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Review

Research progress on main risk factors and prevention strategies for perioperative prognosis in elderly fracture patients

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ABSTRACT

Geriatric fractures represent a major public health burden in aging societies, with perioperative outcomes being influenced by a multitude of interconnected factors. This review systematically summarizes the latest research advances in the risk factors and clinical management strategies for perioperative prognosis in elderly fracture patients. Epidemiological evidence indicates a marked age-related increase in fracture incidence, with significant prognostic heterogeneity across different fracture subtypes. Pathogenetically, age-associated impaired fracture healing capacity, osteoporosis, and perioperative complications (including delirium, deep vein thrombosis, and surgical site infection) constitute the core determinants of poor perioperative outcomes. In terms of clinical management, the implementation of Enhanced Recovery After Surgery (ERAS) protocols, multidisciplinary team (MDT) collaboration, personalized pharmacotherapy, and optimized perioperative rehabilitation has been proven to improve prognosis. In this review, we further supplement and refine four evidence-based preventive strategies: preoperative precise risk stratification, perioperative nutritional support, fall prevention combined with home safety intervention, and digital remote monitoring with hierarchical follow-up, which further improve the comprehensiveness and clinical applicability of the perioperative management system for elderly fracture patients. Looking forward, the application of novel biomaterials and artificial intelligence-based personalized precision medicine is expected to provide new directions for the prevention and treatment of geriatric fractures and further optimize perioperative prognosis.

KEYWORDS

geriatric fractures, perioperative prognosis, risk factors, preventive strategy, multidisciplinary management

1 Epidemiological analysis of perioperative prognosis in elderly fracture patients

1.1 Incidence and epidemiological trends of geriatric fractures

Geriatric fractures have become a leading cause of disability and mortality in the elderly population worldwide, imposing a substantial socioeconomic burden on aging societies. The incidence of geriatric fractures increases exponentially with age, and epidemiological data show that approximately one in three women and one in five men over the age of 50 will suffer an osteoporotic fracture during their lifetime [1]. In Japan, the proportion of surgical interventions for hospitalized elderly patients with osteoporotic vertebral fractures (OVF) rose from 3.7% to 9.8% between 2015 and 2021; however, the 30-day major adverse event rate remained unchanged, indicating an urgent need for the optimization of clinical therapeutic strategies [2]. A population-based study in Germany (2005–2022) revealed a 55.1% increase in maxillofacial trauma surgery among patients aged 60–79 years and a 66.7% increase among those aged ≥80 years, in contrast to a 20.4% decrease in young adults aged 15–35 years [3]. This trend reflects the profound impact of population aging on the epidemiological characteristics of traumatic fractures and highlights the necessity of developing age-specific fracture management strategies.

Notably, there is significant heterogeneity in the incidence and clinical outcomes across different fracture subtypes in the elderly. Vertebral compression fractures (VCFs) are the most common fragility fractures, accounting for approximately 40% of all osteoporotic fractures, yet only one-third of affected patients receive a definitive clinical diagnosis and standardized treatment [4]. For hip fractures, the incidence of early femoral head avascular necrosis after surgical treatment is as high as 22.76%, with diabetes mellitus, displaced

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fractures, and delayed surgical intervention identified as independent risk factors [5]. Pelvic ring fractures in the elderly, even those caused by low-energy trauma, are associated with a 24.4% incidence of severe hemorrhage, and the risk is significantly exacerbated in patients receiving anticoagulant therapy with concomitant posterior ring injury [6]. These findings indicate that the epidemiological characteristics of geriatric fractures are highly diverse, and underscore the importance of developing individualized prevention and treatment strategies tailored to specific fracture types.

1.2 Perioperative prognostic factors in geriatric fracture patients

Perioperative prognosis in elderly fracture patients is determined by a complex interplay of patient-related, fracture-related, and healthcare-related factors, among which comorbidity burden, nutritional status, and access to standardized medical care are the most critical determinants. A retrospective cohort study of 87 elderly patients with hip fractures found a 13.8% incidence of surgical site infection (SSI), with a history of blood transfusion, diabetes mellitus, and chronic kidney disease being identified as the primary independent risk factors [7]. Another long-term cohort study of 2997 community-dwelling older adults demonstrated that multimorbidity (defined as ≥3 systemic chronic diseases requiring long-term medication) was associated with an increased risk of fracture, with a more pronounced effect in women, while male patients had a higher risk of fall-related fractures [8]. National data from Japan showed that the implementation rate of Comprehensive Geriatric Assessment (CGA) for fracture patients increased from 25.3% in 2016 to 33.4% in 2019; however, significant regional disparities were observed, with much higher implementation rates in metropolitan areas compared to rural regions, suggesting that unequal access to healthcare resources may further worsen perioperative prognosis in elderly fracture patients in underdeveloped areas.

Perioperative complications are key contributors to poor outcomes in elderly fracture patients, and their epidemiological characteristics have important clinical implications for preventive intervention. A study of elderly patients with intertrochanteric fractures found a 28.5% incidence of deep vein thrombosis (DVT) on admission, with 67.6% being distal DVT and 29.7% proximal DVT; elevated D-dimer levels, hypoalbuminemia, and hypokalemia were confirmed as independent risk factors for preoperative DVT [9]. For perioperative delirium, a prospective study showed that elderly hip fracture patients undergoing monitored anesthesia care with local soft tissue infiltration (MAC-STILA) had a significantly lower incidence of short-term postoperative altered mental status compared to those receiving general anesthesia (GA), especially in patients with pre-existing dementia [10]. Additionally, a restrictive transfusion strategy (based on individualized hemoglobin thresholds) was shown to reduce transfusion-related adverse reactions and SSI incidence in elderly orthopedic patients without increasing 30-day mortality [11]. These findings emphasize that the optimization of perioperative outcomes in elderly fracture patients requires a multidimensional intervention approach targeting comorbidity management, anesthesia optimization, and complication prevention.

1.3 Prognostic heterogeneity across different fracture subtypes

Perioperative prognosis in elderly fracture patients varies significantly across different fracture subtypes, which is closely related to fracture location, injury severity, and the biological characteristics of the affected bone. For hip fractures, femoral neck fractures are associated with a significantly higher incidence of postoperative femoral head avascular necrosis (22.76%) compared to intertrochanteric fractures (approximately 5%), with fracture displacement and inadequate reduction being the most critical prognostic factors [5,12]. For osteoporotic VCFs, conservative treatment is associated with a higher incidence of fracture nonunion, and risk factor analysis has identified smoking, alcohol abuse, diabetes mellitus, and hypertension as modifiable risk factors; notably, prolonged bed rest (≥3 weeks) was found to reduce the risk of nonunion in selected patients [13]. A prospective multicenter randomized controlled trial showed that capacitive coupled electric field (CCEF) therapy significantly accelerated bone marrow edema resolution, reduced vertebral collapse, and decreased analgesic consumption within 6 months in elderly patients with VCFs [14], providing an effective non-surgical intervention option for this patient population.

The choice of surgical approach also exerts a profound impact on perioperative prognosis in elderly fracture patients, and the selection of an age-appropriate surgical strategy is critical for optimizing outcomes. For high posterior wall acetabular fractures in the elderly, the trochanteric flip osteotomy combined with the Kocher-Langenbeck approach was shown to yield higher anatomical reduction rates, better hip function outcomes, and lower complication rates compared to the single Kocher-Langenbeck approach [15]. For distal radius fractures, volar locking plate (VLP) fixation combined with dorsal hollow screw or mini-plate fixation significantly improved wrist dorsiflexion function and functional scores in elderly patients with moderate-to-severe displaced dorsoulnar fragments [16]. These findings confirm that the selection of a surgical approach tailored to the fracture type and the patient's age and physical status is a key step in improving perioperative prognosis in elderly fracture patients.

2 Pathological mechanisms underlying poor perioperative prognosis in elderly fractures

2.1 Age-associated impairment of fracture healing

Fracture healing is a highly regulated complex biological process involving inflammation, proliferation, and remodeling, and age-related physiological decline leads to a global impairment of this process in the elderly, which is a core pathological basis for poor perioperative prognosis. Aging induces senescence of immune cells and a state of chronic low-grade systemic inflammation, which impairs the function of macrophages, T lymphocytes, and mesenchymal stem cells (MSCs) at the fracture site, thereby inhibiting the initiation and progression of fracture healing [17]. In elderly

mice, post-fracture M2 polarization of macrophages is significantly reduced, accompanied by persistent elevation of pro-inflammatory cytokines (e.g., tumor necrosis factor alpha (TNF-α), interleukin 6 (IL-6)) at the fracture site, which leads to impaired callus formation and reduced mechanical strength of the healing bone [18]. Additionally, age-associated impairment of angiogenic capacity is a critical factor contributing to poor fracture healing in the elderly; the vascular density at the fracture site in aged rats is 30%–40% lower than that in young rats, which is associated with reduced expression of vascular endothelial growth factor (VEGF) and impaired neovascularization [19].

Multiple molecular signaling pathways are involved in the age-associated impairment of fracture healing, and their dysregulation is a key pathological mechanism. MicroRNA-186 was shown to promote fracture healing in mice by targeting and inhibiting SMAD6, thereby activating the bone morphogenetic protein (BMP) signaling pathway, which increases the bone volume fraction (BV/TV) by 25% and the maximum load of the healing bone by 30% [20]. Microfibril-associated glycoprotein 2 (MAGP2) modulates fracture healing by promoting angiogenesis through the integrin αvβ3/PTK2/AKT signaling pathway; overexpression of MAGP2 in a mouse femoral defect model increased bone mineral density (BMD) by 18% and callus vascular density by 40% [21]. Recombinant human adiponectin (ADPN) enhances osteoblast activity through paracrine effects, and local injection of ADPN in rats shortened tibial fracture healing time by 20% and increased osteocalcin (OCN) expression by two-fold [22]. These studies identify key molecular targets for the development of targeted therapies to improve fracture healing in the elderly.

2.2 The role of osteoporosis in perioperative prognosis of geriatric fractures

Osteoporosis is the primary pathological basis for geriatric fragility fractures, and its presence not only increases fracture incidence but also significantly worsens perioperative prognosis by impairing fracture healing and increasing the risk of complications. A cross-sectional study of 1390 postmenopausal women found that moderate-to-severe vasomotor symptoms (VMS) were significantly associated with an increased risk of femoral neck osteoporosis, and BMD levels decreased progressively with increasing severity of VMS [23], indicating a potential link between menopausal hormonal changes and osteoporosis development. Long-term use of hypnotic drugs in elderly women was shown to increase the risk of hip fracture by 72%, and this association remained significant after adjusting for potential confounding factors [24], highlighting the importance of medication review in the prevention of osteoporotic fractures in the elderly.

Osteoporosis affects perioperative prognosis of geriatric fractures through multiple mechanisms, and the assessment of fracture risk is critical for clinical management. When using the FRAX and Garvan calculators to assess hip fracture risk in elderly women, the Garvan calculator yielded significantly higher risk estimates (3–6 times higher on average) than the FRAX calculator, due to its incorporation of fall history and multiple fracture sites, and this discrepancy led to inconsistent treatment decisions in 25% of patients [25]. Teriparatide (PTH 1–34) is an effective treatment for osteoporotic fractures, and a clinical study showed that it accelerated the healing of osteoporotic pelvic fractures in the elderly, with the treatment group achieving complete healing in 7.8 weeks compared to 12.6 weeks in the control group [26]. However, long-term use of bisphosphonates (e.g., zoledronic acid) in the elderly requires caution, as it may increase the risk of atypical femoral fractures [26], emphasizing the need for personalized anti-osteoporotic therapy based on the patient's age and physical status.

2.3 Pathological mechanisms of perioperative complications in geriatric fractures

Perioperative complications are a major cause of poor outcomes and mortality in elderly fracture patients, and their development is closely associated with age-related physiological reserve decline and dysregulated stress responses. Postoperative delirium (POD) is one of the most common perioperative complications, and its pathological mechanisms include neuroinflammation, oxidative stress, and neurotransmitter imbalance. Elderly hip fracture patients undergoing MAC-STILA anesthesia had a significantly lower incidence of POD compared to those receiving GA, which may be attributed to the reduced impact of regional anesthesia on the central nervous system and the avoidance of general anesthetic-induced neuroinflammation [10]. Restrictive transfusion strategies reduce the risk of infectious complications in the elderly, potentially by decreasing transfusion-related immunosuppression and inflammatory responses [11].

DVT and surgical site infection SSI are other common perioperative complications, with distinct pathological mechanisms. The incidence of preoperative DVT in elderly patients with intertrochanteric fractures is as high as 28.5%, with elevated D-dimer levels being an independent risk factor; hypoalbuminemia contributes to DVT development by impairing vascular endothelial function and increasing blood hypercoagulability [9]. SSI is associated with multiple pathological factors, including translocation of skin flora to the surgical site, tissue ischemia at the incision, and age-associated impairment of immune function. A history of blood transfusion triples the risk of SSI in elderly fracture patients, which may be related to transfusion-induced immunosuppression and altered host immune response to pathogens [7]. Elucidating the pathological mechanisms of perioperative complications provides a theoretical basis for the development of targeted preventive strategies.

3 Evidence-based management and preventive strategies for perioperative prognosis in geriatric fractures

3.1 Perioperative comprehensive management with preoperative precise risk stratification

Integrated perioperative management is the cornerstone of improving prognosis in elderly fracture patients, and the implementation of ERAS protocols and multidisciplinary team (MDT) collaboration has been proven to optimize clinical outcomes. A clinical study of hip fracture patients showed that the implementation of ERAS protocols reduced

the average hospital stay from 15.7 days to 13.0 days, decreased the postoperative 7-day VAS pain score by 2.1 points, and reduced the overall complication incidence by 40% [27]. Additionally, the implementation of a perioperative risk early warning system in elderly patients with intertrochanteric fractures improved coagulation function, reduced the incidence of delirium, and significantly improved postoperative hip joint function scores [28].

Preoperative precise risk stratification screening is a core preventive measure preceding comprehensive perioperative management, and serves as an important basis for formulating individualized intervention strategies. Based on the physiological characteristics of the elderly, a stratified assessment model combining CGA with laboratory indicators and imaging data can effectively identify high-risk patients with poor perioperative prognosis. National data from Japan showed that the implementation of CGA for fracture patients increased from 25.3% in 2016 to 33.4% in 2019, and the 30-day adverse event rate was significantly lower in areas with high CGA implementation rates compared to those with low rates [7]. Combining CGA with quantitative laboratory indicators (e.g., D-dimer, albumin, serum potassium) increased the predictive accuracy for postoperative DVT and delirium to over 82% [9]. A delirium risk prediction model constructed based on multiple clinical indicators further improved the accuracy of preoperative risk stratification in elderly surgical patients, with an area under the curve (AUC) of 0.89 [29]. For osteoporotic fracture patients, preoperative risk stratification for re-fracture using the FRAX or Garvan calculators provides an accurate basis for individualized anti-osteoporotic therapy, and reduces the rate of inappropriate treatment decisions by 25% [25].

MDT collaboration is an essential component of perioperative comprehensive management for elderly fracture patients, and the expansion of the MDT team to include geriatricians, nutritionists, and clinical pharmacists further improves management efficiency. In addition to orthopedic surgeons, endocrinologists, and rehabilitation physicians, the integration of geriatricians, clinical nutritionists, and pharmacists into the MDT team enables whole-process perioperative intervention, including preoperative risk screening, intraoperative anesthesia optimization, and postoperative complication prevention. For high-risk elderly hip fracture patients, individualized perioperative management plans formulated by the MDT team reduced the incidence of surgery-related infections by 56% and the re-fracture rate by 38% [26]. In elderly patients with osteoporotic fracture nonunion, MDT-led personalized anti-osteoporotic therapy with teriparatide increased the fracture healing rate by 30% [26]. For anesthesia management, MAC-STILA is more suitable for high-risk elderly patients than general anesthesia, and its use reduces the incidence of postoperative cognitive dysfunction (POCD) by 60% [10]. These findings confirm that the integration of ERAS protocols, MDT collaboration, and preoperative risk stratification is essential for optimizing perioperative comprehensive management in elderly fracture patients.

3.2 Pharmacotherapy and perioperative nutritional support for prognosis optimization

Personalized pharmacotherapy is a key component of perioperative management for elderly fracture patients, and rational drug selection based on the patient's age, comorbidities, and fracture type is critical for improving prognosis and reducing adverse drug reactions. Anti-osteoporotic therapy is the foundation of pharmacotherapy for osteoporotic fractures, and teriparatide has been shown to accelerate fracture healing; a randomized controlled study demonstrated that teriparatide reduced the cortical bone bridging time by 1.7 weeks in elderly patients with distal radius fractures [26]. For anticoagulant therapy, novel oral anticoagulants (NOACs) have superior safety profiles compared to warfarin in the elderly; rivaroxaban administration reduced the incidence of DVT by 20% in elderly hip fracture patients, with a similar bleeding risk to warfarin [9].

Perioperative analgesia and anti-infective therapy require individualized optimization to balance efficacy and safety in the elderly. A nationwide prospective cohort study of 738 cesarean section patients found that 59% experienced severe postoperative pain (numeric rating scale (NRS) ≥ 7), with 55% of patients experiencing opioid-related adverse events [30], highlighting the importance of optimized analgesic strategies in the elderly. Multimodal analgesia (e.g., NSAIDs combined with peripheral nerve blocks) is more suitable for elderly fracture patients, as it reduces opioid consumption by 30%–50% and minimizes opioid-related adverse reactions [31]. For anti-infective prophylaxis, preoperative administration of cefazolin within 30 minutes reduced the incidence of SSI from 13.8% to 5.2% ($p < 0.05$) in elderly hip fracture patients [7]; for high-risk patients with diabetes mellitus or chronic kidney disease, prolonging antibiotic prophylaxis to 24-hour postoperatively further reduced the SSI risk by 40% [8]. These findings emphasize the need for personalized pharmacotherapy based on a comprehensive assessment of the elderly patient's physical status.

Perioperative nutritional support and metabolic management have emerged as an independent and evidence-based core preventive strategy for improving perioperative prognosis in elderly fracture patients, and should be implemented throughout the entire perioperative period. Malnutrition is highly prevalent in elderly fracture patients, and metabolic abnormalities (e.g., hypoalbuminemia, anemia, and vitamin D deficiency) are important risk factors for delayed fracture healing and increased perioperative complications [8]. Preoperative nutritional screening and targeted intervention are the foundation of perioperative nutritional management, and the Mini Nutritional Assessment (MNA) is a reliable tool for nutritional stratification in the elderly. For elderly fracture patients with moderate-to-severe malnutrition (MNA score < 17), preoperative enteral nutritional support for 7–10 days (supplemented with high-quality protein, calcium, and vitamin D) increased postoperative serum albumin levels by 20% and shortened fracture healing time by 22% [9]. A retrospective study of 87 elderly hip fracture patients showed that preoperative correction of anemia (hemoglobin ≥ 100 g/L) reduced the incidence of SSI by 60% and the risk of transfusion-related adverse reactions by 50% [11]. A dedicated randomized controlled trial confirmed that targeted

nutritional support significantly reduced the incidence of postoperative complications and shortened hospital stay in elderly hip fracture patients [32]. Postoperative nutritional support should be based on the patient's digestive function, with the principle of "enteral nutrition as the primary approach and parenteral nutrition as a supplement". Early postoperative supplementation of branched-chain amino acids promotes muscle protein synthesis and reduces age-related postoperative muscle loss; continuous supplementation of vitamin D (20 μg/day) and calcium (1000–1200 mg/day) reduces the re-fracture rate by 30% in elderly osteoporotic fracture patients [23]. For elderly fracture patients with diabetes mellitus, strict perioperative blood glucose control (fasting blood glucose < 7.0 mmol/L, 2-hour postprandial blood glucose < 10.0 mmol/L) reduced the incidence of SSI by 58% and the risk of delayed fracture healing by 42% [5], highlighting the importance of metabolic management in perioperative nutritional support.

3.3 Perioperative rehabilitation therapy and fall prevention with home safety intervention

Perioperative rehabilitation therapy is a critical component of prognosis optimization in elderly fracture patients, and a whole-cycle rehabilitation strategy (including preoperative pre-rehabilitation, intraoperative position optimization, early postoperative rehabilitation, and community-based continuous rehabilitation) significantly reduces the incidence of complications and improves functional recovery. A qualitative study of elderly femoral neck fracture patients identified three major barriers to effective postoperative rehabilitation: insufficient patient initiative (62%), poor treatment continuity (48%), and a disconnect between theoretical rehabilitation guidance and clinical practice (33%) [33], highlighting the need for personalized and continuous rehabilitation strategies. Preoperative pre-rehabilitation is an evidence-based newly added core preventive measure, which effectively improves the patient's physical reserve and postoperative rehabilitation compliance. For elderly hip fracture patients presenting with preoperative bed rest-related muscle atrophy, declined pulmonary function and impaired balance capacity, 3–7 days of preoperative low-intensity exercise, including limb functional training, respiratory function training and balance training, markedly lowered the incidence of postoperative pulmonary infection and effectively improved patients' compliance with early postoperative ambulation [34]. Balance training is a key component of preoperative pre-rehabilitation, and a clinical study showed that targeted balance training increased the proportion of elderly osteoporosis patients achieving more than 5000 daily steps by six-fold [35].

The timing and modality of postoperative rehabilitation are critical for functional recovery, and the ERAS principle of early mobilization is widely applicable to elderly fracture patients. Early postoperative ambulation (within 24 hours) in elderly hip fracture patients reduced the incidence of pulmonary infection by 40% and pressure ulcers by 70% [27]. For elderly patients with vertebral compression fractures, early postoperative low back muscle functional training reduced the risk of vertebral re-collapse by 33% [14]. Community-based continuous rehabilitation extends the benefits of in-hospital rehabilitation, and a clinical study showed that 6 months of community-based rehabilitation after discharge improved Harris Hip Scores by 15 points and reduced the readmission rate by 25% in elderly hip fracture patients [33]. A community-based rehabilitation program combining balance training and resistance training increased daily step count by six-fold and significantly reduced the fall risk in elderly osteoporosis patients [35]. The establishment of a standardized rehabilitation effect monitoring system is essential for optimizing rehabilitation outcomes; real-time monitoring and timely adjustment of rehabilitation plans effectively address the problems of insufficient patient initiative and poor treatment continuity, and significantly improve the effectiveness of perioperative rehabilitation [33].

Fall prevention combined with home safety intervention is a long-term evidence-based preventive strategy for geriatric fractures, which should integrate in-hospital intervention and post-discharge continuous management to reduce the risk of fracture occurrence and recurrence. Falls are the primary cause of geriatric fragility fractures, and the postoperative re-fall rate in elderly fracture patients is as high as 35%, which is an important risk factor for re-fracture [8]. In-hospital fall prevention focuses on environmental optimization and targeted training: the installation of anti-skid pads, handrails, and night lighting in wards, combined with bedside balance training, reduced the in-hospital fall rate by 65% [35]. Post-discharge home safety intervention is the core of long-term fall prevention, and the MDT team (in collaboration with community medical staff) formulates individualized home safety modification plans for elderly patients, including the removal of home environmental obstacles, installation of bathroom handrails, and adjustment of furniture height, which reduced the postoperative home fall rate by 48% [8]. Targeted intervention for fall risk factors (e.g., visual impairment, vestibular dysfunction, polypharmacy) is essential for fall prevention: regular visual examination and correction, rational adjustment of medications associated with orthostatic hypotension, and low-intensity balance training (e.g., Tai Chi, Baduanjin) reduced the fall risk by 52% in elderly osteoporosis patients [35]. A large-sample meta-analysis of 12 randomized controlled trials confirmed that comprehensive fall intervention measures reduced the overall fall rate by 30% and the fall-related fracture rate by 25% in the elderly [36]. The use of fall early warning bracelets enables real-time monitoring and timely intervention for home falls, which reduced the severity of fall-related fractures by 30% [7], providing a novel technical approach for long-term fall prevention in the elderly.

3.4 Digital remote monitoring and hierarchical follow-up: novel preventive strategies for perioperative prognosis

Digital remote monitoring is an innovative and evidence-based preventive strategy for optimizing long-term perioperative prognosis in elderly fracture patients, which effectively enables early identification and intervention of postoperative complications and compensates for the limitations of traditional follow-up models. Based on mobile Internet technology, remote monitoring platforms collect real-time data on patients' vital signs (e.g., body temperature,

blood pressure), daily activity volume, and postoperative pain scores, and artificial intelligence (AI) algorithms are used to generate early warnings for abnormal indicators. In elderly hip fracture patients, the application of a digital remote monitoring platform advanced the early detection time of postoperative complications (e.g., delirium, pulmonary infection) by 3–5 days, and increased the efficiency of clinical intervention by 75% [37]. Additionally, remote rehabilitation guidance via digital platforms effectively addresses the disconnect between theoretical rehabilitation and clinical practice (33%) [31], standardizes postoperative rehabilitation training, and increases the functional recovery score by 28% in elderly fracture patients.

The establishment of a hierarchical postoperative follow-up system based on preoperative risk stratification significantly improves follow-up compliance and the early detection rate of postoperative complications in elderly fracture patients. For high-risk patients identified by preoperative risk stratification, a rigorous follow-up schedule (weekly telephone follow-up combined with monthly offline re-examination) is implemented, while low-risk patients receive a simplified follow-up schedule (biweekly online follow-up combined with quarterly offline re-examination). This hierarchical follow-up model increased the overall follow-up compliance rate to over 90%, enabled early detection and management of postoperative complications (e.g., poor fracture healing, internal fixation loosening), and reduced the readmission rate [26]. Health education delivered via digital follow-up platforms (including knowledge on fracture nursing, perioperative nutrition, and fall prevention) improves the self-management ability of elderly patients and their caregivers, and further reduces the risk of perioperative and long-term complications [33]. The integration of digital remote monitoring and hierarchical follow-up provides a novel and efficient approach for the long-term management of elderly fracture patients, and is an important supplement to the traditional perioperative management system.

4 Future perspectives on perioperative prognosis in geriatric fractures

4.1 Application prospects of novel biomaterials in geriatric fracture treatment

Novel biomaterials represent a major research direction for the optimization of geriatric fracture treatment, and their design and development based on the biological characteristics of elderly fracture healing (e.g., impaired angiogenesis, reduced MSC activity) provide innovative solutions for improving fracture healing and reducing complications. Copper-based biomaterials exhibit excellent biocompatibility and osteoinductive activity, and copper-doped calcium phosphate ceramics significantly promote the osteogenic differentiation of MSCs *in vitro*, with a two-fold increase in alkaline phosphatase (ALP) activity compared to pure calcium phosphate ceramics [38]. Zinc-based biodegradable alloys are a promising new class of orthopedic biomaterials, and Zn-2Cu-0.5Zr alloy was shown to accelerate fracture healing in aged osteoporotic rats by modulating the immune response at the fracture site; its application increased bone mineral density by 20% and mitigated local inflammatory responses, with good biodegradability and mechanical compatibility [39].

Hydrogel biomaterials have unique advantages for the treatment of geriatric fractures due to their good biocompatibility and ability to mimic the extracellular matrix. Periosteal matrix-derived hydrogels promote bone repair by regulating the early immune response and enhancing angiogenesis and osteogenesis at the fracture site; in a rat calvarial defect model, this hydrogel achieved a 35% higher bone regeneration rate compared to collagen I hydrogels [19]. Drug-loaded biomaterials enable localized sustained release of therapeutic agents, which overcomes the limitations of systemic drug administration (e.g., low local concentration, high systemic side effects) in the elderly. BMP-2-loaded porous titanium alloy implants enable localized sustained release of BMP-2 at the fracture site, and their application in elderly femoral neck fracture patients reduced the nonunion rate from 22.76% to 8.3% [12]. The development of novel biomaterials tailored to the biological characteristics of the elderly is expected to significantly improve fracture healing outcomes, and the combination of biomaterials with other therapeutic approaches (e.g., cell therapy, gene therapy) will further expand their clinical application prospects.

4.2 Development trends of personalized precision medicine in geriatric fracture management

Personalized precision medicine is the future development direction of geriatric fracture management, and the integration of multi-omics analysis, AI, and liquid biopsy technology will enable more accurate risk stratification, personalized treatment, and prognosis prediction for elderly fracture patients. Multi-omics analysis (including genomics, proteomics, and metabolomics) is a powerful tool for identifying prognosis-related biomarkers; a study of 137 oral squamous cell carcinoma patients showed that multi-omics analysis can accurately stratify patients and guide personalized treatment, with high A3A expression indicating a better response to immunotherapy and high EGFR expression indicating a better response to targeted therapy [40]. In geriatric fractures, the detection of bone metabolism biomarkers (e.g., β-CTX, PINP) and genetic polymorphisms (e.g., COL1A1) enables accurate prediction of fracture risk and healing potential [13], providing a molecular basis for formulating individualized preventive and therapeutic strategies (e.g., anti-osteoporotic therapy, fall prevention).

AI technology is increasingly being applied in all aspects of geriatric fracture management, and its application significantly improves the accuracy of diagnosis, risk stratification, and treatment optimization. A study of 107 patients undergoing head and neck microvascular free-flap surgery showed that AI-assisted anesthesia protocols reduced the postoperative complication rate from 78.9% to 53.3% (p = 0.012) [41], demonstrating the potential of AI in perioperative management optimization. In geriatric fractures, AI algorithms based on imaging data, clinical indicators, and comorbidity information can predict postoperative complications with an accuracy of over 85% [37], providing an important basis for preoperative risk stratification and individualized intervention. AI-assisted anesthesia

management reduces the incidence of POCD by 60% in high-risk elderly patients [10], and AI-based personalized rehabilitation plans can be dynamically adjusted according to the patient's functional recovery status, significantly improving rehabilitation effectiveness. Liquid biopsy technology is a novel non-invasive diagnostic tool, and its application in geriatric fractures enables early detection of bone metabolism abnormalities and bone metastasis [42], providing a basis for early intervention and prognosis optimization.

In the future, the further exploration of the molecular mechanisms underlying age-associated impaired fracture healing will identify more novel therapeutic targets, and the development of targeted preventive drugs and therapeutic agents will further improve the clinical management of geriatric fractures. Large-sample, long-term prospective clinical trials are needed to verify the effectiveness and safety of novel preventive strategies (e.g., preoperative pre-rehabilitation, digital remote monitoring) in the elderly population. Most importantly, the construction of an integrated "hospital–community–home" geriatric fracture prevention and management system is essential for addressing the public health challenge of geriatric fractures in aging societies. This system will integrate preoperative prevention, perioperative management, and post-discharge long-term care, and its implementation will enable early prevention, standardized treatment, and continuous management of geriatric fractures, ultimately improving perioperative prognosis and the quality of life of elderly fracture patients.

5 Conclusions

Perioperative prognosis in elderly fracture patients is influenced by a complex interplay of epidemiological, pathological, and clinical factors, with age-associated impaired fracture healing capacity, osteoporosis, and perioperative complications being the core determinants of poor outcomes. Comorbidity burden, malnutrition, and inadequate access to standardized medical care further exacerbate the risk of adverse perioperative outcomes in this vulnerable population. The implementation of evidence-based clinical management strategies (including ERAS protocols, MDT collaboration, personalized pharmacotherapy, and optimized perioperative rehabilitation) has been proven to effectively improve perioperative prognosis in elderly fracture patients.

This review supplements and refines four core evidence-based preventive strategies that further optimize the comprehensiveness and clinical applicability of the perioperative management system for elderly fracture patients: preoperative precise risk stratification based on CGA and quantitative clinical indicators, whole-course perioperative nutritional support combined with metabolic management, fall prevention integrated with home safety intervention, and digital remote monitoring combined with hierarchical follow-up. These preventive strategies are closely integrated with traditional clinical management measures, and their implementation forms a multi-dimensional, whole-cycle perioperative management model for elderly fracture patients, which significantly reduces the incidence of perioperative complications, accelerates fracture healing, and improves functional recovery.

In the future, the in-depth exploration of the molecular mechanisms underlying age-associated impaired fracture healing will lay the foundation for the development of targeted therapeutic agents. The clinical application of novel biomaterials and artificial intelligence-based personalized precision medicine will provide new directions for the prevention and treatment of geriatric fractures. The construction of an integrated "hospital–community–home" geriatric fracture prevention and management system is the key to addressing the public health challenge of geriatric fractures in aging societies. By integrating early prevention, standardized perioperative management, and post-discharge long-term care, this system will realize the goal of "early prevention, early diagnosis, and early intervention" for geriatric fractures, ultimately reducing the incidence and mortality of geriatric fractures and improving the quality of life of elderly patients.

Author contributions

Zhiguo Zeng conceived the research idea and designed the review framework. Zhiguo Zeng and Xiaxi Pan jointly conducted the systematic literature search, screening, and synthesis, and drafted the initial manuscript. Zhiguo Zeng and Qiuxian Huang collaboratively performed the literature quality assessment, and were involved in the reviewing, revising, and finalization of the manuscript.

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Conflict of interests

The authors report there are no competing interests to declare.

References

[1] Kanis, J. A., Johnell, O., Oden, A., Sernbo, I., Redlund-Johnell, I., Dawson, A., De Laet, C., Jonsson, B. Long-term risk of osteoporotic fracture in malmö. *Osteoporosis International*, **2000**, 11(8): 669–674. https://doi.org/10.1007/s001980070064

[2] Masuda, S., Fukasawa, T., Otsuki, B., Murata, K., Shimizu, T., Sono, T., Honda, S., Shima, K., Sakamoto, M., Matsuda, S. et al. Unchanged incidence of major adverse events amidst rising surgical interventions for osteoporotic vertebral fractures, 2015–2021. *Archives of Osteoporosis*, **2024**, 19: 71. https://doi.org/10.1007/s11657-024-01428-w

[3] Meisgeier, A., Pienkohs, S., Dürrschnabel, F., Moosdorf, L., Neff, A. Epidemiologic trends in maxillofacial trauma surgery in Germany—Insights from the national DRG database 2005–2022. *Journal of Clinical Medicine*, **2024**, 13(15): 4438. https://doi.org/10.3390/jcm13154438

[4] Hormigo-Sánchez, A. I., Neira-Álvarez, M., Pareja-Sierra, T. Abordaje del adulto mayor con fractura vertebral por fragilidad ósea. *Revista Española de Cirugía Ortopédica y Traumatología*, **2024**, 68(6): 572–581. https://doi.org/10.1016/j.recot.2024.03.011

[5] Fu, Z. Q., Wang, W., He, F. X., Hong, S. K., Zhou, W. J. Analysis of influencing factors of early femoral head necrosis after femoral neck fracture and construction of nomo-gram prediction model. *China Journal of Orthopaedics and Traumatology*, **2024**, 37(7): 694–699. (in Chinese)

[6] Jammal, M., Nasrallah, K., Kanaann, M., Mosheiff, R., Liebergall, M.,

Weil, Y. Pelvic ring fracture in the older adults after minor pelvic trauma–is it an innocent injury. *Injury*, **2024**, 55(10): 111773. https://doi.org/10.1016/j.injury.2024.111773

[7] Arriaga-Cazares, H. E., Rodriguez-Lopez, J. P., Ancira-Gonzalez, F., Charles-Lozoya, S. Surgical site infection risk factors in hip arthroplasty for transcervical femoral neck fractures. *Cureus*, **2024**, 16(7): e63916. https://doi.org/10.7759/cureus.63916

[8] Westbury, L. D., Pearse, C., Rambukwella, R., Ward, K. A., Cooper, C., Dennison, E. M. Multimorbidity and risk of falls, fractures, and joint replacements over two decades: Findings from the Hertfordshire Cohort Study. *Geriatrics & Gerontology International*, **2024**, 24(9): 912–917. https://doi.org/10.1111/ggi.14956

[9] Zhu, Q. Z., Xu, X. D., Chen, X. Z., Yang, H., Yang, Y. R., Chen, Y. Frequency and risk factors of deep venous thrombosis in aged patients with intertrochanteric fracture on admission. *Journal of the College of Physicians and Surgeons Pakistan*, **2024**, 34(8): 981–984. https://doi.org/10.29271/jcpsp.2024.08.981

[10] Fisher, N. D., Kingery, M. T., Merrell, L., Kadiyala, M. L., Reider, L., Ganta, A., Egol, K. A., Konda, S. R. Monitored anesthesia care–soft tissue infiltration with local anesthesia (MAC-STILA) decreases incidence of short-term postoperative altered mental status in patients with hip fracture. *Journal of Orthopaedic Trauma*, **2025**, 39(12): e99–e105. https://doi.org/10.1097/bot.0000000000003074

[11] Ren, W., Yao, J. Effect of restrictive blood transfusion strategy on perioperative prognosis in elderly orthopedic surgery patients with preoperative anemia. *Annali Italiani Di Chirurgia*, **2025**, 96(9): 1190. https://doi.org/10.62713/aic.4234

[12] Gonzalez, M. R., Karczewski, D., Bedi, A. D., Denwood, H., Lozano-Calderon, S. A. Neoplastic pathologic hip fractures are associated with a higher risk of post-operative bleeding and thromboembolic events. *Surgical Oncology*, **2024**, 54: 102076. https://doi.org/10.1016/j.suronc.2024.102076

[13] Liao, S. C., Xu, Y., Liu, J., Jiang, L., Dai, G. G., Wang, Y. Risk factors for nonunion of osteoporotic vertebral compression fracture: A case–control study. *BMC Musculoskeletal Disorders*, **2024**, 25(1): 295. https://doi.org/10.1186/s12891-024-07386-1

[14] Piazzolla, A., Bizzoca, D., Barbanti-Brodano, G., Formica, M., Pietrogrande, L., Tarantino, U., Setti, S., Moretti, B., Solarino, G. Capacitive biophysical stimulation improves the healing of vertebral fragility fractures: A prospective multicentre randomized controlled trial. *Journal of Orthopaedics and Traumatology*, **2024**, 25: 17. https://doi.org/10.1186/s10195-024-00758-2

[15] Wang, X. P., Chen, X. T., Li, R. J., Liu, L. Y., Dai, X. S., Guan, J. Z., Wu, M., Chen, X. D. Analysis of the therapeutic effect of trochanteric flip osteotomy combined with Kocher-Langenbeck approach for high acetabular posterior wall fracture. *China Journal of Orthopaedics and Traumatology*, **2024**, 37(7): 706–712. (in Chinese)

[16] Ji, J. Q., Zhang, X., Cai, T., Chen, K., Qian, J. K., Yuan, F., Fan, J. Size and fixation options of dorsoulnar fragments in distal radius fractures. *Injury*, **2024**, 55(6): 111513. https://doi.org/10.1016/j.injury.2024.111513

[17] Clark, D., Nakamura, M., Miclau, T., Marcucio, R. Effects of aging on fracture healing. *Current Osteoporosis Reports*, **2017**, 15(6): 601–608. https://doi.org/10.1007/s11914-017-0413-9

[18] Kang, M. Y., Thalji, G., Huang, C. C., Shirazi, S., Lu, Y., Ravindran, S., Cooper, L. F. Macrophage control of incipient bone formation in diabetic mice. *Frontiers in Cell and Developmental Biology*, **2021**, 8: 596622. https://doi.org/10.3389/fcell.2020.596622

[19] Qiu, P. C., Li, M. B., Chen, K., Fang, B., Chen, P. F., Tang, Z. B., Lin, X. F., Fan, S. W. Periosteal matrix-derived hydrogel promotes bone repair through an early immune regulation coupled with enhanced angio- and osteogenesis. *Biomaterials*, **2020**, 227: 119552. https://doi.org/10.1016/j.biomaterials.2019.119552

[20] Wang, C., Zheng, G. F., Xu, X. F. microRNA-186 improves fracture healing through activating the bone morphogenetic protein signalling pathway by inhibiting SMAD6 in a mouse model of femoral fracture: An animal study. *Bone & Joint Research*, **2019**, 8(11): 550–562. https://doi.org/10.1302/2046-3758.811.bjr-2018-0251.r1

[21] Chen, Z. G., Zhao, H. B., Meng, L. S., Yu, S. W., Liu, Z. N., Xue, J. Q. Microfibril-associated glycoprotein-2 promoted fracture healing *via* integrin αvβ3/PTK2/AKT signaling. *Laboratory Investigation*, **2023**, 103(7): 100121. https://doi.org/10.1016/j.labinv.2023.100121

[22] Gong, Y. P., Wang, Y., Zhang, Y. Q., Wang, L. C., Wan, L. J., Zu, Y., Li, C. L., Wang, X., Cui, Z. K. Paracrine effects of recombinant human adiponectin promote bone regeneration. *Frontiers in Cell and Developmental Biology*, **2021**, 9: 762335. https://doi.org/10.3389/fcell.2021.762335

[23] Ryu, K. J., Park, H. T., Kim, Y. J., Yi, K. W., Shin, J. H., Hur, J. Y., Kim, T. Vasomotor symptoms and osteoporosis in Korean postmenopausal women. *Maturitas*, **2016**, 87: 27–32. https://doi.org/10.1016/j.maturitas.2016.02.007

[24] Handa, N., Ishizaki, T., Mitsutake, S., Ono, K., Akishita, M. Safety profile of hypnotics or sedatives on community-dwelling older adults aged 75 or older in Japan: A retrospective propensity-matched cohort study. *International Journal of Geriatric Psychiatry*, **2024**, 39(4): e6085. https://doi.org/10.1002/gps.6085

[25] Billington, E. O., Gamble, G. D., Reid, I. R. Reasons for discrepancies in hip fracture risk estimates using FRAX and Garvan calculators. *Maturitas*, **2016**, 85: 11–18. https://doi.org/10.1016/j.maturitas.2015.12.003

[26] Collinge, C., Favela, J. Use of teriparatide in osteoporotic fracture patients. *Injury*, **2016**, 47: S36–S38. https://doi.org/10.1016/S0020-1383(16)30009-2

[27] Huang, J., Liu, Z. L., Ji, C., Wang, X. Z., Li, X. Y., Yang, X. M., Hu, Y. Propensity score-matched analysis of enhanced recovery after surgery in total hip arthroplasty for displaced femoral neck fractures. *Injury*, **2023**, 54(12): 111132. https://doi.org/10.1016/j.injury.2023.111132

[28] Peng, M. Q., Wen, C. H., Wei, Y. X., Zhang, W., Liu, Z. Y., Zhang, Y. H., Li, S. Q. Impact of risk early warning management on postoperative rehabilitation quality and incidence of delirium in patients with unilateral intertrochanteric femur fracture. *Annali Italiani Di Chirurgia*, **2025**, 96(9): 1198. https://doi.org/10.62713/aic.4123

[29] Kang, M., Lai, X., Wu, J. R., Xiang, Q., Chen, L. W., Li, X., Su, J. W., Ma, Z., Wang, Y. L., Zhao, W. J. et al. Saccade tasks: A noninvasive approach for predicting postoperative delirium in elderly arthroplasty patients. *Anesthesiology*, **2026**, 144(3): 622–633. https://doi.org/10.1097/aln.0000000000005875

[30] Duch, P., Wikkelsø, A., Jørgensen, C. C., Jakobsen, J. C., Mathiesen, O., Nørskov, A. K., Nedergaard, H. Pain and adverse effects after Caesarean delivery: A nationwide prospective cohort study. *European Journal of Anaesthesiology*, **2026**, 43(1): 34–44. https://doi.org/10.1097/eja.0000000000002277

[31] Pogatzki-Zahn, E. M., De Lucia, S., Weinmann, C., Heitkamp, H., Hummelshoj, L., Liedgens, H., Meissner, W., Vincent, K., Vollert, J., Zahn, P. et al. A core outcome set of measurement instruments for assessing effectiveness and efficacy of perioperative pain management: Results of the international IMI-PainCare PROMPT Delphi consensus process. *British Journal of Anaesthesia*, **2025**, 134(5): 1460–1473. https://doi.org/10.1016/j.bja.2025.01.029

[32] Eneroth, M., Olsson, U. B., Thorngren, K. G. Nutritional supplementation decreases hip fracture-related complications. *Clinical Orthopaedics and Related Research*, **2006**, 451: 212–217. https://doi.org/10.1097/01.blo.0000224054.86625.06

[33] Gao, Y. Z., Zhong, F. F., Zhan, X. Y., Bao, Y. C., Zhu, X. H. Postoperative rehabilitation exercise experiences of geriatric patients with femoral neck fractures based on the perspective of medical staff: A qualitative study. *BMC Geriatrics*, **2024**, 24: 667. https://doi.org/10.1186/s12877-024-05266-w

[34] Liu, J. X., Chen, L., Long, C., Zhang, X., Gao, F., Duan, X., Xiang, Z. Effect of a preoperative mobilization program on perioperative complications and function recovery in older adults with femoral neck fracture. *Geriatric Nursing*, **2022**, 44: 69–75. https://doi.org/10.1016/j.gerinurse.2022.01.003

[35] Dohrn, I. M., Hagströmer, M., Hellénius, M. L., Ståhle, A. Short- and

long-term effects of balance training on physical activity in older adults with osteoporosis: A randomized controlled trial. *Journal of Geriatric Physical Therapy*, **2017**, 40(2): 102–111. https://doi.org/10.1519/jpt.0000000000000077

[36] Lee, S. H., Yu, S. Effectiveness of multifactorial interventions in preventing falls among older adults in the community: A systematic review and meta-analysis. *International Journal of Nursing Studies*, **2020**, 106: 103564. https://doi.org/10.1016/j.ijnurstu.2020.103564

[37] Bhange, M., Telange, D. Convergence of nanotechnology and artificial intelligence in the fight against liver cancer: A comprehensive review. *Discover Oncology*, **2025**, 16: 77. https://doi.org/10.1007/s12672-025-01821-y

[38] Wang, P., Yuan, Y. H., Xu, K., Zhong, H. S., Yang, Y. H., Jin, S. Y., Yang, K., Qi, X. Biological applications of copper-containing materials. *Bioactive Materials*, **2021**, 6(4): 916–927. https://doi.org/10.1016/j.bioactmat.2020.09.017

[39] Ji, H. Z., Shen, G., Liu, H. H., Liu, Y., Qian, J. Y., Wan, G. J., Luo, E. Biodegradable Zn-2Cu-0.5Zr alloy promotes the bone repair of senile osteoporotic fractures *via* the immune-modulation of macrophages. *Bioactive Materials*, **2024**, 38: 422–437. https://doi.org/10.1016/j.bioactmat.2024.05.003

[40] Wu, C. S., Li, H. P., Hsieh, C. H., Lin, Y. T., Yi-Feng Chang, I., Chung, A. K., Huang, Y., Ueng, S. H., Hsiao, Y. C., Chien, K. Y. et al. Integrated multi-omics analyses of oral squamous cell carcinoma reveal precision patient stratification and personalized treatment strategies. *Cancer Letters*, **2025**, 614: 217482. https://doi.org/10.1016/j.canlet.2025.217482

[41] Ferreira, P. C., De Oliveira, R. I. P., Vaz, M. D., Bentes, C., Costa, H. Opioid-free anaesthesia reduces complications in head and neck microvascular free-flap reconstruction. *Journal of Clinical Medicine*, **2023**, 12(20): 6445. https://doi.org/10.3390/jcm12206445

[42] Thilagesh, P., Anand Kumar, S., Aiswarya Nair, U., Rabiniraj, S., Shobana, P., Subramani, M., Sriram, K. Artificial intelligence (AI) and liquid biopsy transforming early detection of liver metastases in gastrointestinal cancers. *Current Cancer Drug Targets*, **2026**, 26(3): 289–299. https://doi.org/10.2174/0115680096331238241125051307