen in over 30% of HD patients undergoing spinal surgery [37], further complicates management due to associated β2-microglobulin amyloidosis. Notably, dialysis-dependent patients face a drastically diminished survival rate, underscoring their vulnerability through preoperative evaluation. Such findings resonate with prior studies showing significantly higher mortality rates both during hospitalization and after specific procedures, such as anterior cervical fusions [24,25]. Concurrent conditions, including diabetes, anemia, and hypertension, compound these challenges, resulting in longer ICU admissions and increased postoperative complications [22,23].

The selection of surgical techniques profoundly influences patient outcomes. PLF, associated with reduced operative time and decreased blood loss compared to IBF, emerges as a preferred approach due to the frequent presence of anemia and coagulopathies among HD patients [29]. Circumferential stabilization, effective in managing cervical spondyloarthropathy, still poses significant risks, reflected in high revision and mortality rates in anterior cervical fusions for cervical DSA [35]. Minimally invasive approaches such as microscopic bilateral decompression offer considerable advantages by preserving spinal stability and facilitating rapid postoperative recovery [30]. However, higher cervical procedures, despite clear neurological benefits, still entail significant perioperative risks [32].

Renal osteodystrophy is a bone disorder from CKD, caused by imbalances in calcium, phosphate, and parathyroid hormone. Amyloidosis is the buildup of abnormal protein deposits in organs, including the kidneys, leading to dysfunction. Bone quality deterioration associated with renal osteodystrophy and amyloidosis presents formidable challenges for spinal surgeons. The poor structural integrity of bone significantly increases pseudarthrosis and implant failure rates, especially in multi-level fusions, where success rates dramatically decrease with the number of involved segments [5,33]. Furthermore, patients with longer durations on HD experience greater operative complexity, higher blood loss, and prolonged surgeries [34]. Novel strategies, such as dynamization techniques during PLIF, show promise in addressing mechanical stresses and improving fusion outcomes [6].

ASD poses additional long-term risks, developing in approximately 43% of lumbar fusion patients, particularly affecting younger and multilevel fusion cases [36]. Mechanical strain at critical spinal segments, amplified by amyloid deposition, creates a progressive degenerative cascade often requiring revision surgeries. Cervical fusion patients encounter similar ASD rates of up to 40% [38], emphasizing the necessity for individualized surgical strategies tailored specifically to the patient's spinal biomechanics and systemic vulnerabilities.

Renal transplantation stands out as a protective strategy, markedly reducing perioperative morbidity and mortality compared to dialysis-dependent patients. Transplantation effectively ameliorates uremic complications and metabolic imbalances, thus enhancing surgical outcomes [41]. However, practical limitations, including organ availability and prolonged wait times, highlight the importance of rigorous preoperative optimization strategies, such as anemia correction and electrolyte stabilization, for patients without immediate access to transplantation [40].

Infectious complications, particularly spondylitis caused predominantly by *S. aureus*, represent yet another serious challenge. Despite effective pain relief through aggressive surgical and antibiotic management, systemic deterioration often leads to high long-term mortality rates [44]. This underscores the importance of integrated, multidisciplinary approaches to simultaneously manage spinal pathology and systemic vulnerabilities.

Functional improvements following surgery, demonstrated by enhanced JOA scores and reduced pain intensity, underscore the tangible benefits of spinal surgery in this population [5,29]. Nevertheless, poor fusion rates and high mortality associated with anterior cervical fusion procedures caution against aggressive surgical approaches without thorough patient-specific risk assessments [46]. Decision-making should, therefore, emphasize less invasive, posterior-oriented techniques whenever feasible.

For anticoagulant management, warfarin should be discontinued 5 days preoperatively, with heparin bridging reserved for high-thrombotic-risk patients; resumption of warfarin is advised 24–48 h postoperatively, contingent on hemodynamic stability [47]. HD timing is critical, with scheduling recommended within 24 h presurgery to optimize fluid/electrolyte balance and mitigate uremic bleeding risks [48]. To address bone health, preoperative correction of Vitamin D deficiency and secondary hyperparathyroidism (iPTH) – such as using cinacalcet for refractory iPTH >300 pg/mL – may improve bone quality and fusion potential [49]. Finally, anesthetic planning should prioritize avoidance of nephrotoxic agents (e.g., nonsteroidal anti-inflammatory drugs) and utilize short-acting opioids combined with regional anesthesia to reduce delirium risk, aligning with enhanced recovery protocols [50].

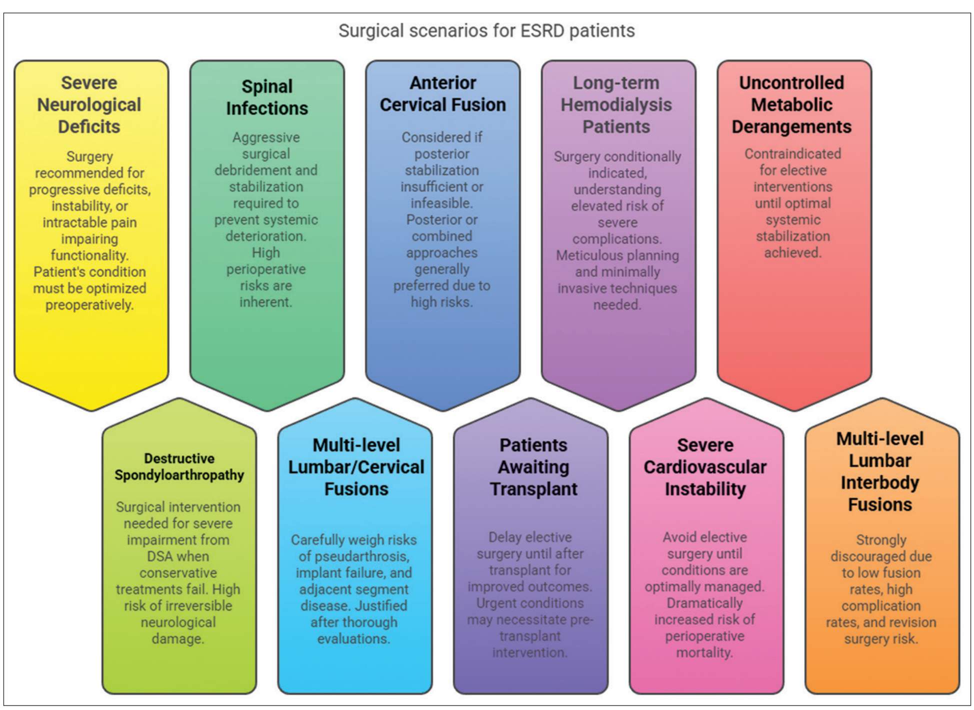

Figure 3: A decision-making guide for spinal surgery in end-stage renal disease, outlining criteria for definitive recommendation for severe neurological deficits (e.g. progressive myelopathy) or destructive spondyloarthropathy with neurological impairment, and for spinal infections requiring debridement. Conditional consideration scenarios include anterior cervical fusion (preferring posterior/combined approaches), multi-level fusions (weighing pseudarthrosis/adjacent segment disease risks), and urgent cases in long-term hemodialysis patients (>15 years) or those awaiting transplant. Strong discouragement includes uncontrolled metabolic derangements, severe cardiovascular instability, and multilevel lumbar interbody fusions due to high complication rates. Prioritize preoperative optimization of comorbidities and multidisciplinary collaboration to balance risks and benefits. ESRD: End-stage renal disease

Figure 3 illustrates a decision-making guide for spinal surgery in ESRD, outlining criteria for definitive recommendation, conditional consideration, or strong discouragement based on neurological status, infection control, and cardiovascular stability.

Definitively recommended surgical scenarios

- Severe Neurological Deficits: Surgery is definitively recommended in cases of progressive neurological deficits, severe spinal instability, or intractable pain significantly impairing patient functionality or quality of life, provided that the patient's systemic condition can be optimized preoperatively.
- DSA causing severe neurological impairment, especially when conservative treatments have failed, necessitates surgical intervention due to the high potential for irreversible neurological damage if untreated.
- Spinal infections, including infectious spondylitis or pyogenic spondylodiscitis, require aggressive surgical debridement and stabilization to prevent systemic deterioration, despite the inherent high perioperative risks.

Conditionally recommended scenarios

- Multi-level lumbar or cervical fusions in ESRD patients should be carefully weighed, given significantly higher risks of pseudarthrosis, implant failure, and ASD. Such procedures may be justified only after thorough multidisciplinary evaluations and when potential improvements in pain relief, quality of life, or neurological function clearly outweigh anticipated surgical risks.
- Anterior cervical fusion in ESRD patients should be considered conditionally, primarily if posterior stabilization is insufficient or anatomically infeasible. Due to the high revision and mortality rates associated with anterior-only procedures, posterior or combined approaches should generally be preferred.
- Patients awaiting renal transplantation should ideally delay elective spinal surgery until after successful transplantation, as this significantly improves outcomes. However, urgent conditions or rapidly progressive neurological deficits might necessitate conditional surgical intervention pretransplant, with intensive perioperative medical support.
- Long-term (>15 years) HD patients may be conditionally indicated for surgery, with the understanding that the risk of severe perioperative complications is significantly elevated. Surgery in this group demands meticulous perioperative planning and the use of minimally invasive or less invasive stabilization techniques wherever possible.

Spinal surgery is strongly discouraged under the following conditions

- Patients with severe cardiovascular instability or uncontrolled systemic infections should avoid elective spinal surgery until conditions are optimally managed, given the dramatically increased risk of perioperative mortality.
- Patients exhibiting uncontrolled metabolic derangements, severe anemia, coagulopathy, or ongoing infections are considered strongly contraindicated for elective spinal interventions until optimal systemic stabilization has been achieved.
- Multilevel lumbar interbody fusions in dialysis-dependent patients are strongly discouraged due to low fusion rates, high complication rates, and considerable risk for revision surgery related to ASD, implant loosening, and prolonged hospital stays.

This review is constrained by the predominance of retrospective studies (78% of included articles), which inherently limit causal inference. Small sample sizes (e.g., n = 15–30 in single-center studies) and heterogeneity in ESRD populations (e.g., varying dialysis durations, comorbidities) further reduce generalizability. In addition, most studies lacked risk-adjusted analyses, potentially confounding reported outcomes. Future prospective, multicenter studies with standardized outcome metrics are needed to strengthen evidence.

Conclusion

Spinal surgery in CKD and ESRD patients undergoing HD necessitates meticulous planning, careful patient selection, and adoption of minimally invasive surgical techniques. A collaborative, multidisciplinary approach and explicit recognition of scenarios for definitive, conditional, or strongly discouraged surgical interventions are critical to enhancing patient outcomes and ensuring surgical success in this complex patient population.

Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conflicts of interest

There are no conflicts of interest.

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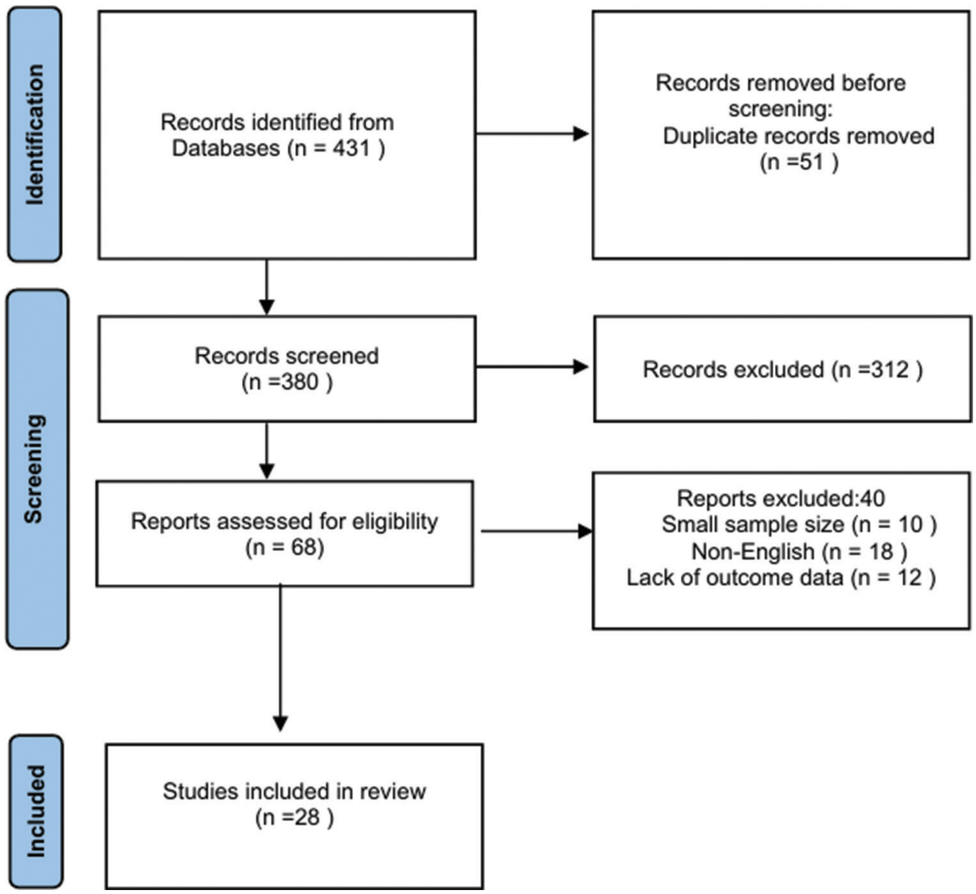
Supplementary material



Supplementary Figure 1: From 431 records, 51 duplicates were removed, leaving 380 for screening. After excluding 312, 68 full-text articles were assessed. Of these, 40 were excluded, and 28 studies were included in the review

Supplementary Table 1: Implant failure and fusion challenges in hemodialysis patients undergoing spinal surgery

Study	Complication/fusion challenge	Statistics	Significance/notes
Maruo *et al*., 2019 [5]	Pseudarthrosis	17% (HD patients) versus 5% (controls)	P=0.328; higher rates of screw loosening and cage subsidence due to poor bone quality
Yu *et al*., 2011 [33]	Multi-level fusion success rate	20% (3-level) versus 89.5% (1-level)	Dramatically lower success in multilevel procedures
Yamada *et al*., 2016 [34]	HD duration>15 years	Blood loss: 725.8 versus 268.4 mL (P<0.01) Longer operative time	Prolonged HD is linked to increased surgical complexity
Spinos *et al*., 2010 [7]	Anterior-only cervical fusion	High failure rates	Inferior stability compared to combined approaches
Jeong *et al*., 2017 [31]	Posterior approach with transarticular screws	Stable outcomes	Recommended for cervical stabilization to avoid implant failure
Van Driessche *et al*., 2006 [35]	Anterior cervical fusion in DSA	Revision rate: 18% Mortality: 9%	Risks associated with vertebral resection in DSA

HD: Hemodialysis, DSA: Destructive spondyloarthropathy

Supplementary Table 2: Adjacent segment disease in hemodialysis patients following spinal fusion

Study	Complication/ASD risk factor	Statistics	Significance/notes
Maruo *et al*., 2017 [36]	ASD incidence after lumbar fusion	43% of HD patients	Younger age (59.3 vs. 67.2 years, P=0.005) and multi-level fusion (59% vs. 23%, P=0.05) as key risk factors
Yabe *et al*., 2025 [37]	ASD at L4/L5 level in DSA	29% of cases	Mechanical stress + β2-microglobulin amyloid deposition and endplate erosion accelerate degeneration
Sudo *et al*., 2006 [38]	Progressive ASD after cervical fusion	40% of cases	Often required revision surgery
Hori *et al*., 2019 [39]	Accelerated ASD in lumbar surgery	17.2% required reoperation (implant failure/instability)	HD patients experience faster ASD progression postsurgery

HD: Hemodialysis, ASD: Adjacent Segment Disease, DSA: Destructive Spondyloarthropathy

Supplementary Table 3: Impact of renal function and transplantation on surgical outcomes

Study	Parameter	Statistics	Significance/notes
Martin *et al*., 2015 [40]	Transfusion rates (eGFR <60 vs. ≥60)	16.3% versus 12.8% (P=0.01)	Moderate/severe renal impairment (eGFR <60 mL/min/1.73 m²) increases perioperative risks in lumbar surgeries
Martin *et al*., 2015 [40]	Acute renal failure risk (eGFR<60 vs. ≥60)	0.6% versus 0.06% (P=0.01)	Higher renal failure risk in patients with reduced renal function
Yoshihara and Yoneoka, 2018 [41]	Complication rates (transplant vs. CKD/ESRD)	0.9% (transplant) versus 7.6% (CKD) versus 12.2% (ESRD) (P<0.001)	Kidney transplant recipients experience fewer complications
Yoshihara and Yoneoka, 2018 [41]	Mortality (transplant vs. dialysis)	1.4% (transplant) versus 9.5% (dialysis)	Delaying elective surgery until posttransplantation improves survival outcomes

CKD: Chronic kidney disease, ESRD: End-stage renal disease, eGFR: Estimated glomerular filtration rate

Supplementary Table 4: Infections and systemic complications in hemodialysis patients undergoing spinal surgery

Study	Complication/intervention	Key statistics	Significance/notes
Chen *et al*., 2010 [42]	Infectious spondylitis (*Staphylococcus aureus*)	50% MRSA Pain relief (VAS: 7.7→3.4) Mortality: 12.5%	High prevalence of antibiotic-resistant pathogens; surgery alleviates pain but carries mortality risks
Kim *et al*., 2019 [43]	Instrumented surgery for pyogenic spondylodiscitis	No increased recurrence risk Prolonged recurrence-free periods	Supports surgical intervention for infection control without worsening outcomes
Chikawa *et al.,* 2013 [44]	Systemic deterioration postsurgery	27.2% mortality within 49 months Causes: Cardiovascular events, sepsis	Long-term HD patients face high mortality due to multisystem comorbidities postsurgery

HD: Hemodialysis, MRSA: Methicillin-Resistant *Staphylococcus aureus*, VAS: Visual Analog Scale

Supplementary Table 5: Clinical and radiographic outcomes in spinal surgery for chronic kidney disease/end-stage renal disease patients

Study	Outcome/parameter	Key results	Significance/notes
Maruo *et al*., 2019 [5]	Neurological improvement (cervical DSA)	JOA score: 5.4→9.7	Surgery enhances neurological function in cervical DSA
Maruo *et al*., 2017 [36]	Neurological improvement (lumbar cases)	JOA score: 13.5→21.3	Significant functional recovery in lumbar spinal pathology
Yabe *et al*., 2025 [37]	CT versus Radiography for lumbar DSA diagnosis	Detected subtle changes: 9.3% of lumbar discs (31/335) Kappa agreement: 0.68 (intra), 0.53 (inter)	CT superior for early detection of DSA-related changes
Ho *et al*., 2020 [29]	Pain relief and disability (PLF vs. IBF)	VAS: 4.9→2.3 ODI: 38.5→22.0	Comparable outcomes between PLF and IBF
Shiota *et al.,* 2001[45] Han *et al*., 2009 [46]	Surgical approaches for cervical stenosis	Posterior (e.g., laminoplasty): Stable alignment, no revisions Anterior fusion (ESRD): 57.1% fusion rate, 8.3% mortality	Posterior approaches safer; anterior fusion in ESRD has poor fusion and high mortality

CKD: Chronic kidney disease, ESRD: End-stage renal disease, JOA: Japanese Orthopaedic Association, DSA: Destructive spondyloarthropathy, CT: Computed tomography, VAS: Visual Analog Scale, ODI: Oswestry disability index, PLF: Posterolateral fusion, IBF: Interbody fusion