

Determinants of Mortality After Hip Fracture Surgery in Older Adults: Influence of Surgical, Anesthetic, and Radiologic Factors — A Systematic Review and Meta-Analysis

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ABSTRACT

Background: Hip fractures in older adults are associated with substantial morbidity and mortality, particularly within the first year following surgery. Identifying modifiable perioperative determinants is essential for improving outcomes and optimizing healthcare systems.

Objective: To evaluate the impact of surgical timing, anesthetic technique, and perioperative transfusion on mortality in older adults undergoing hip fracture surgery, and to narratively assess radiologic determinants.

Methods: A systematic review and meta-analysis were conducted following PRISMA 2020 guidelines. Major databases including PubMed/MEDLINE, Cochrane Library, Embase, Web of Science, and Scopus were searched up to 2025. Observational studies assessing mortality outcomes and relevant determinants were included. Random-effects meta-analysis was performed where ≥ 3 comparable studies were available. Risk of bias was assessed using the Newcastle–Ottawa Scale, and certainty of evidence was evaluated using GRADE.

Results: Nine studies involving over 300,000 patients were included. Surgical delay beyond 48 hours was associated with increased 30-day mortality (pooled OR 1.42, 95% CI 1.20–1.68; $I^2 \approx 11\%$). No significant difference was observed between general and spinal/regional anesthesia (pooled OR 0.98, 95% CI 0.94–1.03; $I^2 = 0\%$). Blood transfusion was associated with higher mortality (pooled RR 1.33–1.53), although this likely reflects confounding by indication. Radiologic determinants showed inconsistent associations due to heterogeneity in classification systems and reporting.

Conclusion: Early surgical intervention within 48 hours is associated with improved survival. Anesthetic technique does not significantly influence mortality, while transfusion appears to be a marker of disease severity rather than a causal factor. Standardization of radiologic reporting and improved study designs are needed to strengthen future evidence.

Keywords: Hip fracture, mortality, surgical delay, anesthesia, transfusion, elderly, meta-analysis

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Introduction

Hip fractures represent a major global health burden, particularly among older adults. With increasing life expectancy and aging populations worldwide, the incidence of hip fractures is expected to rise substantially in the coming decades. These injuries are associated with significant morbidity, functional decline, and mortality, with reported 30-day mortality rates ranging from 5% to 10% and one-year mortality reaching up to 30%.

The management of hip fractures typically involves surgical intervention, which aims to restore mobility, reduce pain, and minimize complications associated with prolonged immobilization. However, outcomes vary considerably depending on patient characteristics, healthcare system factors, and perioperative management strategies.

Among the various determinants of mortality, several potentially modifiable factors have been identified. These include the timing of surgery, anesthetic technique, and perioperative transfusion practices. Early surgery is often advocated to reduce complications such as thromboembolism, pneumonia, and pressure ulcers. Similarly, the choice between general and spinal anesthesia has been widely debated, with conflicting evidence regarding its impact on mortality and postoperative complications. Blood transfusion, commonly required in this patient population due to anemia and intraoperative blood loss, has also been associated with adverse outcomes, although its causal role remains unclear.

In addition to these perioperative factors, radiologic characteristics such as fracture type, displacement, and bone quality may influence surgical complexity and outcomes. However, the role of radiologic determinants in predicting mortality has not been consistently established due to variability in classification systems and reporting.

Given these uncertainties, a comprehensive synthesis of available evidence is required to better understand the relative importance of these determinants. This systematic review and meta-analysis aims to evaluate the impact of surgical timing, anesthetic technique, and transfusion on mortality following hip fracture surgery in older

adults, while also providing a narrative assessment of radiologic factors.

Methods

Study Design

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines.

Search Strategy

A comprehensive literature search was performed across the following databases:

PubMed/MEDLINE

Cochrane Library

Embase

Web of Science

Scopus

Search terms included combinations of controlled vocabulary and keywords related to:

Population: “hip fracture,” “femoral neck fracture,” “intertrochanteric fracture”

Intervention: “surgery,” “time-to-surgery,” “anesthesia,” “transfusion”

Outcome: “mortality,” “30-day mortality,” “1-year mortality”

Citation chasing and reference list screening were also performed to identify additional relevant studies.

Eligibility Criteria

Inclusion Criteria:

Adults undergoing surgical management of hip fractures

Studies including patients aged ≥ 60 years or clearly geriatric populations

Reported postoperative mortality outcomes (in-hospital, 30-day, 90-day, or 1-year)

Evaluated at least one determinant (surgical timing, anesthetic technique, transfusion, or radiologic factors)

Exclusion Criteria:

Nonoperative management

Elective arthroplasty for osteoarthritis

Periprosthetic or pathological fractures without separable data

Studies without extractable effect measures

Non-English studies without sufficient translation data

Data Extraction

Data were extracted independently and included:

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- Study characteristics: author, year, country, design, sample size
- Patient characteristics: age, sex distribution
- Determinants: surgical timing, anesthesia type, transfusion, radiologic classification
- Outcomes: mortality timepoints and definitions
- Effect measures: odds ratios (OR), risk ratios (RR), hazard ratios (HR)

Risk of Bias Assessment

Observational studies were assessed using the Newcastle–Ottawa Scale (NOS), focusing on selection, comparability, and outcome assessment domains.

Certainty of Evidence

The GRADE framework was applied to assess the overall certainty of evidence for each determinant.

Statistical Analysis

Meta-analysis was conducted when at least three studies reported comparable exposures and outcomes.

- Random-effects model (DerSimonian–Laird method)
- Heterogeneity assessed using I^2 statistic
- Effect measures harmonized where necessary
- Sensitivity analyses performed to assess robustness

Results

Study Characteristics

Nine studies were included, comprising a mix of large registry-based analyses and single-center cohorts. Sample sizes ranged from 388 to over 100,000 patients. Most studies reported 30-day mortality as the primary outcome.

Surgical Timing

Three studies evaluated the impact of surgical delay beyond 48 hours.

The pooled analysis demonstrated:

- **OR 1.42 (95% CI 1.20–1.68; $I^2 \approx 11\%$)**
This indicates a statistically significant increase in mortality associated with delayed surgery.

Interpretation:

The consistency of findings across studies suggests that early surgery is beneficial. Delays may contribute to complications related to immobilization, including respiratory infections, thromboembolism, and cardiovascular instability. However, residual confounding remains a concern, as sicker patients may experience unavoidable delays for medical optimization.

Anesthetic Technique

Three studies compared general anesthesia with spinal/regional anesthesia.

The pooled estimate showed:

OR 0.98 (95% CI 0.94–1.03; $I^2 = 0\%$)

There was no statistically significant difference in mortality between the two approaches.

Interpretation:

These findings suggest that anesthetic technique alone does not significantly influence short-term mortality. Instead, perioperative management factors such as hemodynamic stability, sedation depth, and postoperative care may play a more important role.

Transfusion

Three studies evaluated the association between blood transfusion and mortality.

The pooled results showed:

RR 1.53 (95% CI 1.10–2.12; $I^2 \approx 65\%$)

Sensitivity analysis: **RR 1.33 (95% CI 1.12–1.57; $I^2 = 0\%$)**

Interpretation:

Patients receiving transfusions had higher mortality rates. However, this association is likely confounded by underlying severity, including anemia, bleeding, and frailty. Therefore, transfusion should be considered a marker of risk rather than a direct cause of mortality.

Radiologic Determinants

Radiologic factors were assessed qualitatively due to heterogeneity in reporting.

More complex fracture patterns (e.g., subtrochanteric fractures) were associated with worse outcomes

Displacement and bone quality may influence surgical complexity

However, variability in classification systems (e.g., AO/OTA, Garden classification) limited comparability.

Discussion

This systematic review and meta-analysis provides a comprehensive synthesis of key determinants influencing mortality following hip fracture surgery in older adults. By focusing on clinically actionable domains—surgical timing, anesthetic technique, transfusion practices, and radiologic characteristics—this study highlights both modifiable and non-modifiable contributors to postoperative mortality. The findings reinforce the importance of system-level efficiency, individualized perioperative care, and the need for improved data standardization in future research.

Surgical Timing and Mortality

The most robust and clinically meaningful finding of this analysis is the association between delayed surgery beyond 48 hours and increased 30-day mortality. The pooled estimate (OR 1.42, 95% CI 1.20–1.68) demonstrates a consistent direction of effect across heterogeneous healthcare systems and study designs. This finding aligns with a substantial body of prior literature emphasizing the importance of early surgical intervention in hip fracture patients.

The biological plausibility of this association is well established. Delayed surgery prolongs immobilization, which predisposes patients to complications such as venous thromboembolism, pneumonia, pressure ulcers, and muscle deconditioning. Additionally, prolonged pain and inflammatory responses may exacerbate cardiovascular stress, particularly in frail elderly individuals with limited physiological reserve. Early surgery facilitates mobilization, reduces hospital stay, and may prevent the cascade of complications that ultimately contribute to mortality.

However, the interpretation of this association must be approached with caution due to the potential for confounding by indication. Patients who experience surgical delays are often those with greater comorbidity burden or acute medical instability requiring optimization prior to anesthesia. Studies included in this analysis attempted to adjust for confounders such as age, comorbidities, and ASA classification, yet residual confounding remains inevitable in observational designs. Notably, attenuation of effect sizes after adjustment for ASA status in some studies suggests that baseline patient severity partially explains the observed association.

Despite these limitations, the consistency of findings across multiple studies and the low heterogeneity ($I^2 \approx 11\%$) strengthen the argument for a true association. From a clinical and systems perspective, the emphasis should be on minimizing avoidable delays rather than indiscriminately expediting surgery. Implementation of orthogeriatric co-management models, standardized preoperative protocols, and dedicated operating room pathways have been shown to reduce time-to-surgery and improve outcomes. Therefore, the findings of this study support current guideline recommendations

advocating surgery within 24–48 hours, while acknowledging the necessity of individualized clinical judgment.

Anesthetic Technique and Mortality

The analysis of anesthetic technique revealed no significant difference in 30-day mortality between general and spinal/regional anesthesia (pooled OR 0.98, 95% CI 0.94–1.03). This finding is consistent with contemporary large-scale observational studies and randomized controlled trials, including the REGAIN trial, which reported no survival advantage associated with spinal anesthesia at similar time horizons.

The lack of mortality difference suggests that anesthetic modality alone is unlikely to be a primary determinant of survival in this population. Instead, mortality appears to be driven predominantly by patient-related factors such as frailty, comorbidity burden, and baseline physiological reserve, as well as system-level factors such as surgical timing and postoperative care.

It is important to recognize that anesthetic technique is not a binary variable but encompasses a range of intraoperative management strategies. Factors such as sedation depth, hemodynamic stability, fluid management, oxygenation, and analgesia may have a more significant impact on outcomes than the choice between general and spinal anesthesia per se. For example, intraoperative hypotension has been associated with adverse outcomes, including myocardial injury and acute kidney injury, which may indirectly influence mortality.

Additionally, spinal anesthesia without heavy sedation has been suggested to reduce the incidence of postoperative delirium, a common complication in elderly patients that is associated with increased mortality and prolonged hospitalization. However, such intermediate outcomes were not consistently reported across studies and therefore could not be quantitatively analyzed in this review.

The findings of this analysis have important clinical implications. Rather than prioritizing one anesthetic technique over another, clinicians should focus on optimizing perioperative management, tailoring anesthetic approach to individual patient characteristics, and minimizing intraoperative complications. Future research should aim to disentangle the effects of specific anesthetic practices, including sedation strategies

and hemodynamic targets, rather than treating anesthesia as a homogeneous exposure.

Transfusion and Mortality

The association between perioperative blood transfusion and increased mortality observed in this analysis (pooled RR 1.33–1.53) highlights a complex and clinically relevant issue. While transfused patients demonstrated higher mortality rates, the causal relationship remains uncertain due to significant confounding by indication.

Patients requiring transfusion are typically those with greater intraoperative blood loss, pre-existing anemia, or higher surgical complexity—all of which are independently associated with worse outcomes. Therefore, transfusion may serve as a surrogate marker of disease severity rather than a direct contributor to mortality. This interpretation is supported by the reduction in heterogeneity and attenuation of effect size observed in sensitivity analyses excluding smaller, high-risk cohorts.

From a pathophysiological perspective, transfusion-related complications such as immunomodulation, infection risk, and circulatory overload could theoretically contribute to adverse outcomes. However, contemporary transfusion practices have improved safety profiles, and evidence from randomized trials in other surgical populations suggests that restrictive transfusion strategies are generally safe.

The findings of this study underscore the importance of patient blood management (PBM) strategies in hip fracture care. These include preoperative optimization of anemia, use of antifibrinolytic agents such as tranexamic acid, meticulous surgical technique to minimize blood loss, and adherence to evidence-based transfusion thresholds. Importantly, clinicians should avoid both under-transfusion, which may lead to tissue hypoxia, and over-transfusion, which may expose patients to unnecessary risks.

Future research should focus on distinguishing the independent effects of anemia, blood loss, and transfusion, ideally through well-designed prospective studies or randomized trials. Advanced statistical methods such as propensity score matching and instrumental variable analysis may also help mitigate confounding in observational data.

Radiologic Determinants and Mortality

Radiologic factors, including fracture type, displacement, and bone quality, represent an important but underexplored domain in the context of mortality after hip fracture surgery. While some studies suggest that more complex fracture patterns, such as subtrochanteric fractures, are associated with higher mortality, the evidence remains inconsistent and insufficient for quantitative synthesis.

One potential explanation is that radiologic characteristics are closely intertwined with both patient factors and surgical complexity. For example, extracapsular fractures may be associated with greater blood loss and longer operative times, which could indirectly influence outcomes. Similarly, poor bone quality may reflect underlying osteoporosis and frailty, both of which are associated with increased mortality.

The lack of standardized reporting across studies represents a major limitation in this . Different classification systems, such as AO/OTA and Garden classification, are used inconsistently, and detailed radiologic parameters are often not captured in large administrative databases. As a result, the ability to compare findings across studies and perform meta-analysis is limited.

To address these gaps, future research should prioritize the development of standardized radiologic datasets integrated with clinical and outcome data. Advances in imaging techniques, including quantitative CT and artificial intelligence-based fracture analysis, may provide more objective and reproducible measures of fracture severity and bone quality. Such approaches could enhance risk stratification and inform surgical decision-making.

Integration of Findings and Clinical Implications

Taken together, the findings of this study emphasize that mortality after hip fracture surgery is multifactorial, with contributions from patient characteristics, surgical factors, and healthcare system processes. Among the determinants evaluated, surgical timing emerges as the most consistently modifiable factor, highlighting the importance of efficient care pathways.

The lack of mortality difference between anesthetic techniques suggests that clinical focus should shift toward optimizing perioperative care rather than debating anesthetic modality.

Similarly, the association between transfusion and mortality underscores the need for careful interpretation of observational data and the importance of individualized patient management. From a systems perspective, the implementation of multidisciplinary care models, including orthogeriatric collaboration, has been shown to improve outcomes in hip fracture patients. These models facilitate early surgery, comprehensive medical optimization, and coordinated postoperative care, addressing multiple determinants simultaneously.

Research Gaps and Future Directions

Despite the insights provided by this study, several important gaps remain. First, the predominance of observational data limits causal inference. While randomized trials are challenging in this population, innovative study designs such as target trial emulation and pragmatic trials may provide more robust evidence.

Second, there is a need for standardized definitions and reporting of key variables, particularly radiologic and anesthetic factors. The development of core outcome sets and data standards would enhance comparability across studies and facilitate meta-analysis.

Third, future research should explore subgroup-specific effects, including differences based on frailty, comorbidity burden, and functional status. Identifying high-risk subgroups may enable targeted interventions with greater impact on mortality.

Finally, the integration of large-scale registry data with detailed clinical and imaging information represents a promising avenue for advancing research in this field.

Strengths and Limitations of the Study

This study has several strengths, including a focused evaluation of clinically relevant determinants, use of meta-analysis to synthesize available evidence, and application of standardized risk of bias and certainty assessment frameworks.

However, limitations must be acknowledged. The reliance on observational studies introduces potential bias and confounding. Heterogeneity in study designs, populations, and outcome definitions may affect the generalizability of findings. Additionally, the limited number of studies available for each determinant restricts the

ability to explore publication bias and perform subgroup analyses.

In conclusion, this analysis highlights the critical role of timely surgical intervention in reducing mortality after hip fracture surgery in older adults. Anesthetic technique does not appear to significantly influence survival, while transfusion reflects underlying patient risk rather than causation. Radiologic determinants remain an area of uncertainty due to inconsistent reporting. Future research should focus on improving data standardization, reducing confounding, and identifying targeted interventions to further improve outcomes in this vulnerable population.

Conclusion

Early surgical intervention within 48 hours is associated with reduced mortality in older adults with hip fractures. Anesthetic technique does not significantly influence survival, while transfusion reflects underlying patient risk rather than causation. Future research should focus on standardized data collection and advanced study designs to improve causal inference.

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