



## Emergency Hemorrhage Control Strategies and Outcomes in Hemodynamically Unstable Pelvic Fracture Trauma: A Systematic Review

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### ABSTRACT

**Objectives:** This systematic review aimed to evaluate and compare emergency hemorrhage control interventions for hemodynamically unstable pelvic fracture trauma, assessing clinical outcomes, including mortality, transfusion requirements, and complication rates.

**Methods:** A comprehensive literature search of PubMed, Scopus, Web of Science, and Google Scholar was conducted in December 2024. Studies were selected based on predefined inclusion criteria, which considered adult patients ( $\geq 18$  years) with hemodynamically unstable pelvic fractures. Data extraction and quality assessment were performed using standardized tools. Interventions of interest included preperitoneal pelvic packing (PPP), angioembolization (AE), resuscitative endovascular balloon occlusion of the aorta (REBOA), and mechanical stabilization.

**Results:** Ten studies were included. PPP and AE demonstrated comparable in-hospital mortality rates. However, PPP was associated with shorter intervention times and reduced early transfusion requirements. Mechanical stabilization was universally recommended as an initial step, while REBOA served as a temporizing measure. The overall strength of evidence was moderate, derived primarily from retrospective studies and meta-analyses, with no randomized controlled trials identified.

**Conclusion:** Both PP and AE were effective for hemorrhage control in hemodynamically unstable pelvic fractures, with the choice of first-line intervention often dependent on logistical factors. The development of standardized protocols and prospective studies should be prioritized in future work to optimize management strategies.

**Keywords:** Pelvic fractures; Hemorrhage control; Preperitoneal packing; Angioembolization, Trauma care.

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## Introduction

Pelvic fractures resulting from high-energy trauma represent one of the most critical challenges in emergency medicine, as they are frequently complicated by life-threatening hemorrhage that demands immediate and coordinated intervention [1, 2]. Hemodynamic instability in these patients signifies a high risk of mortality, primarily due to profuse bleeding from venous plexuses, cancellous bone surfaces, and, less commonly, arterial sources within the pelvis [2, 3]. These injuries are associated with a high mortality, particularly if patients are hemodynamically unstable upon presentation, and exsanguination accounts for 30-50% of the mortality within the first 24 hours [4-6].

The mainstay strategies for hemorrhage control in hemodynamically unstable pelvic fractures include preperitoneal pelvic packing (PPP), angioembolization (AE), resuscitative endovascular balloon occlusion of the aorta (REBOA), and mechanical stabilization (e.g., pelvic binders or external fixation), typically supported by massive transfusion protocols (MTP) and tranexamic acid (TXA) [7-9]. Each intervention carries distinct advantages and limitations. PPP provides rapid surgical tamponade but requires operative capacity and carries a risk of infection [10, 11]. AE effectively controls arterial hemorrhage yet can be delayed by logistical constraints [12, 13]. REBOA serves as a bridging measure to definitive care; nonetheless poses a risk of ischemia-reperfusion injury [14, 15]. While mechanical stabilization is universally recommended for initial pelvic volume reduction, it is rarely sufficient as a standalone treatment [16, 17]. These modalities are employed most frequently, but their relative merits remain debated due to the heterogeneity of study designs and hospital policies.

Over the past two decades, several hemorrhage control strategies for pelvic trauma have been developed and refined, including PPP, AE, REBOA, and early mechanical stabilization [18, 19]. These techniques are often combined with balanced MTP and adjunctive pharmacologic therapies. The selection and sequence of interventions generally depend on institutional resources, team expertise, and patient physiology [20, 21]. However, significant controversy persists regarding the relative safety, efficacy, and timing of these therapies. The literature is dominated by observational and retrospective studies, and to date, there is limited consensus on the superiority of any single strategy. This is largely due to a lack of randomized controlled trials (RCTs) and significant heterogeneity in study protocol, patient populations, and research design [22, 23].

This uncertainty presents a significant challenge for clinicians aiming to deliver evidence-based, protocolized care for hemodynamically unstable pelvic fractures. Given the persistently high mortality and the critical importance of timely intervention,

a synthesis of current evidence is essential to guide practice. Therefore, this systematic review aimed to comprehensively evaluate and compare emergency hemorrhage control techniques for hemodynamically unstable pelvic fractures in adult patients, focusing on clinical outcomes, including mortality, transfusion requirement, and complication rates [24, 25]. By critically appraising the strengths and limitations of each strategy, this review aimed to aid clinicians and trauma systems in optimizing management for this high-risk patient population.

## Materials and Methods

This systematic review was conducted to synthesize evidence on emergency hemorrhage control interventions and clinical outcomes in hemodynamically unstable pelvic fracture trauma. The systematic review adhered to the PRISMA guidelines [26]. Although the protocol was not prospectively registered in PROSPERO due to the perceived urgent clinical need for this evidence synthesis, all other aspects of the review process followed standard systematic review principles.

### Research Questions

This systematic review aimed to address the following research questions:

1. What emergency interventions are used for hemorrhage control in adult patients with hemodynamically unstable pelvic fractures?
2. How do different hemorrhage control strategies (e.g., PPP, AE, mechanical stabilization, REBOA) compare with regard to clinical outcomes, including mortality, transfusion requirements, and complication rates?
3. What is the quality of the current evidence supporting these strategies in the trauma and emergency care setting?

### Databases and Search Strategy

A systematic literature search was conducted across several electronic databases, including PubMed (MEDLINE), Scopus, Web of Science, and Google Scholar. Google Scholar was included specifically to identify relevant gray literature not indexed in conventional biomedical databases. The search strategy utilized a combination of keywords, Medical Subject Headings (MeSH) terms, and Boolean operators. The core search concepts included derivatives of “pelvic fracture” or “pelvic trauma,” combined with terms for bleeding control, such as “hemorrhage,” “hemorrhagic shock,” or “hemodynamic instability.” Additional terms dealt with intervention strategies, including “preperitoneal packing,” “angioembolization,” “REBOA,” and “mechanical stabilization”. The search was further limited by including context-relevant words such as “emergency,” “acute,” or “trauma” to ensure applicability to acute clinical settings.

**Table 1.** Search Strategy for Literature Review

Database	Search Strategy
PubMed	((“pelvic fracture”[MeSH] OR “pelvic trauma” OR “pelvic ring injury”) AND (“hemorrhage control”[MeSH] OR “hemorrhagic shock” OR “bleeding”) AND (“preperitoneal packing” OR “angioembolization” OR “REBOA” OR “mechanical stabilization”) AND (“emergency”[MeSH] OR “acute” OR “trauma”))
Scopus	TITLE-ABS-KEY((“pelvic fracture” OR “pelvic trauma”) AND (“hemorrhage control” OR “bleeding”) AND (“preperitoneal packing” OR “angioembolization” OR “REBOA”) AND (“emergency” OR “acute”))
Web of Science	TS=((“pelvic fracture” OR “pelvic trauma”) AND (“hemorrhage control” OR “hemorrhagic shock”) AND (“preperitoneal packing” OR “embolization” OR “REBOA”) AND (“emergency” OR “acute”))
Google Scholar	(intitle: “pelvic fracture” OR intitle: “pelvic trauma”) AND (“hemorrhage control” OR “bleeding control”) AND (“preperitoneal packing” OR “angioembolization” OR “REBOA”) AND (“emergency management” OR “acute care”) -pediatric -elective

The search strategy was tailored for each database to account for differences in indexing and search functionality (Table 1). For instance, MeSH terms were used in PubMed, while Scopus and Web of Science searches were conducted on titles, abstracts, and keywords. Google Scholar’s broader search function was employed to capture more gray literature, such as conference abstracts and institutional reports. To improve precision in Google Scholar, title limits and exclusion terms (-pediatric) were used. The final search was conducted in December 2024. No start date restrictions were applied, allowing for a comprehensive review of all available evidence published up to that point.

#### Inclusion Criteria

Studies were included if they met the following criteria:

- **Populations:** Adult patients ( $\geq 18$  years) with hemodynamically unstable pelvic fractures.
- **Interventions:** Emergency hemorrhage control via PPP, AE, mechanical stabilization, REBOA, or related adjuncts.
- **Outcomes:** Reporting of at least one primary outcome: mortality, transfusion requirements, hemorrhagic complications, or definitive procedure success rates.
- **Study Designs:** RCTs, observational cohort studies, case-control studies, cross-sectional studies, systematic reviews, or meta-analyses.

Studies were included if they defined hemodynamic instability based on at least one objective criterion: 1) Systolic blood pressure (SBP)  $< 90$  mmHg at any point pre-intervention; 2) Requirement of blood transfusion within the first 24 hours due to pelvic hemorrhage; 3) Base excess  $\leq -4$  mEq/L or lactate  $\geq 4$  mmol/L; 4) Use of vasopressors to maintain perfusion.

While TXA and MTP are standard adjuncts to trauma resuscitation, this review prioritized the comparison of direct hemorrhage control interventions (PPP, AE, REBOA, mechanical stabilization). TXA and MTP data were extracted only as context variables, as their independent effect on pelvic fracture mortality requires dedicated analysis beyond the scope of this study.

#### Exclusion Criteria

Studies were excluded if they focused exclusively on non-trauma populations, elective surgical settings, or non-pelvic fracture hemorrhage. Ineligible publication types included case reports, narrative reviews lacking outcome data, editorials, and commentaries. Books, low-quality or retracted studies, and articles for which a full text was inaccessible were also excluded. We further excluded studies where outcome data for pelvic fracture cases could not be isolated for analysis, those with exclusively pediatric populations ( $< 18$  years old), and studies focusing on acquired or congenital coagulopathies without a direct link to pelvic fracture trauma. Finally, due to a lack of translation resources, the review was limited to studies published in English. While this might introduce a language bias, this approach was necessary for practical feasibility and to ensure the accuracy of data extraction.

Titles and abstracts from the search were screened for eligibility by two independent reviewers. The full texts of potentially relevant studies were then assessed against the inclusion criteria. Any disagreements were resolved through consensus or by consultation with a third reviewer.

#### Study Selection and Data Extraction

A standardized data extraction form was developed to systematically collect relevant information from each included study. The extracted data encompassed study characteristics (author, year, setting, study design, sample size), participants’ demographics (age, sex distribution, injury severity), and details regarding the type and sequence of emergency hemorrhage control interventions. Primary outcomes of interest were in-hospital mortality, 24-hour mortality, transfusion requirement (volume, timing), and complications (thromboembolism, re-bleeding, and infection). Additional parameters included the duration of mechanical ventilation, ICU and hospital length of stay, limitations of the study, and primary conclusions. This systematic approach yielded consistent and comprehensive data synthesis for all studies.

#### Quality Assessment

The methodological quality and risk of bias of

the included studies were evaluated using standard tools. For observational studies, the Newcastle-Ottawa Scale (NOS) was used to evaluate three domains: (1) selection of study groups (0-4 stars), (2) comparability of groups (0-2 stars), and (3) outcome evaluation (0-3 stars). Studies with a score of  $\geq 7$  stars were considered low risk, 5-6 stars moderate risk, and  $\leq 4$  stars high risk. Systematic reviews and meta-analyses were evaluated using AMSTAR-2, which evaluates 16 domains (e.g., protocol registration, comprehensive search, conflict of interest control) to rate overall confidence as high, moderate, low, or critically low. Two reviewers performed the assessments independently, with conflicts resolved by consensus.

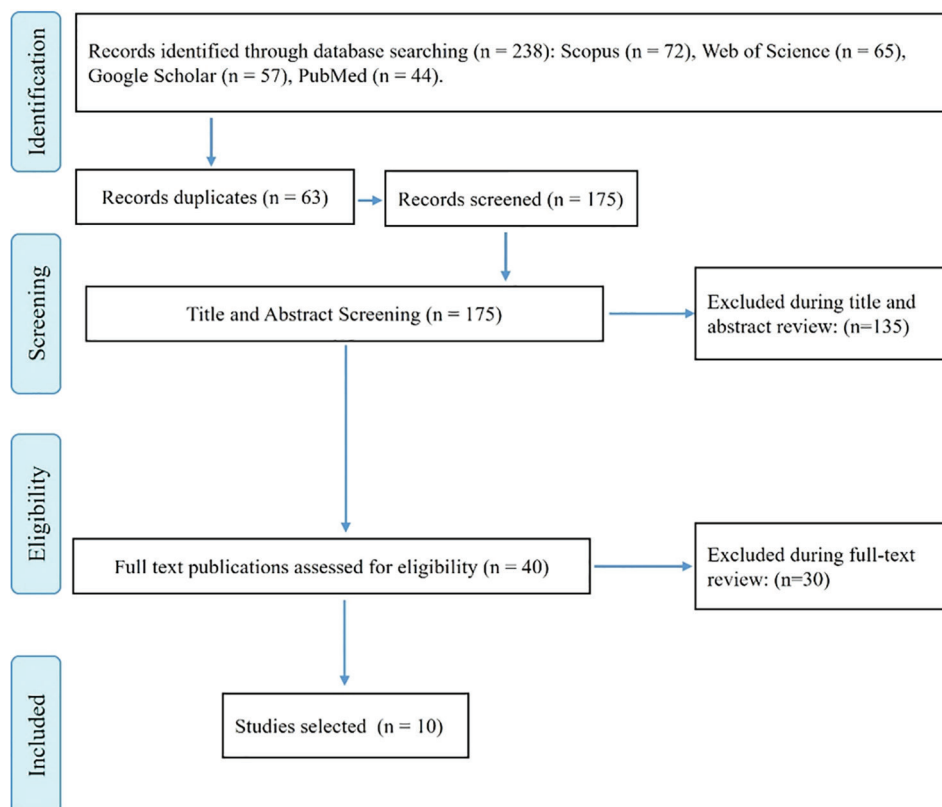
## Results

The study selection process adhered to PRISMA guidelines to ensure a systematic and transparent approach. A comprehensive literature search was conducted in December 2024 across PubMed, Scopus, Web of Science, and Google Scholar, yielding a total of 238 records (PubMed: 44, Scopus: 72, Web of Science: 65, Google Scholar: 57). After removing the duplicates, 175 articles underwent title and abstract screening. During this stage, 135 articles were excluded based on the pre-specified exclusion criteria, such as a focus on non-trauma populations, elective surgery, non-pelvic fracture hemorrhage, or being an ineligible publication type, such as case reports, narrative reviews without outcome data, editorials, commentary papers,

pediatric-only studies, and studies exclusively addressing acquired or congenital coagulopathies without reference to pelvic fracture trauma. The full-text reviews of the remaining 40 articles were assessed for eligibility. Of these, 30 articles were excluded primarily due to a lack of relevant outcome data, an inability to extract data specific to pelvic fracture cases, or a population that did not meet the criteria for hemodynamic instability. Ultimately, 10 studies were included in the systematic review. The included studies comprised a mix of retrospective cohort studies, systematic reviews, meta-analyses, and guideline syntheses, which are further detailed in the data extraction and quality appraisal sections (Figure 1).

A standardized data extraction form was used to systematically gather pertinent information from all included studies. The extracted variables encompassed study characteristics (authors, year, setting, study design, and sample size), participant demographics (age distribution, sex, and severity of injury), and details of the interventions, including the specific types and sequences of emergency hemorrhage control strategies. Data on primary and secondary outcomes were collected, including in-hospital and 24-hour mortality, transfusion requirement, complication rates, duration of mechanical ventilation, and ICU and hospital length of stay. Major study limitations and primary conclusions were also recorded for each study. The data extraction sheet is provided in [Supplementary File 1](#).

The risk of bias assessment indicated that six of the ten studies had a moderate risk of bias (NOS scores: 5-6 stars),



**Fig. 1.** The flow diagram shows the study selection strategies according to the PRISMA guidelines.

primarily due to inadequate control for confounding factors or inherent limitations of their retrospective design. The remaining four studies were judged to have a low risk of bias ( $\geq 7$  stars). The AMSTAR-2 evaluation of the included meta-analyses revealed a moderate level of confidence, with common limitations being a lack of prospective protocol registration and the exclusion of unpublished data (Supplementary File 2).

### Emergency Hemorrhage Control Interventions

For hemodynamically unstable adult patients with pelvic fractures, the first-line emergency hemorrhage control interventions described in the literature included PPP, AE, REBOA, mechanical stabilization, massive transfusion protocol activation (MTPs), and TXA administration.

The PPP is a surgical technique that provides rapid tamponade, particularly for venous bleeding. It is generally associated with faster intervention times and reduced early transfusion requirements compared to other methods and is frequently utilized as a first-line treatment or in conjunction with other interventions [4, 18, 27]. AE, performed by interventional radiology, directly addresses arterial hemorrhage and may be employed as a primary or adjunctive procedure based on institutional resources and protocols [18, 25, 27, 28]. In the reviewed studies, REBOA was used exclusively in Zone III (distal aorta) for pelvic hemorrhage control [24, 27]. However, outcome data were derived from small case series ( $n=3$  studies) with no comparisons to non-REBOA management or other occlusion zones. Mechanical stabilization using pelvic binders or external fixation is universally recommended as an initial measure to reduce pelvic volume and promote hemostasis [4, 22].

Resuscitation consistently involves MTPs, which utilize balanced ratios of red blood cells, plasma, and platelets to address both volume deficit and trauma-induced coagulopathy [4, 22, 27]. The early administration of TXA is a standard of care to inhibit hyperfibrinolysis [4, 22]. Further details, including the studies quantifying these interventions and relevant

procedural characteristics, are presented in Table 2.

### Comparative Clinical Outcomes of Hemorrhage Control Strategies

Several studies have compared the clinical outcomes of various hemorrhage control techniques for hemodynamically unstable pelvic fractures, primarily PPP, AE, mechanical stabilization, and REBOA. The literature suggested that PPP and AE are the most extensively investigated interventions. Several systematic reviews, meta-analyses, and cohort studies have reported comparable in-hospital mortality rates for both these interventions among patients [18, 24]. While mechanical stabilization (e.g., external fixation, pelvic binders) is universally recommended as a first-line management to reduce pelvic volume and cause tamponade, its clinical impact has been inferred primarily from physiological principles rather than direct outcome reports [18, 24, 30]. None of the included studies isolated its effect on transfusion requirements or mortality, as it is consistently applied alongside other interventions such as PPP, AE [25]. This reflected its foundational role in hemorrhage management and the ethical challenges of studying it in isolation [18]. A specific finding was that PPP was associated with a mean reduction of approximately 1.0 units of packed PRBC within the first 24 hours compared to AE [18, 24].

Mechanical stabilization, universally recommended as a first step, is significant for early control. However, its independent effect on overall mortality, separate from definitive interventions, has not been specifically examined [4, 22]. The evidence for using REBOA in pelvic trauma is insufficient ( $n=3$  studies), and a lack of comparative data prevents definitive conclusions [24, 27]. Additional details on the comparative outcomes of these interventions from the referenced studies are reported in Table 3.

Although a meta-analysis by Li *et al.*, [25] observed a mortality advantage for PPP (all-cause mortality RR=0.63; 24-hour mortality RR=0.42), subsequent, larger meta-analyses by Martinez *et al.*, [18] and Cullinane *et al.*, [22] found no significant difference between PPP and AE.

**Table 2.** Emergency hemorrhage control interventions in hemodynamically unstable pelvic fractures

Intervention	References	Description/Notes
Preperitoneal pelvic packing (PPP)	[4, 18, 22, 24, 25, 27-30]	Surgical tamponade of venous bleeding; associated with rapid intervention and reduced early transfusion.
Angioembolization (AE)	[4, 18, 22, 24, 25, 27-30]	Interventional radiologic control of arterial bleeding; primary or adjunctive according to protocol.
REBOA	[24, 27]	Zone III aortic occlusion as a bridge to PPP/AE; limited evidence for mortality benefit vs. risks (15% limb ischemia).
Mechanical stabilization	[4, 22]	Use of pelvic binders or external fixation to decrease pelvic volume and bleeding.
Massive transfusion protocol (MTP) <sup>a</sup>	[4, 22, 27]	Balanced transfusion (often 1:1:1 RBC:FFP:platelet) in early resuscitation to address shock and coagulopathy.
Tranexamic acid (TXA) <sup>a</sup>	[4, 22]	Early antifibrinolytic therapy; included in contemporary trauma management protocols.

<sup>a</sup>TXA and MTP are included as standard adjunct therapies but were not analyzed for comparative outcomes due to heterogeneity in administration protocols and lack of controlled studies isolating their effects in pelvic fracture populations.

**Table 3.** Comparative outcomes of hemorrhage control strategies.

Strategy	Mortality	Transfusion requirements	Time-to-intervention	Complication rates	References
Preperitoneal pelvic packing (PPP)	Similar to AE, some meta-analyses report lower overall and 24h mortality (RR=0.63 overall, RR=0.42 at 24h); no significant in-hospital mortality difference compared to AE in larger meta-analyses.	Mean reduction in 24h PRBC transfusions: 1.0 units compared to AE	Median 45 min	No significant difference vs AE; DVT and other complications are similar	[18, 24, 25, 30]
Angioembolization (AE)	Similar in-hospital mortality to PPP; frequently second-line if persistent bleeding after PPP; slower time-to-intervention compared to PPP*	Greater PRBC transfusion in the first 24h compared to PPP	Median 120 min	Similar to PPP, no significant increase in major complications	[18, 24, 30]
Mechanical stabilization	Evidence for benefit is indirect (physiological rationale/expert consensus); no studies reported isolated outcomes due to universal use with other interventions.	Not specifically reported	Not reported	Not specifically reported	[4, 22, 31]
REBOA	Outcome data limited; used as adjunct/bridge; clinical impact not separately quantified due to small series and adjunctive use.	Not specifically reported	Not reported	Not specifically reported	[24, 27]

\*Time-to-intervention for PPP is significantly shorter than AE (e.g., median 45 min vs. 120 min)

**Table 4.** Quality of evidence for hemorrhage control strategies

Strategy	Evidence source	Evidence type	Evidence quality (GRADE)	Limitations	References
Preperitoneal pelvic packing (PPP)	Multi-institutional/Single-center cohorts, systematic reviews, meta-analyses	Retrospective observational studies, meta-analyses	Moderate*	Lacks RCTs, relies on observational data, heterogeneity in protocols	[18, 24, 25, 30]
Angioembolization (AE)	Multi-institutional/Single-center cohorts, systematic reviews, meta-analyses	Retrospective observational studies, meta-analyses	Moderate**	Same limitations as PPP; no direct RCTs compared to PPP; analysis often combines with other interventions	[18, 24, 30]
Mechanical stabilization	Guideline recommendations, narrative reviews	Consensus-driven protocols, expert opinion, and some observational data	Low-Moderate	Considered standard but not specifically studied in isolation	[4, 22, 31]
REBOA	Registry/cohort studies, case series	Observational data, limited case series	Low	Limited cases, adjunct use, insufficient studies for clear outcome or comparative data	[24, 27]
General guideline synthesis	Systematic review and guideline (EAST)	Mixed evidence graded by an expert panel	Moderate***	Rigorous synthesis, but consensus required due to lack of RCTs and inconsistent observational study quality	[22, 32]

Criteria for GRADE Rating: \*Primarily retrospective cohort studies and meta-analyses with consistent effects on mortality and transfusion outcomes, but lack RCTs, with moderate heterogeneity in protocols. \*\*Primarily retrospective cohort studies and meta-analyses with consistent effects, but no direct RCTs comparing to PPP, with moderate heterogeneity in intervention protocols. \*\*\*Rigorous synthesis of retrospective studies with consistent effects, but consensus required due to lack of RCTs and inconsistent observational study quality.

This disparity could be attributed to several factors: (1) Li *et al.*, included fewer studies (n=5) with a higher percentage of hypotensive patients, who may benefit more from immediate PPP; (2) variability how hemodynamic instability was defined across the studies; (3) institutional

protocol variation, where PPP was preferentially used for more compromised patients, potentially confounding the results; and (4) temporal elements, as earlier studies in Li *et al.*'s review (2007-2016) might reflect less advanced AE techniques compared to later studies [25].

### Quality of Evidence Supporting Hemorrhage Control Strategies

The current evidence for hemorrhage control procedures, such as PPP, AE, mechanical stabilization, and REBOA, is primarily moderate and consists almost exclusively of retrospective cohort studies, systematic reviews, and meta-analyses, with a notable absence of RCTs. According to the GRADE system, evidence quality is rated Moderate for PPP, AE, and guideline syntheses, and Low for mechanical stabilization and REBOA, reflecting the predominance of observational studies and lack of RCTs (Table 4).

Most of the available evidence comes from multi-institutional registries, single-institution experience, and comprehensive meta-analyses, which have collectively established these interventions as standards of care despite inherent methodological biases. Systematic guideline production, such as that by the Eastern Association for the Surgery of Trauma (EAST), incorporates this evidence into formal grades and expert opinion, but explicitly acknowledges the lack of high-level, prospective evidence [22]. Both guideline statements and meta-analyses report marked heterogeneity in protocols, patient groups, and the use of observational data, restricting firm conclusions, particularly on the relative superiority of individual interventions. RCTs are noticeably absent. Further details and evidence of grading by strategy are presented in Table 4.

### Discussion

This systematic review confirms that hemodynamically unstable pelvic fractures in adults represent a persistent challenge in trauma care. While a variety of emergency hemorrhage control strategies are available, each with distinct procedural characteristics, they yield broadly similar outcomes in terms of overall mortality and complication rates. Based on the examined literature, PPP and AE were the primary definitive interventions, which were routinely supplemented by early mechanical stabilization, massive transfusion protocols, and, in particular instances, REBOA. Despite refinements in these techniques and their integration into contemporary trauma care, the evidence base was limited by methodological quality and a lack of generalizability across all patient populations.

An integrated approach—combining rapid mechanical stabilization with PPP and/or AE—constitutes the cornerstone of contemporary pelvic trauma management. Systematic reviews and retrospective cohort analyses consistently report comparable in-hospital mortality for hemodynamically unstable patients treated with PPP and AE [18, 24]. However, procedure logistics and resource availability create significant real-world disparities. PPP consistently demonstrates an advantage in time-to-intervention, with prospective

studies suggesting substantially shorter time to surgical control (e.g., a median of 45 min for PPP vs. 120 min for AE) than the more resource-intensive AE [18, 24, 30]. This expedited control translates into a clinically meaningful reduction in transfusion requirements, with PPP associated with a mean decrease of approximately 1.0 unit of PRBC within the first 24 hours [18]. This finding is particularly beneficial in circumstances where rapid control of hemorrhage is critical and interventional radiology is not immediately available.

Any purported survival advantage of PPP over AE must be interpreted with caution. While some meta-analyses, such as that by Li *et al.*, reported a reduction in overall and 24-hour mortality with PPP (relative risk of 0.63 for overall mortality and 0.42 for 24-hour mortality) [25], larger and more diverse systematic reviews have not consistently confirmed this finding. Crucially, no data from RCTs were available. The existing evidence is universally observational, rendering conclusions susceptible to confounding from selection bias, where more unstable patients may be triaged to one modality over another, and institutional variations in availability and proficiency [18, 24, 25]. In addition, PPP and AE are often utilized sequentially or concurrently in cases of ongoing hemorrhage, which obscures the assessment of one strategy's superiority over the other.

These conflicting mortality findings between Li *et al.*, [25] and the larger meta-analyses point to important knowledge gaps. First, the apparent survival benefit for PPP in Li *et al.*, might be due to selection bias. Their analysis included studies where PPP was employed as initial therapy for patients in severe shock (systolic BP <70 mmHg), whereas AE was generally reserved for those who had been stabilized. Second, institutional capability influenced outcomes—hospitals with rapid access to interventional radiology (a context ideal in Martinez *et al.*,’s comparison) might achieve equivalent outcomes despite longer procedural times. Third, evolving transfusion practices (e.g., earlier TXA use, balanced MTPs) might have mitigated mortality differences in the more recent studies [18, 22, 25]. These factors underscore the need for risk-stratified analyses in future studies.

Complication rates were not significantly different between PPP and AE, at least for major sequelae such as deep vein thrombosis or organ dysfunction [18]. This similarity suggested the risks from each procedure were approximately equivalent when protocols were competently followed. However, since follow-up duration and reporting standards vary greatly between studies, subtle differences or unusual adverse events might go undetected. The impact of other patient variables, such as age, comorbidities, and concomitant trauma, also remained poorly understood.

Mechanical stabilization, typically involving

pelvic binders or external fixation, is universally acknowledged as the cornerstone first step in hemorrhage control. Its physiological basis—reducing pelvis volume and promoting the tamponade of venous bleeding—is strongly supported by expert consensus and guideline policy [4, 22]. Despite its wide acceptance, direct comparative data isolating the effect of mechanical stabilization alone on post-survival outcomes are limited. This is because it is consistently introduced early during resuscitation and is generally used as an adjunct to more definitive therapy.

Although REBOA is theorized to resuscitate unstable patients into definitive care (e.g., PPP/AE), our analysis found insufficient comparative data to support this benefit [24, 27]. No trials directly compared REBOA versus no-REBOA mortality, and complication rates (e.g., ischemia) were variably reported. Thus, the use of REBOA remained hypothesis-generating, and its role as an adjunct in pelvic fracture treatment regimens requires definition by future trials.

The routine use of Zone III REBOA in pelvic trauma is based on its anatomical rationale (distal aortic occlusion) [24, 27]. However, this practice highlighted a significant evidence gap, as no studies have compared Zone III with Zone I occlusion or non-REBOA resuscitation in similar patient cohorts. This lack of comparative data makes any conclusions about its relative safety and efficacy impossible.

The evidence for all these interventions is best described as moderate. According to the GRADE system, the quality of evidence is generally Moderate for PPP and AE, and Low for mechanical stabilization and REBOA, due to the reliance on observational data and heterogeneity in study designs (Table 4). Most of the available data are from institutional case series, retrospective cohort analyses, meta-analyses of non-randomized studies, and guideline syntheses from expert opinions [18, 24, 25, 30]. RCTs—the gold standard for interventional comparison—are absent in this field. This deficiency reflects the ethical and logistical challenges of researching time-sensitive, high-mortality trauma conditions. Consequently, established best practices are influenced as much by logistical considerations (e.g., intervention speed and availability, team training, and institutional preference) as by direct comparative efficacy. Guideline programs, such as the updated EAST guidelines, acknowledge these biases and attempt to minimize the risk of bias through explicit evidence grading and multidisciplinary consensus [22].

Significant heterogeneity also existed in the delivery and sequence of intervention, particularly between centers with convenient access to interventional radiology and those that rely more on surgical methods. For example, European centers have long utilized PPP, while North American trauma algorithms have recently incorporated packing into a previously AE-dominant paradigm [30].

This evolution is reflected in updated guideline recommendations and by the growing number of centers adopting a hybrid or algorithmic approach that combines PPP and AE based on patient physiology and institutional resources. As combined methods are now the standard, they further obscure the distinct outcome effects attributable to any single intervention.

Additionally, the vast majority of the literature includes general adult trauma populations and excludes special groups, such as children or patients with inherited bleeding disorders. Thus, the direct applicability of these findings to such subgroups is unknown. Similarly, while the efficacy of interventions such as early TXA administration and balanced MTPs is widely accepted in principle, evidence for their specific benefit in pelvic fracture trauma remains either sporadic or indirect [4, 22].

This systematic review underscored the pressing need for prospective, randomized trials comparing protocolized approaches (e.g., ‘PPP-first’ vs. ‘AE-first’ channels) for hemodynamically unstable pelvic fractures. While observational data confirmed the logistical benefit of PPP (shorter time to intervention) and accuracy of AE (precise arterial targeting), no trial has compared these strategies under controlled conditions with standardized resuscitation protocols. Such trials should be designed with the following considerations: (1) a clear definition of hemodynamic instability; (2) stratification by bleeding source and injury severity (venous vs. arterial); and (3) composite outcome measures including 24-hour mortality, complication rates, and functional status. The establishment of multicenter trauma networks now makes such studies feasible, and their results would resolve the longstanding equipoise in clinical practice.

Besides addressing evidence gaps, institutional protocol must align with logistical realities. For example, PPP might be prioritized in institutions without 24/7 interventional radiology (IR) support, given its more rapid deployment (<60 minutes) and surgical nature, while AE remains a viable option where IR is readily available. Hybrid approaches (e.g., PPP for initial hemostasis followed by AE for arterial hemorrhage) require interdisciplinary coordination while reflecting the heterogeneity of resources in practice. Crucially, anticipated intervention delays should inform decision-making; a PPP-first strategy may enhance survival when delays to AE are expected to exceed 90 minutes. Therefore, trauma systems should adapt algorithms based on local infrastructure and expertise rather than applying rigid, universal protocols.

The findings of this systematic review are subject to several important limitations. First, the evidence base was dominated by retrospective cohort analyses, single-center case series, and meta-analyses of non-randomized data, with a notable scarcity of RCTs. This lack of high-level prospective evidence

introduced risks of selection bias, confounding, and heterogeneity in institutional protocols, making it challenging to establish the absolute comparative efficacy of different hemorrhage control techniques. Second, there was considerable diversity in study designs, patient populations, intervention protocols, and outcomes reporting, which complicated direct comparison and limited the generalizability of the findings. For instance, variations in the timing, sequence, and combination of interventions (e.g., PPP followed by AE) between institutions confounded the independent effects of any single strategy.

Third, significant heterogeneity in how hemodynamic instability was defined across studies (e.g., using SBP thresholds versus transfusion requirements) affected the consistency and generalizability of the aggregated results. Fourth, while mechanical stabilization is a standard practice, our review found no direct evidence quantifying its independent clinical impact, as it is universally applied alongside other interventions. Fifth, although we reported on the use of TXA and MTPs, their independent contribution to outcomes could not be distinguished from that of the primary hemorrhage control interventions. Sixth, the exclusion of non-English language studies might have omitted relevant data, particularly from high-volume trauma centers where English is not the primary research language.

Furthermore, while this review was conducted in accordance with PRISMA guidelines, the prospective protocol was not registered in PROSPERO, which might affect the perceived transparency of our a priori approach. Finally, although guideline syntheses such as those from the Eastern Association for the Surgery of Trauma (EAST) provided structured recommendations, their foundation in expert consensus and observational evidence underscored the need for more standardized, high-quality studies. The absence of prospective trials directly comparing integrated protocols (e.g., PPP-first versus AE-first algorithms) means clinicians lack evidence-based guidance on optimal sequencing, even in institutions capable of deploying both modalities rapidly.

Thus, while the aggregate data have progressively clarified the roles and outcome of PPP, AE, and adjunctive strategies in the emergency treatment of hemodynamically unstable pelvic fracture trauma, these findings could be best understood as complementary rather than competitive. Both PPP and AE are effective, with logistical considerations

significantly influencing first-line selection. Although the quality of the evidence is improving, it continues to be limited by the absence of randomized trials and methodological variation, necessitating further study. Ultimately, prospective registries, standardized outcome reporting, and, where feasible, direct comparative trials will be essential to enhance care and personalize recommendations for this high-risk and complex trauma population.

## Declaration

**Ethics approval and consent to participate:** Not applicable.

**Consent for publication:** All authors have agreed to the publication of this manuscript.

**Conflict of Interest:** The authors declare that they have no competing interests related to this work.

## Declaration of Generative AI in Scientific Writing:

During the development of this work, the authors used ChatGPT version 4 to improve grammar, spelling, and clarity, as well as to enhance sentence structure and overall readability. The AI tool was not employed to generate original scientific content, design experiments, perform data analysis, or draw conclusions. All ideas, interpretations, and conclusions in this work are solely those of the authors. The authors have carefully reviewed and verified all AI-assisted edits to ensure accuracy and integrity of the final manuscript. After using this tool, the authors reviewed and edited the content as needed and accept full responsibility for the published article.

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