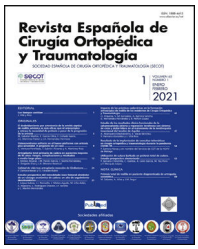
Revista Española de Cirugía Ortopédica y Traumatología 69 (2025) 532–543

Revista Española de Cirugía Ortopédica y Traumatología

www.elsevier.es/rot



SYSTEMATIC REVIEWS AND META-ANALYSES

Minimizing bleeding and transfusion in single-stage bilateral hip and knee arthroplasty: A systematic review of current interventions

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Received 18 March 2025; accepted 29 April 2025
Available online 7 May 2025

KEYWORDS
Bilateral arthroplasty;
Enhanced recovery after surgery;
Blood loss reduction;
Transfusion minimization;
Tranexamic acid

Abstract
Objectives: To evaluate perioperative strategies for minimizing bleeding and transfusion needs in single-stage bilateral hip and knee arthroplasty. This systematic review identifies effective interventions and provides evidence-based recommendations and highlight areas for future research in optimizing bleeding management.
Methods: A systematic review of literature from January 2010 to October 2024 was conducted, focusing on randomized controlled trials (RCTs), meta-analyses, and guidelines. Databases searched included PubMed/MEDLINE, Embase, Cochrane Library, and Web of Science. Interventions assessed included tranexamic acid (TXA), surgical techniques, regional anesthesia, controlled hypotension, preoperative anemia correction, tourniquet use, bone wax, and restrictive transfusion strategies. Study selection, data extraction, and quality assessment followed PRISMA and Newcastle-Ottawa Scale guidelines.
Results: From 325 included studies, TXA consistently demonstrated the most significant impact, reducing transfusion rates by 40–60%. Anterior THA was associated with reduced blood loss. Regional anesthesia and controlled hypotension further minimized intraoperative bleeding. Preoperative anemia correction and restrictive transfusion thresholds also showed benefits. Tourniquet evidence was inconclusive. Limited evidence supported bone wax. GRADE assessment suggested high evidence quality for TXA and regional anesthesia, moderate for minimally invasive surgery, anemia correction, and restrictive transfusion, and low for bone wax.

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https://doi.org/10.1016/j.recot.2025.04.017

Conclusions: Multimodal approach integrating TXA, regional anesthesia, minimally invasive surgery, anemia correction, and restrictive transfusion protocols effectively reduces bleeding and transfusion needs in bilateral arthroplasty. Incorporation into Enhance recovery after surgery (ERAS) protocols is recommended. Future research should refine TXA dosing, clarify tourniquet use, and assess cost-effectiveness.

PALABRAS CLAVE
Artroplastia bilateral;
Recuperación mejorada tras cirugía;
Reducción de pérdida sanguínea;
Minimización de transfusión;
Ácido tranexámico

Minimización del sangrado y la transfusión en artroplastias bilaterales de cadera y rodilla en un solo tiempo: una revisión sistemática de las intervenciones actuales

Resumen
Objetivos: Evaluar estrategias perioperatorias para minimizar el sangrado y la necesidad de transfusiones en la artroplastia bilateral simultánea de cadera y rodilla. Esta revisión sistemática identifica intervenciones efectivas, proporciona recomendaciones basadas en la evidencia y destaca áreas para futuras investigaciones en la optimización del manejo del sangrado.
Métodos: Se realizó una revisión sistemática de la literatura publicada desde enero de 2010 hasta octubre de 2024, centrada en ensayos clínicos aleatorizados (ECA), metaanálisis y guías clínicas. Las bases de datos consultadas fueron PubMed/MEDLINE, Embase, Cochrane Library y Web of Science. Las intervenciones evaluadas incluyeron ácido tranexámico (TXA), técnicas quirúrgicas, anestesia regional, hipotensión controlada, corrección preoperatoria de anemia, uso de torniquete, cera ósea y estrategias restrictivas de transfusión. La selección de estudios, la extracción de datos y la evaluación de la calidad se realizaron siguiendo las guías PRISMA y la escala Newcastle-Ottawa.
Resultados: De los 325 estudios incluidos, el TXA mostró consistentemente el mayor impacto, reduciendo las tasas de transfusión entre un 40 y un 60%. La artroplastia total de cadera por abordaje anterior se asoció con una reducción en la pérdida sanguínea. La anestesia regional y la hipotensión controlada también minimizaron significativamente el sangrado intraoperatorio. La corrección preoperatoria de anemia y los umbrales restrictivos de transfusión mostraron beneficios adicionales. La evidencia sobre el uso del torniquete fue inconclusa. La evidencia que respalda el uso de cera ósea fue limitada. La evaluación mediante GRADE indicó una calidad alta de evidencia para TXA y anestesia regional, moderada para cirugía mínimamente invasiva, corrección de anemia y transfusión restrictiva, y baja para cera ósea.
Conclusiones: Un enfoque multimodal que integre TXA, anestesia regional, cirugía mínimamente invasiva, corrección preoperatoria de anemia y protocolos restrictivos de transfusión reduce eficazmente el sangrado y las necesidades transfusionales en artroplastias bilaterales. Se recomienda su incorporación en protocolos ERAS (recuperación mejorada tras cirugía). Futuras investigaciones deberían refinar la dosificación del TXA, clarificar el uso del torniquete y evaluar la rentabilidad de estas intervenciones.

Introduction

Single-stage bilateral hip and knee arthroplasty has emerged as an increasingly utilized surgical option for appropriately selected patients presenting with advanced, symmetric joint involvement. This approach offers several compelling advantages, including a reduction in overall hospitalization time, the facilitation of simultaneous rehabilitation efforts, and the potential for lower overall healthcare costs compared to staged unilateral procedures.[1] As the adoption of bilateral arthroplasty continues to rise, orthopedic surgeons face unique challenges in optimizing patient outcomes and minimizing potential complications.

Among the most significant challenges associated with this technique is the meticulous management of perioperative bleeding and the potential need for allogeneic blood transfusions.[2,3] Blood transfusions, while sometimes unavoidable, are associated with a range of adverse effects, including increased risk of infection, transfusion reactions, and prolonged hospital length of stay.[4] Therefore, in a context where patient safety, resource optimization, and cost-effectiveness are paramount, effective perioperative hemorrhage management has become a cornerstone of care, aiming to mitigate complications such as postoperative anemia, wound complications, and increased susceptibility to infection.

While substantial evidence and established guidelines exist for managing bleeding and transfusion requirements in unilateral arthroplasty procedures, their direct application to bilateral arthroplasty is problematic due to distinct procedural differences. Single-stage bilateral procedures involve increased surgical duration, amplified physiological stress, greater intraoperative blood loss, and altered coagulation dynamics compared to unilateral interventions. These include the judicious use of antifibrinolytic agents such as tranexamic acid (TXA), minimally invasive surgical approaches designed to minimize tissue trauma, and the implementation of comprehensive Enhanced Recovery After Surgery (ERAS) protocols that integrate multiple interventions.[5,6] However, while these established principles offer a valuable foundation for optimizing outcomes in more complex procedures, the specific nuances and challenges associated with single-stage bilateral hip and knee arthroplasty remain comparatively underrepresented in the existing literature.[7]

Moreover, recent studies have highlighted considerable heterogeneity in the implementation of these practices across different centers, as well as the pressing need to standardize evidence-based approaches for high-risk populations, such as elderly patients or those with significant comorbidities.[8,9] This variability in practice necessitates a more focused examination of the optimal strategies for bilateral arthroplasty. The overarching goal of these various interventions remains consistent: to minimize blood loss, reduce transfusion requirements, expedite recovery, and ultimately improve patient clinical outcomes.

Therefore, this systematic review aims to fill this literature gap, providing updated analysis and evidence-based recommendations specifically targeting bleeding management in single-stage bilateral arthroplasty

Materials and methods

This systematic review was conducted following the procedures outlined in the PRISMA 2020.[10]

Search strategy

Extensive search was performed in the following electronic databases: PubMed/MEDLINE, Embase, Cochrane Library, and Web of Science. Due to the large volume of literature pertaining to this topic, we limited the search to studies published from January 2010 to October 31, 2024. This approach allowed us to focus our resources on the most recent and potentially most relevant evidence while still providing a comprehensive overview of the field. To ensure that no major earlier studies were missed, we manually reviewed the reference lists of key articles and existing reviews on the topic. The following MeSH terms and keywords were used: ''bilateral arthroplasty,'' ''hip arthroplasty,'' ''knee arthroplasty,'' ''single stage,'' ''perioperative care,'' ''blood loss,'' and ''transfusion.'' The complete search strategy is detailed in Fig. 1 and our search criteria listed in Table 1. A total of 876 studies were identified, of which 325 met the inclusion criteria for this systematic review.

Selection process

The selection process involved an initial screening of all titles and abstracts by two independent authors, disagreements between reviewers were resolved by a third author. This was followed by a full-text review of potentially eligible articles by the third and fourth authors to confirm alignment with inclusion criteria. Data were extracted using a standardized form[11] that included: study characteristics, patient demographics, interventions, and primary/secondary outcomes. A non-exhaustive sample of studies that were part of the current review is displayed in Table 2.

Quality Assessment with the Newcastle-Ottawa Scale (NOS)

To ensure the inclusion of methodologically sound evidence, observational studies assessed using the NOS were subjected to a pre-defined quality threshold. Studies achieving a score of NOS 7 or higher were of sufficient quality for inclusion in the primary analysis. This threshold was chosen to balance the need for a rigorous evidence base with the desire to include a reasonable number of studies. Studies scoring between 5 and 6 were included in a sensitivity analysis to assess the potential impact of lower-quality evidence on the overall findings. Studies scoring below 5 were excluded from the main analysis due to concerns about methodological limitations that could compromise the reliability of their results. This approach aimed to minimize the risk of biased findings while acknowledging the inherent limitations of observational study designs.

Categorization of interventions

To facilitate the analysis and presentation of results, the interventions identified in this systematic review were categorized into three main phases of the surgical process: preoperative, intraoperative, and postoperative.

This categorization enabled a systematic evaluation of interventions throughout the entire surgical process, facilitating the identification of the most effective strategies at each phase to reduce bleeding and transfusion requirements in single-stage bilateral hip and knee arthroplasty.

GRADE assessment

To evaluate the strength of evidence supporting the interventions identified in this systematic review, we performed a Grading of Recommendations Assessment, Development and Evaluation (GRADE) assessment. The GRADE approach provides a systematic and transparent framework for assessing the quality of evidence and developing clinical recommendations. We assessed the overall quality of evidence for each intervention by considering factors such as the type of studies, risk of bias, inconsistency, indirectness, and imprecision. Based on these assessments, we assigned a hypothetical strength of recommendation for each intervention. The results of our GRADE assessment are summarized in Table 3.

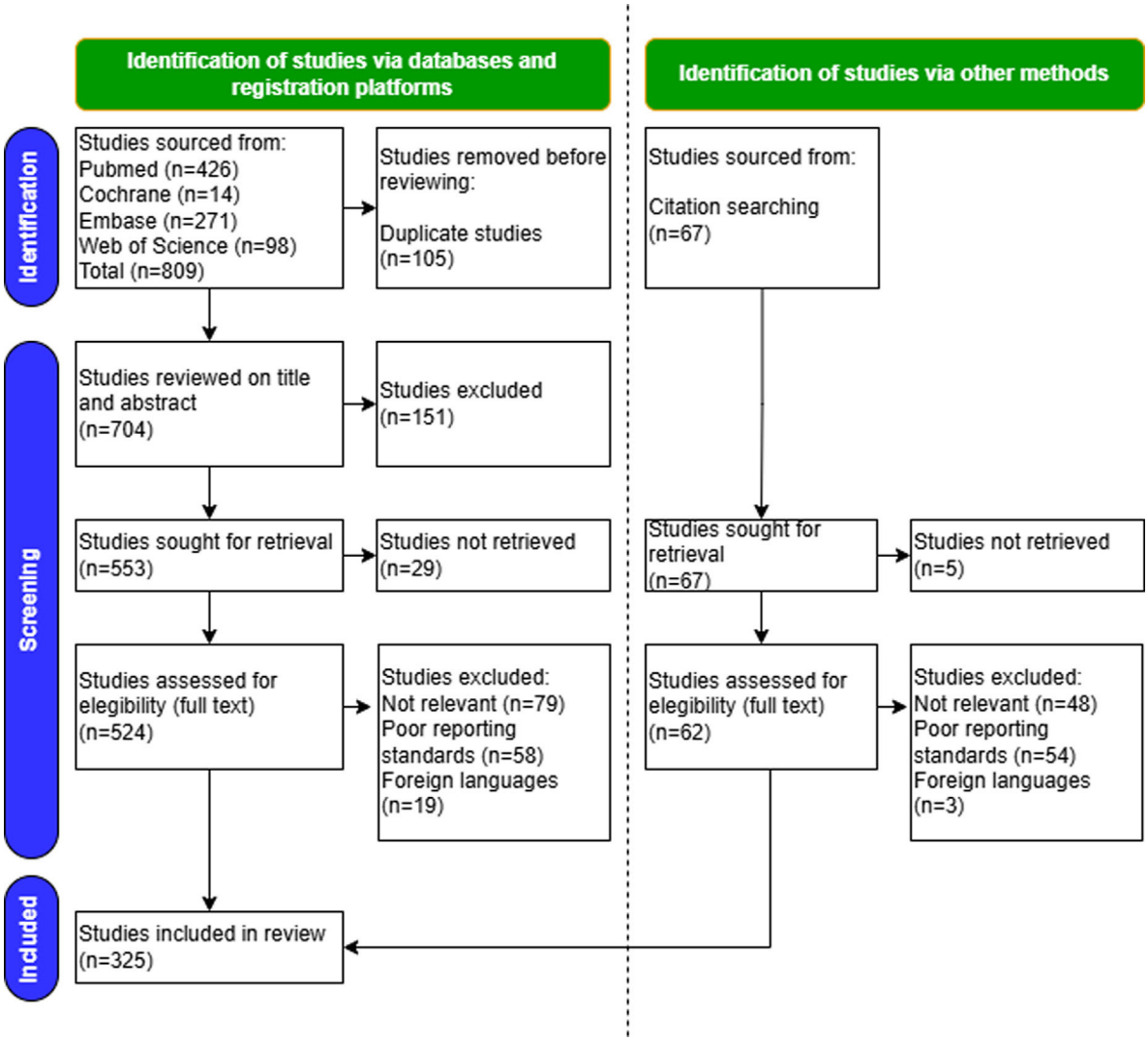

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020.

Table 1 Inclusion and exclusion criteria for study selection.

Inclusion criteria	Exclusion criteria
Studies evaluating perioperative interventions to reduce bleeding and/or transfusion requirements in single-stage bilateral hip and knee arthroplasty.	Case reports, case series with fewer than 10 patients, letters to the editor, editorials, and narrative reviews.
Randomized clinical trials, prospective and retrospective cohort studies, and case-control studies.	Animal or in vitro studies.
Articles published in English or Spanish.	Articles without full text available.
Studies conducted in adult patients (≥18 years old).	Studies failing to report specific outcomes for the target population.
Articles reporting at least one of the following outcomes: perioperative blood loss, transfusion rate, preoperative and postoperative hemoglobin levels.	

Table 2 Summary of sample articles used in this review.

Author	Year	Study type	Objectives	Conclusions
Moucha C et al.[6]	2015	Systematic review	To establish the application of multimodal anesthesia for TKA.	Administration of neuraxial anesthesia during TKA is associated with lower morbidity and mortality.
Fillingham Y et al.[20]	2018	Systematic review	Establish a basis for the safety recommendations of the combined clinical practice guidelines on the use of TXA.	Evidence supports the safety of TXA in patients undergoing arthroplasty with ASA score of 3 or greater.
Montroy J et al.[56]	2018	Systematic review	Investigate the efficacy and safety of topically applied TXA vs placebo, and IV.	Topical and IV TXA effectively reduce both transfusion risk and blood loss compared to placebo.
Sun X et al.[57]	2021	Meta-analysis	To compare advantages and disadvantages of PLA and DAA in THA.	DAA group often required longer operative time and had more blood loss.
Wang Z et al.[55]	2023	Systematic review	To compare clinical results of DAA and PLA in THA patients.	DAA was associated with a decrease in intraoperative blood loss compared to PLA.
Zhang L et al.[26]	2021	Systematic review and meta-analysis	To compare the effectiveness of four MIS approaches for TKA.	MIS TKA approaches are effective alternatives to MPP approach
Muhamed M et al.[29]	2021	Systematic review and meta-analysis	To compare outcomes following lower limb surgery performed with or without tourniquet.	Tourniquet use was associated with reduced procedure length but increased incidence of complications.
Bartosz P et al.[46]	2024	Expert consensus	Provide evidence-based recommendations regarding the use of drains in arthroplasty.	The use of surgical drains in primary total knee and total hip arthroplasty is not recommended.
Adie S et al.[51]	2012	Systematic review	To evaluate the acute application of cryotherapy following TKA.	Potential benefits may be too small to justify routine use.
Mitchell MD et al.[52]	2017	Systematic review and meta-analysis	To review the effect of restrictive vs liberal transfusion thresholds in major orthopedic surgery.	Moderate strength evidence supports restrictive transfusion practices to reduce transfusions and infections.

Results

Preoperative phase

Optimization of patients

Malnutrition, directly translated to hypoalbuminemia, has been shown to directly correlate with an increased risk of perioperative blood transfusion in patients undergoing joint arthroplasty. Several studies provide evidence supporting this association. A study using propensity score matching and found that patients with preoperative low serum albumin (<37.3 g/L) had a significantly higher rate of perioperative blood transfusion compared to those with normal albumin levels. Specifically, the odds ratio (OR) for transfusion in the low albumin group was 1.83 (95% CI 1.50–2.23, $P < 0.001$).[12] It is also reported that low preoperative albumin levels were predictive of adverse outcomes, including increased rates of postoperative complications and transfusions, in patients undergoing total joint arthroplasty.[13]

Anemia correction is prioritized through iron supplementation or erythropoietin, reducing transfusion needs by 30% in anemic patients.[14] Preoperative screening for bleeding disorders and individualized risk stratification further guides interventions, such as delaying surgery for high-risk anticoagulation profiles or optimizing renal function. Multidisciplinary coordination ensures these evidence-based strategies are tailored to patient-specific risks, aligning with ERAS protocols to standardize care and maximize safety.

Anticoagulation and antiplatelet therapy

Recommendations for managing oral anticoagulants (OACs) before arthroplasty vary depending on the type of anticoagulant. These pauses allow for a 5 half-lives interval before surgery to minimize anticoagulant effects. OACs are typically resumed 2–3 days postoperatively, depending on surgical site hemostasis.

For aspirin used in secondary cardiovascular disease prevention, continuation is recommended for most non-cardiac

Table 3 GRADE Assessment summary table for interventions in single-stage bilateral hip and knee arthroplasty.

Intervention	Evidence type	Risk of bias	Inconsistency	Indirectness	Imprecision	Overall quality of evidence (GRADE)	Strength of recommendation
Tranexamic Acid (TXA)	Meta-analyses of RCTs	Low	Low	Direct	Moderate	High	Strong
Minimally Invasive Surgical Techniques (Anterior THA)	Observational studies, some RCTs	Moderate	Moderate	Direct	Imprecise	Moderate	Conditional
Regional Anesthesia	Meta-analyses of RCTs	Low	Low	Direct	Moderate	High	Strong
Preoperative Anemia Correction	Observational studies, some RCTs	Moderate	High	Direct	Imprecise	Low	Conditional
Limited Tourniquet Use (Cementation Only)	RCTs, some observational	Moderate	Moderate	Direct	Imprecise	Moderate	Conditional
Bone Wax Application	Observational studies	High	N/A	Direct	Imprecise	Low	Weak
Restrictive Transfusion Strategy	Meta-analyses of RCTs	Low	Low	Direct	Imprecise	Moderate	Strong

TXA, tranexamic acid; RCT, randomized controlled trials; THA, total hip arthroplasty.

procedures, including arthroplasty, as cardiovascular benefits often outweigh bleeding risks. However, evidence on aspirin interruption is mixed: some studies suggest increased cardiac risk upon discontinuation, while others show no significant rise in thrombotic events.[15]

For dual antiplatelet therapy, aspirin combined with an ADP receptor inhibitor (e.g., clopidogrel, ticagrelor, prasugrel), aspirin is generally continued, while the ADP inhibitor is discontinued preoperatively.[16] Clopidogrel may be continued in hip surgery but should be stopped $\geq$7 days before neuraxial anesthesia.

Anesthetic planning

Neuraxial anesthesia (spinal/epidural) is a cornerstone of perioperative strategies to reduce bleeding and transfusion requirements in bilateral hip and knee arthroplasty.[6,17] Compared to general anesthesia, neuraxial techniques are associated with 20–25% lower intraoperative blood loss and reduced transfusion rates due to controlled hypotension, reduced sympathetic activation, and improved hemostasis. A national registry for 779,491 patients demonstrated that regional anesthesia significantly lowered transfusion needs, likely through its effects on coagulation and platelet function.[18] Combining neuraxial anesthesia with TXA protocols further enhances outcomes, with meta-analyses showing 40–60% reductions in transfusion rates in bilateral procedures.[19] ERAS protocols, which integrate these strategies, emphasize minimizing hemodynamic fluctuations and optimizing surgical conditions to reduce bleeding risks.

Tranexamic acid and other antifibrinolytic agents

TXA, a synthetic antifibrinolytic agent, is a cornerstone of perioperative blood management strategies in arthroplasty. It reduces perioperative blood loss and transfusion requirements by inhibiting fibrin degradation, thereby stabilizing clot formation.[20] Our systematic review identified TXA as the most consistently effective intervention for minimizing blood loss and transfusion in single-stage bilateral hip and knee arthroplasty.

Intravenous (IV) administration remains the most common route, though topical and oral formulations demonstrate comparable efficacy to placebo. While optimal dosing lacks universal consensus, evidence supports IV doses of 10–20 mg/kg (max 1 g), with or without a postoperative infusion, as safe and effective.[20] For topical use, doses range from 250 mg to 3 g diluted in saline, applied intraarticularly or during wound closure. Timing varies by procedure: in hip arthroplasty, TXA is administered 5–20 min pre-incision, while in knee arthroplasty, it is given pre-tourniquet release or wound closure. Recent meta-analyses confirm that a single preoperative dose is as effective as multiple doses in reducing blood loss, transfusion rates, and hospital stay duration.[21]

Recent literature does not show a statistically significant increase in thrombotic events with TXA use in knee or hip arthroplasties. This applies to both the general patient population and higher-risk subgroups (ASA III–IV or with a history of thrombosis), according to evidence from meta-analyses and large cohort studies.[20,22,23] Therefore, TXA is considered safe in terms of thrombotic risk, while providing substantial benefits in reducing blood loss and transfusion rates.

Alternative antifibrinolytics include epsilon-aminocaproic acid (EACA), a lysine analog 7–10 times less potent than TXA, which shows similar transfusion reduction efficacy in total knee arthroplasty.[24] Fibrin glue, a hemostatic sealant, enhances clot stability but is limited by cost and inconsistent adoption.[25]

Intraoperative phase

Surgical approach

Multiple studies suggest that the anterior approach for hip arthroplasty is associated with a reduced risk of bleeding and blood transfusions compared to other approaches.[26] Systematic reviews and meta-analyses frequently highlight its advantages, including lower intraoperative blood loss and reduced transfusion rates relative to posterior or lateral approaches. Additionally, the anterior approach facilitates patient management and mobilization during single-stage bilateral procedures due to its anatomical advantages and patient supine positioning.

For bilateral knee arthroplasty, no single optimal approach is established, but minimally invasive techniques are recommended.[27] These involve smaller incisions and reduced disruption of surrounding tissues, which may contribute to lower blood loss and faster recovery.[28]

Tourniquet use

Tourniquets are commonly used in knee arthroplasty to reduce intraoperative blood loss and transfusion needs.[29] A study notes that approximately 58% of members of the American Association of Hip and Knee Surgeons (AAHKS) employ tourniquets during total knee arthroplasty.[30] Tourniquet application improves surgical visibility by limiting blood flow, thereby reducing blood loss and shortening operative time. However, potential complications include soft tissue injury, muscle damage, local inflammation, and nerve injuries.[31] The recommended approach for tourniquet pressure setting is initially preferably base on limb occlusion pressure in conjunction with limb circumference, alternatively base on systolic blood pressure.

Current evidence remains conflicting. While studies suggest tourniquets may reduce intraoperative blood loss and shorten operative time, these benefits do not consistently translate to reduced transfusion rates, with most meta-analyses reporting only a minor or nonsignificant effect on transfusion requirements. Conversely, prolonged tourniquet use (e.g., throughout surgery) is associated with safety concerns, including elevated risks of DVT (OR 1.8), peroneal nerve palsy (2–5% incidence), and wound complications such as delayed healing or infection.[32]

Current guidelines, including those from the European Society of Anaesthesiology,[33] caution against routine full-duration tourniquet application. Prolonged tourniquet use may lead to complications such as vascular injury, reduced range of motion, rhabdomyolysis, nerve paralysis, thigh edema, and subcutaneous fat necrosis due to local hypoxia.[34] Instead, evidence supports limited use during cementation to optimize fixation while minimizing ischemia-reperfusion injury and soft-tissue damage. This selective approach balances surgical efficiency with patient safety, aligning with ERAS protocols that prioritize minimizing perioperative morbidity.

Cell salvage

An intraoperative autologous blood recycling technique significantly reduces reliance on allogeneic transfusions.[6,8,35] During bilateral arthroplasty, blood from the surgical site is processed to remove debris and anticoagulants, yielding washed red blood cells that are safely returned to the patient.[36] This technique have demonstrated to lowers allogeneic transfusion rates by 30–50% in major joint replacements, particularly in high-blood-loss procedures like bilateral hip or knee arthroplasty.[5,26] This method mitigates risks associated with donor blood, including immunologic reactions, transfusion-transmitted infections, and transfusion-related acute lung injury.[37] While cost and logistical constraints may limit universal adoption, cell salvage remains a cornerstone of patient blood management protocols, especially in ERAS pathways, aligning with goals to enhance safety and reduce healthcare costs.[38] Guidelines from the American Association of Blood Banks[39] (AABB) endorse its use in surgeries with anticipated blood loss exceeding 1000 mL, underscoring its role in optimizing outcomes for high-risk patients.[40,41]

Bone wax

The use of bone wax in arthroplasty to reduce perioperative blood loss and transfusion rates, as it mechanically seals exposed cancellous bone surfaces,[42] is supported by recent evidence.[43,44]

Bone wax significantly reduces total blood loss on postoperative days, its integration into standard surgical practice is justified, cost-effective and easily integrated into surgical protocols, particularly in high-bleeding-risk cases as bilateral arthroplasty.[45] However, limitations include small sample sizes in most random control trials, which limit statistical power for transfusion outcomes.

Postoperative phase

Drain use

The use of drains in primary arthroplasty has been a topic of considerable controversy. While some low-evidence studies suggested that drains could help reduce complications by preventing hematoma formation, more recent high-level evidence indicates that their effectiveness may be limited.[46] Specifically, numerous randomized controlled trials and meta-analyses have found no significant differences in blood loss or transfusion rates between patients who had drains inserted and those who did not, even in complex procedures.[47,48] This growing body of evidence challenges the previously held notion that surgical drains have a positive impact on postoperative outcomes in arthroplasty patients, prompting surgeons to reconsider their routine use. Consequently, the 2024 World Expert Meeting in Arthroplasty reached a consensus that the routine use of surgical drains in standard primary arthroplasty is not recommended.[49]

Postoperative protocols

Relying solely on hemoglobin (Hb) levels to guide transfusions can be misleading, as Hb reflects oxygen-carrying capacity but not actual tissue oxygenation.[50] Non-invasive hemodynamic monitors, such as pulse oximetry and lactate levels (indicating anaerobic metabolism due to poor perfusion), provide real-time insights into tissue oxygen delivery and perfusion status. Elevated lactate (>2 mmol/L) or low oxygen saturation (<92%) may signal inadequate

Table 4 Evidence-based criteria summary for restrictive transfusion protocols based on AABB International Guidelines (JAMA, 2023).

Clinical setting	Transfusion threshold	Quality of evidence	Strength of recommendation
Hospitalized, hemodynamically stable adult patients, asymptomatic	Hb < 7 g/dL	Moderate	Strong
Patients undergoing orthopedic surgery	Hb < 8 g/dL	Moderate	Strong
Patients with preexisting cardiovascular disease	Hb < 8 g/dL (individualized)	Moderate	Strong
Patients with symptomatic anemia	Hb < 8 g/dL + clinical signs	Moderate	Strong
Patients with active bleeding	Hb < 8 g/dL + hemodynamic instability	Low	Conditional

The strength of recommendation and quality of evidence are based on the GRADE system used in the AABB guidelines. In deciding when a particular patient should undergo transfusion, the panel considers it good clinical practice to consider not only the hemoglobin concentration but also symptoms, signs, other laboratory data, patients' values and preferences, and the overall clinical context.

tissue oxygenation, even with borderline Hb levels, prompting targeted interventions (e.g., fluids, oxygen therapy) instead of reflexive transfusions.[5,8,35] This approach prioritizes physiological need over arbitrary Hb thresholds, reducing unnecessary transfusions while ensuring organs receive adequate oxygen.

Controlled hypotension involves intentionally maintaining a lower mean arterial pressure (MAP) of 60–70 mmHg during surgery to reduce intraoperative blood loss. By minimizing vascular pressure at the surgical site, this technique decreases bleeding without compromising vital organ perfusion.[6,51] Achieved through methods like neuraxial anesthesia (e.g., spinal/epidural) or precise fluid management, it avoids pharmacologic agents. Close monitoring ensures MAP stays within the safe range, balancing reduced blood loss with adequate oxygen delivery to organs like the brain and kidneys.[52] This approach is particularly useful in bilateral arthroplasty and aligns with ERAS protocols to optimize outcomes.

Ice therapy (cryotherapy)

Ice therapy aims to reduce swelling and pain via vasoconstriction, but its direct effect on blood loss or transfusion rates is minimal. A 2023 Cochrane review found no high-quality evidence that cryotherapy reduces blood loss in total knee arthroplasty.[53]

A 2012 meta-analysis[54] reported that ice therapy slightly reduced postoperative blood loss in unilateral TKA (by ~50 mL), but this difference was not clinically significant and did not affect transfusion rates. Studies focusing on bilateral arthroplasty specifically lack evidence for ice therapy reducing transfusion requirements.

Specific indications and thresholds for blood transfusion

Blood transfusion decisions in bilateral hip or knee arthroplasty should follow restrictive, evidence-based thresholds to minimize unnecessary transfusions while ensuring patient safety (Table 4).

A restrictive transfusion strategy is recommended for managing patients' hemoglobin levels. In asymptomatic patients, transfusions should be administered only if Hb falls below 7 g/dL, in alignment with guidelines from the AABB and ASA.[5] However, exceptions are made for patients with acute coronary syndrome, or cerebrovascular disease, such as symptomatic patients exhibiting clinical signs of anemia such as tachycardia, hypotension, dyspnea, angina, or altered mental status, transfusions are indicated when Hb levels drop below 8 g/dL. Conversely, a liberal transfusion strategy, which involves transfusing at Hb levels greater than 8 g/dL without the presence of symptoms, is discouraged, as it does not improve patient outcomes and is associated with increased risks such as infections and fluid overload. A 2017 meta-analysis[55] showed that restrictive transfusion protocols reduced transfusion rates by 35% in arthroplasty.

Clinical indications for transfusion can be categorized into absolute and relative indications.[38,55,56] Absolute indications include active bleeding characterized by hemodynamic instability, such as a systolic blood pressure below 90 mmHg or a heart rate exceeding 120 bpm, combined with Hb levels below 8 g/dL. Relative indications involve patients over the age of 65 who exhibit frailty or have limited cardiopulmonary reserves. Special considerations must be made for bilateral arthroplasty, where the higher baseline risk inherently doubles blood loss compared to unilateral surgeries. Despite this, restrictive transfusion thresholds (Hb < 7–8 g/dL) remain applicable unless there is active bleeding. Furthermore, intraoperative blood loss exceeding 30% of the total blood volume (e.g., more than 1500 mL in a 70 kg adult) warrants a transfusion if Hb levels drop below 8 g/dL.[55,57]

Discussion

This systematic review aimed to synthesize the available evidence regarding perioperative strategies to minimize bleeding and transfusion requirements in patients undergoing single-stage bilateral hip and knee arthroplasty. Our analysis of 325 studies revealed several key interventions that demonstrate promise in optimizing bleeding management and reducing the need for allogeneic blood transfusions in this complex surgical setting.

The consistent finding across numerous studies highlights the efficacy of TXA as a cornerstone of bleeding reduction

strategies. Our review confirms previous research indicating that TXA, administered preoperatively and/or intraoperatively, can significantly reduce transfusion rates by 40–60% in bilateral arthroplasty procedures. This finding is particularly relevant given the increased blood loss typically associated with bilateral surgeries compared to unilateral procedures.[7] The mechanism of action of TXA, inhibiting fibrinolysis and stabilizing clot formation, directly addresses a key driver of perioperative bleeding. Importantly, the evidence indicates that TXA is safe for both THA and TKA even in high risk populations (ASA grade III or IV), and that the risk of DVT is not increased.

Beyond pharmacological interventions, our review underscores the importance of surgical approach in mitigating blood loss. Minimally invasive surgical techniques, particularly the anterior approach for hip arthroplasty, were associated with lower blood loss compared to traditional approaches. This likely results from reduced muscle damage and soft tissue disruption.[58] However, our findings suggest that there is not a clearly beneficial approach for TKA in bilateral procedures. Minimally invasive techniques for both THA and TKA should be considered for their lower disruption of surrounding tissues.

Anesthetic techniques also play a critical role in bleeding management. Combined regional anesthesia and controlled hypotension further reduced intraoperative bleeding, resulting in lower blood loss and reducing the need for allogeneic blood transfusions. Regional techniques can reduce systemic sympathetic activation. ERAS protocols are increasingly important when combining these three perioperative strategies.

Preoperative optimization of patients, including correction of anemia, is an essential component of a comprehensive blood management program. We observed that addressing preoperative anemia through iron supplementation or erythropoietin can significantly reduce transfusion needs. This highlights the importance of early identification and treatment of anemia in patients scheduled for bilateral arthroplasty. Future studies can investigate how this correction reduces blood loss.

While tourniquet use in TKA is common, evidence regarding its impact on transfusion rates remains conflicting. Some studies indicate that limited tourniquet use, primarily during cementation, may optimize fixation while minimizing ischemic damage, whereas other studies suggest more long term tourniquet use to improve operative visibility. This lack of clear benefit underscores the need for individualized decision-making regarding tourniquet use based on patient-specific factors and surgeon experience.

Postoperatively, a restrictive transfusion strategy based on evidence-based thresholds is recommended to minimize unnecessary transfusions while ensuring patient safety. This approach emphasizes clinical assessment and hemodynamic monitoring over relying solely on hemoglobin levels. We observed that this can significantly reduce transfusion rates.

Overall, the current balance of evidence remains inconclusive for tourniquet use, bone wax, and cryotherapy, highlighting the need for future well-designed studies to strengthen clinical guidance and enhance patient outcomes in single-stage bilateral hip and knee arthroplasty.

Limitations

This systematic review is not without limitations. Despite a comprehensive search, there is a possibility of missing relevant studies, particularly those published in languages other than English and Spanish. In addition, heterogeneity among the included studies in terms of study design, patient populations, surgical techniques, and outcome measures limits the ability to perform a meta-analysis and draw firm conclusions. The quality of evidence also varied across studies, with some observational studies being more prone to bias. Future research may include subgroup analysis based on certain comorbidities to improve data collection techniques.

Conclusions

This systematic review solidifies the critical importance of integrating preoperative patient optimization, judicious pharmacological interventions, refined surgical techniques, and evidence-based transfusion thresholds into routine perioperative care. The findings should be interpreted in the context of significant variability across surgical and clinical practices. The choice of surgical approach, particularly in THA, directly influences blood loss. Likewise, patient selection for single-stage bilateral arthroplasty varies considerably, as factors such as age, comorbidities (ASA $\geq$ III), and nutritional status influence transfusion risk and postoperative complications.

Specifically, the evidence unequivocally supports the routine use of preoperative and/or intraoperative TXA, combined with regional anesthesia, as the most impactful strategy for reducing blood loss and transfusion rates in this population. Furthermore, our findings highlight the benefits of minimally invasive surgical approaches, particularly the anterior approach for hip arthroplasty, in minimizing tissue trauma and promoting early mobilization.

While recognizing the potential value of tourniquets in bilateral knee arthroplasty, the evidence for their consistent benefit remains inconclusive, underscoring the need for individualized, patient-centered decision-making. Similarly, while bone wax has shown a reduction in blood loss, more evidence is needed to strongly support its efficacy. Preoperative albumin and anemia correction and adherence to restrictive transfusion protocols are essential adjunctive measures to further reduce allogeneic blood exposure.

The systematic implementation of these evidence-based practices within ERAS protocols empowers orthopedic surgeons and multidisciplinary teams to achieve substantial reductions in blood loss and minimize transfusion rates, thereby optimizing patient outcomes.

These integrated measures not only enhance patient safety, comfort, and satisfaction, but also contribute to improved resource utilization and reduced healthcare costs, often achieving transfusion rates of <10%. Therefore, we advocate for the widespread adoption of ERAS as the gold standard for perioperative blood management in single-stage bilateral hip and knee arthroplasty.

Acknowledging persistent gaps in the evidence base, we call for future research to prioritize high-quality randomized controlled trials definitively addressing the role of

tourniquet management and optimizing postoperative blood management strategies, including economic analyses. Ultimately, the continued refinement and rigorous evaluation of these multimodal strategies will be essential to ensuring the highest quality and value of care for patients undergoing this increasingly common and complex surgical procedure.

Level of evidence

Level of evidence I.

Authors' contributions

All authors contributed to the conception and design of the study. Ramón González Pola and Rubén Omar Tafoya Olivos prepared the material. Data collection was performed by all authors. All material was analyzed by Ramón González Pola, Alejandro Culebras Almeida, and Alberto Herrera Lozano. The first draft of the manuscript was written by Ramón González Pola and Alberto Herrera Lozano, and all authors commented on earlier versions. All authors read and approved the final manuscript.

Ethical considerations

The article does not involve the use of human subjects. Privacy protocols regarding the publication of patient data have been followed and protected.

Funding

The authors declare that they have not received any funding for this article.

Conflicts of interest

None.

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