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Perioperative challenges in spine surgery among patients with chronic kidney disease

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ABSTRACT

Chronic kidney disease (CKD) is a global health concern that significantly complicates the perioperative management of patients undergoing spine surgery. CKD patients face heightened risks due to multisystem involvement, including fluid and electrolyte imbalances, coagulopathy, impaired bone metabolism, increased infection susceptibility, and altered drug pharmacokinetics. This narrative review synthesizes current evidence to delineate the perioperative risks and management strategies for CKD patients undergoing spine surgery. Key areas addressed include anesthesia considerations, fluid and electrolyte management, bleeding and coagulopathy, infection risk, bone quality and instrumentation challenges, acute kidney injury (AKI) incidence and prevention, postoperative outcomes, preoperative optimization, medication adjustments, hemodynamic monitoring, dialysis timing, thrombosis risk, perioperative imaging, and enhanced recovery after surgery protocols. The review of evidence indicates that spine surgery in patients with CKD requires careful, multidisciplinary perioperative management. Individualized optimization, advanced monitoring, and tailored protocols are key to reducing complications and improving outcomes.

Review

Implication for health policy/practice/research/medical education:
Patients with chronic kidney disease (CKD) who undergo spine surgery face significant and complex perioperative challenges. Their care demands a coordinated, multidisciplinary strategy that emphasizes personalized risk assessment, careful management of fluids and electrolytes, customized anesthetic planning, and the application of enhanced recovery protocols. Through thorough preoperative preparation and the use of advanced monitoring, clinicians can reduce complications and improve both immediate and long-term results. Ongoing investigation and refinement of perioperative practices remain vital to meet the specific needs of this high-risk population and to promote safer surgical outcomes.

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Introduction

Chronic kidney disease (CKD) affects approximately 9–16% of the global population, with prevalence rising due to aging demographics and increased rates of diabetes and hypertension (1-3). It is characterized by progressive loss of renal function, leading to multisystem complications that profoundly impact perioperative risk profiles (1,4). As life expectancy improves and access to renal replacement therapies expands, more CKD patients are presenting for spine surgery, including complex procedures such as spinal fusion, deformity correction, and instrumentation (1). Spine surgery in CKD patients is associated with increased morbidity and mortality, driven by factors such as impaired bone metabolism, heightened infection risk, bleeding diathesis, fluid and electrolyte disturbances, and altered drug handling (1,5,6). The perioperative period is particularly challenging due to the interplay of CKD-related pathophysiology and surgical stress. This review aims to provide a comprehensive synthesis of current evidence on perioperative challenges and management strategies for CKD patients undergoing spine surgery, with a focus on optimizing outcomes through multidisciplinary, individualized care.

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Search strategy

A comprehensive literature search was conducted across PubMed, Scopus, Web of Science, Embase, and Google Scholar to identify articles addressing perioperative challenges in spine surgery among patients with CKD. Keywords used in the search included 'chronic kidney disease', 'acute kidney injury', 'Dialysis', 'Spine surgery', 'Perioperative risk', 'Anesthesia', 'Fluid management', 'Coagulopathy', and 'infection'. Boolean operators (AND, OR) were applied to refine results, and filters were set to include only human studies published in English. The final selection prioritized clinical trials, observational studies, systematic reviews, and narrative reviews that specifically addressed perioperative risks, anesthetic considerations, fluid and electrolyte management, bleeding and coagulopathy, infection, and postoperative outcomes in CKD patients undergoing spine surgery.

General risks

Patients with CKD undergoing surgery face significantly higher perioperative risks than the general population. They are more prone to acute kidney injury (AKI), bleeding, infection, poor bone quality, fluid and electrolyte disturbances, altered drug handling, cardiovascular-specific mortality, and thromboembolic events. These vulnerabilities contribute to longer hospital stays, higher reoperation rates, and increased mortality (7-9). Meta-analyses confirm that CKD and dialysis patients have markedly greater odds of complications such as deep vein thrombosis, pulmonary embolism, surgical site infection, sepsis, reoperation, and in-hospital death compared with non-CKD controls (1).

Perioperative risk stratification

Risk stratification in CKD patients should be comprehensive, incorporating CKD stage, comorbidities (e.g., diabetes, cardiovascular disease, and anemia), nutritional status, bone quality, and functional capacity (1,10). Preoperative assessment should include:

- Detailed history and physical examination
- Laboratory evaluation: Estimated glomerular filtration rate (eGFR), albuminuria, electrolytes, hemoglobin, coagulation profile, bone metabolism markers (Parathyroid hormone [PTH], calcium, phosphate, vitamin D)
- Imaging: Dual-energy X-ray absorptiometry (DEXA) for bone density, magnetic resonance imaging (MRI) for bone marrow composition, and assessment of vascular calcification
- Functional assessment: Cardiopulmonary fitness, frailty, and nutritional status

Multidisciplinary team involvement (nephrology, anesthesiology, orthopedics, and endocrinology) is recommended for complex cases, particularly those with advanced CKD, dialysis dependence, or severe bone disease (11).

Anesthesia considerations

General principles

Anesthetic management in CKD patients requires careful selection of agents, dosing adjustments, and vigilant monitoring due to altered pharmacokinetics, increased risk of hemodynamic instability, and susceptibility to drug-induced nephrotoxicity. Both general anesthesia and neuraxial techniques (spinal anesthesia) are used in spine surgery, with emerging evidence supporting the feasibility and benefits of spinal anesthesia in selected cases (12-14).

Spinal vs. general anesthesia

Recent studies suggest that spinal anesthesia may offer several advantages over general anesthesia for spine surgery, including:

- Superior immediate postoperative analgesia
- Potential reductions in intraoperative blood loss
- Faster operating room egress
- Decreased rates of postoperative nausea and vomiting
- Reduced anesthesia time, minimized medication use, and improved cost efficiency

However, evidence regarding hemodynamic stability, postoperative outcomes, and hospital length of stay is mixed, and patient selection is crucial (12,13).

Airway management

Airway management in the prone position for most of the spine surgery, especially under spinal anesthesia with sedation, requires meticulous planning and vigilance. Advanced airway adjuncts (video-laryngoscope, bronchoscope) should be readily available, and contingency plans for emergent airway access must be established (12,15).

Hemodynamic monitoring

Advanced hemodynamic monitoring (e.g., continuous non-invasive blood pressure, cardiac output, and stroke volume variation) is recommended to guide fluid and vasopressor therapy, detect hypotension early, and optimize organ perfusion. Goal-directed therapy, individualized to patient needs, can reduce the incidence of AKI and other complications (16).

Fluid and electrolyte management

Pathophysiology

CKD impairs the kidneys' ability to regulate fluid, electrolyte, and acid-base balance, leading to common perioperative complications such as hypervolemia and fluid overload, hyponatremia and hypernatremia, hyperkalemia, hyperphosphatemia and hypocalcemia, andmetabolic acidosis.

These disturbances exacerbate cardiovascular, neuromuscular, and bone complications and increase perioperative morbidity and mortality (17).

Fluid therapy strategies

Three main strategies are described:

- Liberal fluid therapy: Traditional approach, associated with risk of fluid overload and pulmonary edema
- Restrictive fluid therapy: Aims for net zero balance; may increase risk of renal hypoperfusion and AKI
- Goal-directed therapy: Individualized fluid administration based on dynamic hemodynamic parameters; shown to optimize outcomes and reduce AKI incidence.

Recent evidence favors goal-directed therapy, using minimally invasive monitors (esophageal Doppler, arterial waveform analysis) to guide therapy and avoid both hypovolemia and hypervolemia. (16).

Electrolyte management

Preoperative optimization of electrolyte status is essential, and intraoperative monitoring should be continuous, with prompt correction of abnormalities.

- Hyperkalemia: Managed with preoperative dialysis, avoidance of potassium-sparing drugs, and intraoperative monitoring; succinylcholine avoided if serum potassium ≥5.5 mEq/L (18).
- Hyperphosphatemia and hypocalcemia: Controlled with dietary modifications, phosphate binders, and vitamin D supplementation; secondary hyperparathyroidism is addressed to prevent bone disease (19).
- Metabolic acidosis: May require dialysis or bicarbonate therapy preoperatively (20).

Dialysis timing

Emerging evidence indicates that the timing of preoperative dialysis is critical. Surgery performed soon after dialysis (same day or day before) is associated with lower 90-day postoperative mortality, while longer intervals increase risk (21). Scheduling surgery around dialysis sessions and performing dialysis immediately before surgery is recommended for optimal outcomes.

Bleeding, coagulopathy, and transfusion management

Hemostatic alterations in CKD

Patients with CKD have a paradoxical tendency toward both bleeding and thrombosis, driven by multiple overlapping abnormalities. Impaired platelet adhesion, aggregation, and secretion, along with endothelial dysfunction, disrupt normal hemostasis, while elevated levels of coagulation factors such as von Willebrand factor, factor VIII, fibrinogen, and D-dimer promote a prothrombotic state. At the same time, reduced natural anticoagulants, diminished fibrinolytic activity, anemia, and the accumulation of uremic toxins further complicate coagulation balance. These disturbances become more pronounced as CKD progresses to advanced stages and end-stage renal disease, and are often intensified by dialysis-related physiological stresses (5,22).

Bleeding risk

Bleeding diathesis in CKD patients often presents as prolonged bleeding times, easy bruising, gastrointestinal bleeding, and increased perioperative hemorrhage, largely driven by platelet dysfunction and worsened by anemia. Management focuses on correcting anemia to a hematocrit above 30%, using agents such as desmopressin, cryoprecipitate, and carefully dose-adjusted tranexamic acid, while avoiding platelet transfusions unless necessary. Although tranexamic acid and other antifibrinolytics can effectively reduce intraoperative blood loss, they may heighten the risk of AKI, making prudent patient selection and close perioperative monitoring essential (5,23).

Thrombotic risk

CKD is associated with a hypercoagulable state, increasing the risk of deep vein thrombosis, pulmonary embolism, and vascular access thrombosis. Risk factors include:

- Elevated procoagulant factors (FVII, FVIII, vWF)
- Comorbidities (diabetes, dyslipidemia, heart failure)
- Dialysis membrane-induced thrombogenicity

Thromboprophylaxis must balance bleeding risk, with preference for mechanical methods (sequential compression devices) and cautious use of pharmacologic agents (low-molecular-weight heparin, dose-adjusted for renal function) (24,25).

Transfusion management

CKD and dialysis patients require more blood transfusions perioperatively due to increased blood loss and anemia. Transfusion thresholds should be individualized, and risks of volume overload and transfusion reactions must be considered (1).

Infection risk and wound healing

Increased susceptibility

Patients with CKD face an elevated risk of infection stemming from impaired immune cell function, endothelial dysfunction with chronic inflammation, malnutrition and hypoalbuminemia, as well as repeated vascular access and invasive procedures. These vulnerabilities translate into higher rates of surgical site infections, sepsis, and pneumonia, with dialysis patients experiencing the greatest burden (1,26).

Risk factors

Major risk factors for surgical site infection in spine surgery include diabetes mellitus, cardiovascular disease, chronic obstructive pulmonary disease, obesity, prolonged operative duration, multilevel fusion, use of instrumentation, and poor nutritional status reflected by low albumin. These risks are further amplified in patients with CKD, particularly those on dialysis, where surgical site infection rates are markedly higher compared with

non-dialysis controls. This underscores the importance of rigorous perioperative optimization and infection prevention strategies in this vulnerable population (1,26,27).

Pathogens

Staphylococcus aureus (including methicillin-resistant *Staphylococcus aureus* [MRSA]) and *Staphylococcus epidermidis* are the most common pathogens, with gram-negative organisms more prevalent in patients with prolonged preoperative hospitalization (26,27).

Prophylactic antibiotic

Standard prophylactic regimens (e.g., cefazolin) are recommended, with vancomycin or clindamycin for beta-lactam allergies or MRSA colonization. Duration should be limited to <24 hours post-closure to minimize adverse events (*Clostridium difficile*, AKI, resistance). Prolonged antibiotic use may increase AKI risk and should be avoided unless clinically indicated (28).

Bone quality and CKD-mineral and bone disorder (CKD-MBD)

Pathophysiology

CKD-MBD is a systemic bone metabolic disorder characterized by secondary hyperparathyroidism, vitamin d deficiency, disordered calcium and phosphate metabolism, trabecular sclerosis and cortical bone loss, and increased bone marrow fat.

These changes lead to reduced bone strength, increased fracture risk, and challenges with instrumentation and fusion in spine surgery (11,29,30).

Assessment

Bone quality assessment includes:

- Biochemical markers: PTH, calcium, phosphate, vitamin D
- Imaging: DEXA for bone density, MRI for bone marrow composition (R2* mapping), high-resolution peripheral quantitative computed tomography (HR-pQCT) for microarchitecture
- Bone turnover markers and, in select cases, bone biopsy
- Low bone mineral density and trabecular bone changes are associated with increased risk of non-union, instrumentation failure, and postoperative fractures (29).

Conclusion

Patients with CKD undergoing spine surgery face a complex array of perioperative challenges that demand meticulous, multidisciplinary management. Key risks include AKI, bleeding and coagulopathy, infection, poor bone quality, fluid and electrolyte disturbances, and altered drug handling. Recent evidence supports the use of goal-directed fluid therapy, advanced hemodynamic monitoring, tailored anesthesia, and medication regimens to optimize outcomes. Preoperative optimization, individualized risk stratification, and multidisciplinary team involvement are essential for reducing complications and improving long-term prognosis. Ongoing research and refinement of perioperative protocols are needed to address the unique needs of this high-risk population.

Authors' contribution

Conceptualization: Zahra Sahraei and Karim Moradian.
Data curation: Karim Moradian.
Investigation: Zahra Sahraei and Seyed Sam Mehdi Hosseininasab.
Supervision: All authors.
Validation: Zahra Sahraei.
Visualization: Seyed Sam Mehdi Hosseininasab.
Writing–original draft: All authors.
Writing–review and editing: All authors.

Conflicts of interest

The authors declare that they have no competing interests.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors utilized Grammarly and Copilot to refine grammar points and language style in writing. Subsequently, the authors thoroughly reviewed and edited the content as necessary, assuming full responsibility for the accuracy and content of the publication.

Ethical issues

Ethical issues (including plagiarism, data fabrication, and double publication) have been completely observed by the authors.

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