

Endovascular Therapy Versus Open Surgical Repair for Lower Limb Vascular Trauma

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Introduction: Lower limb vascular trauma is a time-critical emergency with a high risk of limb loss. Open surgical repair (OSR) has traditionally been the standard treatment, but endovascular therapy (ET) is increasingly utilized. This study aimed to compare the effectiveness and safety of ET versus OSR.

Methods: A systematic review and meta-analysis of comparative observational studies was performed. Adult patients with traumatic lower limb arterial injuries involving the popliteal artery and/or superficial femoral artery were included. A random-effects model was used to calculate pooled risk ratios (RRs) with 95% confidence intervals (CIs). Statistical heterogeneity was assessed using the I^2 statistic.

Results: Six retrospective cohort studies involving 9,503 patients were included. Of these, 1,315 patients underwent ET and 8,188 underwent OSR. ET was associated with a reduced risk of amputation compared with OSR (RR 0.67; 95% CI 0.50–0.91). Subgroup analyses demonstrated no significant difference in blunt (RR 0.90; 95% CI 0.59–1.37) or penetrating popliteal artery injuries (RR 0.84; 95% CI 0.21–3.34). ET significantly reduced the risk of compartment syndrome (RR 0.43; 95% CI 0.33–0.56) and the need for fasciotomy (RR 0.43; 95% CI 0.27–0.69).

Conclusions: ET might provide limb salvage outcomes comparable to OSR while significantly reducing ischemia-related morbidity, particularly compartment syndrome and fasciotomy. These findings suggest that ET may be considered in selected patients, although the evidence remains limited.

Keywords: Vascular Trauma; Endovascular Therapy; Open Surgical Repair; Compartment Syndrome; Fasciotomy; Meta-Analysis

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INTRODUCTION

Lower limb vascular trauma is a time-critical surgical emergency associated with high risks of hemorrhage, acute limb ischemia, amputation, and mortality [1–3]. Injuries to major vessels—particularly the superficial femoral artery (SFA) and popliteal artery—most commonly result from high-energy blunt or penetrating mechanisms and are frequently accompanied by complex musculoskeletal, venous, and soft tissue injuries [3,4]. Delayed revascularization might lead to irreversible

ischemic damage, ischemia–reperfusion injury, and permanent limb dysfunction [5,6].

Historically, open surgical repair (OSR) has been considered the gold standard for traumatic lower extremity arterial injury, providing reliable arterial control and acceptable limb salvage when performed promptly [2,4,7]. However, OSR is inherently invasive and often requires extensive exposure, vascular clamping, and prolonged operative time, which might exacerbate ischemia–reperfusion injury and contribute to postoperative morbidity [8–10]. A major complication following OSR is acute compartment syndrome, driven by prolonged ischemia, reperfusion edema, venous obstruction, and extensive soft tissue dissection, frequently necessitating fasciotomy and leading to increased morbidity [11–14].

Over the past two decades, endovascular therapy (ET) has emerged as an alternative or adjunct to OSR in selected trauma patients [1,2,15]. Advances in imaging, device technology, and operator expertise have enabled minimally invasive approaches such as covered stent placement and intraluminal revascularization in the acute

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trauma setting [15–17]. These techniques offer potential advantages, including reduced soft tissue trauma, shorter ischemic times, and avoidance of prolonged arterial clamping, which might mitigate ischemia-related complications [9,10,18]. The expansion of hybrid operating rooms and multidisciplinary trauma teams has further facilitated the integration of ET into modern damage control strategies [19–22]. Recent international guidelines, including those from the American Association for the Surgery of Trauma–World Society of Emergency Surgery (AAST–WSES) and the European Society for Vascular Surgery (ESVS), emphasize rapid diagnosis and timely restoration of arterial perfusion as key principles in the management of extremity vascular injuries [20–21].

Despite these advances, the comparative effectiveness of ET versus OSR remains debated. Concerns regarding durability, thrombosis, reintervention, and delayed complications persist, and observational studies are inherently limited by selection bias, as ET is often applied to older patients or anatomically favorable injuries [23–27]. While recent database analyses suggest comparable limb salvage outcomes between ET and OSR for SFA and popliteal artery injuries, the impact of ET on ischemia-related morbidity—particularly compartment syndrome and fasciotomy—remains incompletely defined [11,14,28].

Accordingly, this systematic review and meta-analysis aimed to evaluate the comparative effectiveness and safety of ET versus OSR for traumatic lower limb vascular injury in adult patients, with a specific focus on limb salvage and ischemia-related morbidity, including compartment syndrome and fasciotomy, in accordance with a prospectively registered study protocol.

METHODS

Study Design and Protocol

This study was conducted as a systematic review and meta-analysis in accordance with a prospectively registered PROSPERO (the International Prospective Register of Systematic Reviews) protocol (CRD420251243627).

Outcomes

The prespecified primary outcome was limb salvage. As the included studies did not consistently report a uniform time frame (e.g., 30-day or long-term amputation), amputation was defined as any reported limb loss during the study-specific follow-up period. Reported timeframes varied across studies and included in-hospital, 30-day, or unspecified follow-up durations. Secondary outcomes included ischemia-related morbidity, specifically compartment syndrome and the need for fasciotomy. Additional outcomes of interest included mortality, arterial patency, reintervention, and length of hospital stay; however, these were not consistently reported and were not included in the quantitative synthesis.

Protocol Registration and Deviations

Although risk of bias assessment using ROBINS-I (Risk Of Bias In Non-randomized Studies of Interventions) and certainty assessment using GRADE (Grading of Recommendations Assessment, Development and Evaluation) were prespecified, its application was limited by incomplete reporting in the included studies, which were primarily retrospective database analyses [29,30].

Literature Search

A systematic search was conducted in PubMed, Cochrane CENTRAL, and ScienceDirect for studies published between January 1, 2016, and March 14, 2026 using the search terms (“Vascular Injuries”[Mesh] OR “vascular trauma” OR “arterial injury”) AND (“Lower Extremity”[Mesh] OR femoral OR popliteal OR tibial OR peroneal) AND (“Endovascular Procedures”[Mesh] OR endovascular OR stent* OR embolization OR angioplasty).

Eligibility Criteria

Out of 1,540 publications identified, and 75 studies assessed for full-text eligibility, six met the criteria for quantitative synthesis. Adults were defined as patients aged ≥ 18 years. ET was defined as minimally invasive vascular repair techniques including stent or stent-graft placement and other catheter-based interventions. OSR was defined as conventional open vascular reconstruction procedures, including interposition grafting, bypass grafting, primary repair (direct suture), and patch angioplasty.

Data Extraction

Extracted data included study characteristics, study design, study period, arterial segment involved, and reported outcomes.

Subgroup analyses based on the specific arterial segment (SFA versus popliteal artery, including injuries below the knee) were not performed in this meta-analysis, as most included studies did not report outcomes stratified by precise injury location. Consequently, differences in prognosis or the utilization of endovascular therapy between SFA and popliteal artery injuries could not be assessed. Subgroup analysis by mechanism of injury was only feasible for studies that reported stratified data.

Risk of Bias Assessment

Risk of bias was assessed using the ROBINS-I tool, evaluating seven domains including confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement, and selective reporting.

Statistical Analysis

All statistical analyses were conducted using Review Manager (RevMan) version 5.4.1 (The Cochrane Collaboration, Copenhagen, Denmark). A random-effects model (DerSimonian and Laird method) was used to account for inter-study variability. Dichotomous outcomes were analyzed using the Mantel–Haenszel method and reported as risk ratios (RRs) with 95% confidence intervals (CIs). Statistical heterogeneity among studies was assessed using the I^2 statistic, with thresholds of 25%, 50%, and 75% indicating low, moderate, and high heterogeneity, respectively. A p -value <0.05 was considered statistically significant.

Ethical Approval Statement

Ethical approval was not required for this study because it is based exclusively on previously published data.

RESULTS

Study Selection

The database search identified 1,540 records (PubMed $n = 107$, CENTRAL $n = 16$, ScienceDirect $n = 1,417$). After removal of 210 duplicate records and 10 unrelated records, 1,320 records remained for title and abstract screening. Of these, 1,240 records were excluded during the screening stage. Eighty reports were sought for retrieval and five reports were not retrieved. Seventy-five full-text articles were assessed for eligibility. Sixty-nine reports were excluded for the following reasons: non-traumatic population or non-traumatic acute limb ischemia ($n = 28$), conference abstracts only ($n = 9$), systematic or narrative reviews without primary data ($n = 14$), single-arm studies without a relevant comparator ($n = 10$), and insufficient or non-extractable outcome data ($n = 8$). Ultimately, six studies were included in both the qualitative synthesis and the quantitative meta-analysis [22–27] (Figure 1). The PRISMA flow diagram was reviewed and corrected to ensure consistency in record counts across all stages of study selection. The study selection process is illustrated in Figure 1.

Study Characteristics

The six included studies comprised a total of 9,503 adult patients (≥ 18 years) with traumatic lower extremity arterial injury. Of these, 1,315 patients (13.8%) underwent ET and 8,188 patients (86.2%) underwent OSR. Vascular injuries involved the popliteal artery, SFA, and the tibioperoneal arteries. One study reported outcomes stratified by mechanism of injury, including blunt and penetrating popliteal artery injuries, allowing for subgroup analyses [22], whereas the remaining five studies evaluated mechanism cohorts without stratified reporting [23–27]. All included studies were retrospective

observational analyses derived from large national trauma or administrative databases. The characteristics of the included studies are summarized in Table 1.

Baseline patient characteristics, including age, sex, injury severity score (ISS), and mechanism of injury, are summarized in Table 2.

Patients undergoing ET tended to be older across several studies; however, ISSs were inconsistently reported and could not be reliably compared between groups (Table 2).

Amputation

Across individual studies, amputation rates were broadly comparable between ET and OSR, although the magnitude and direction of effect varied by study population. The pooled analysis is presented in Figure 2. In the study focusing on popliteal artery injury with stratification by mechanism of injury, ET was associated with a reduced risk of amputation in pooled analysis, although subgroup analyses did not demonstrate consistent significance across all injury mechanisms [22]. Subgroup analyses demonstrated no significant difference in blunt popliteal artery injuries (RR 0.90; 95% CI 0.59–1.37) or penetrating injuries (RR 0.84; 95% CI 0.21–3.34).

In studies where the injury mechanism or arterial segment was not specified in detail, ET was associated with a significantly lower amputation risk compared with OSR (RR 0.46; 95% CI 0.29–0.73; Figure 2).

In the pooled meta-analysis of the five studies that reported amputation as an outcome [22,24–27], ET was associated with a reduced risk of amputation compared with OSR (RR 0.67; 95% CI 0.50–0.91; Figure 2). Statistical heterogeneity was negligible ($I^2 = 0\%$), indicating highly consistent effect estimates across studies. The overall effect was statistically significant ($Z = 2.58$; $p = 0.010$). Pooled estimates should be interpreted as overall amputation risk rather than time-specific outcomes.

Compartment Syndrome

The three included studies that reported compartment syndrome outcomes were incorporated into the pooled analysis [22–24]. Across all studies, ET was consistently associated with a lower incidence of compartment syndrome compared with OSR. Effect estimates from individual studies demonstrated a similar direction and magnitude of benefit, irrespective of differences in study design and patient populations. The pooled analysis is shown in Figure 3.

Pooled meta-analysis demonstrated a statistically significant reduction in the risk of compartment syndrome among patients treated with ET (RR 0.43, 95% CI 0.33–0.56; Figure 3). Importantly, no statistical heterogeneity was observed ($I^2 = 0\%$), indicating a highly consistent treatment effect across included studies.

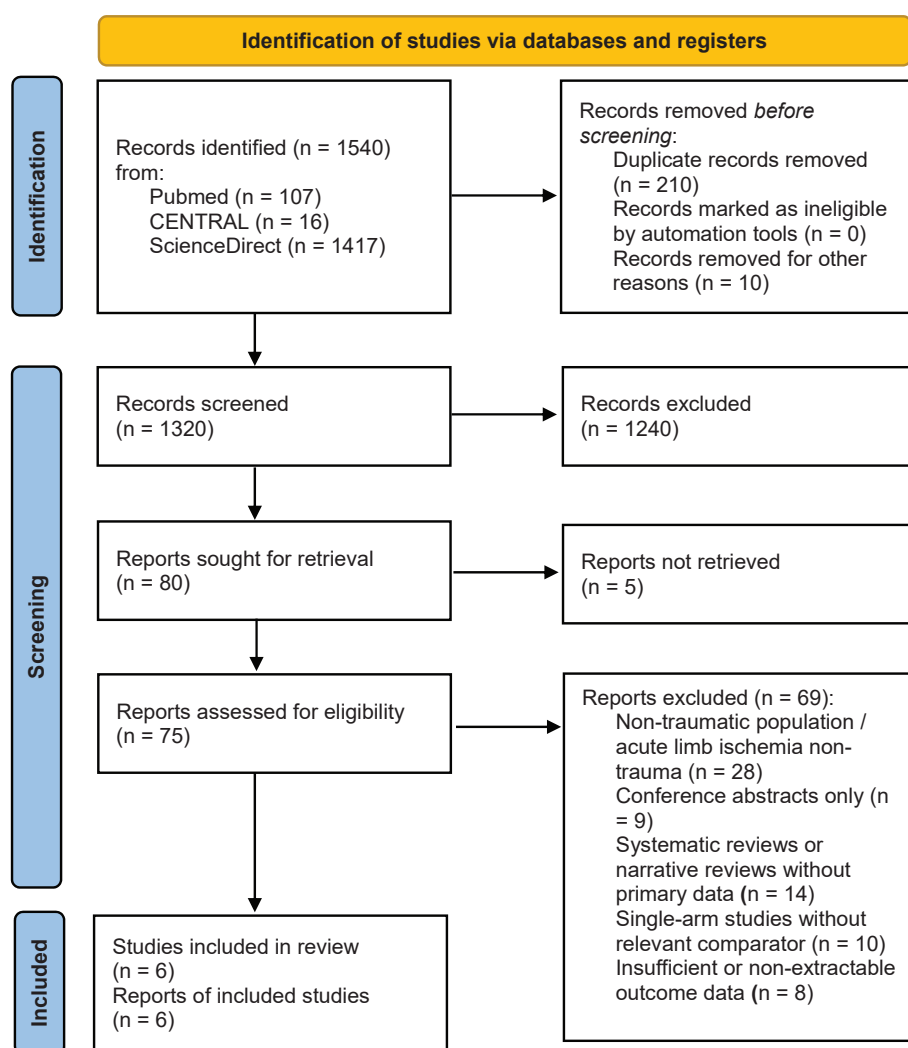


Figure 1 PRISMA flow diagram illustrating the study selection process. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only.

Source: Adapted from Page MJ, et al. *BMJ* 2021;372:n71. doi: <https://doi.org/10.1136/bmj.n71>. This work is licensed under CC BY 4.0 (<https://creativecommons.org/licenses/by/4.0/>).

Table 1 Characteristics of studies included in the meta-analysis.

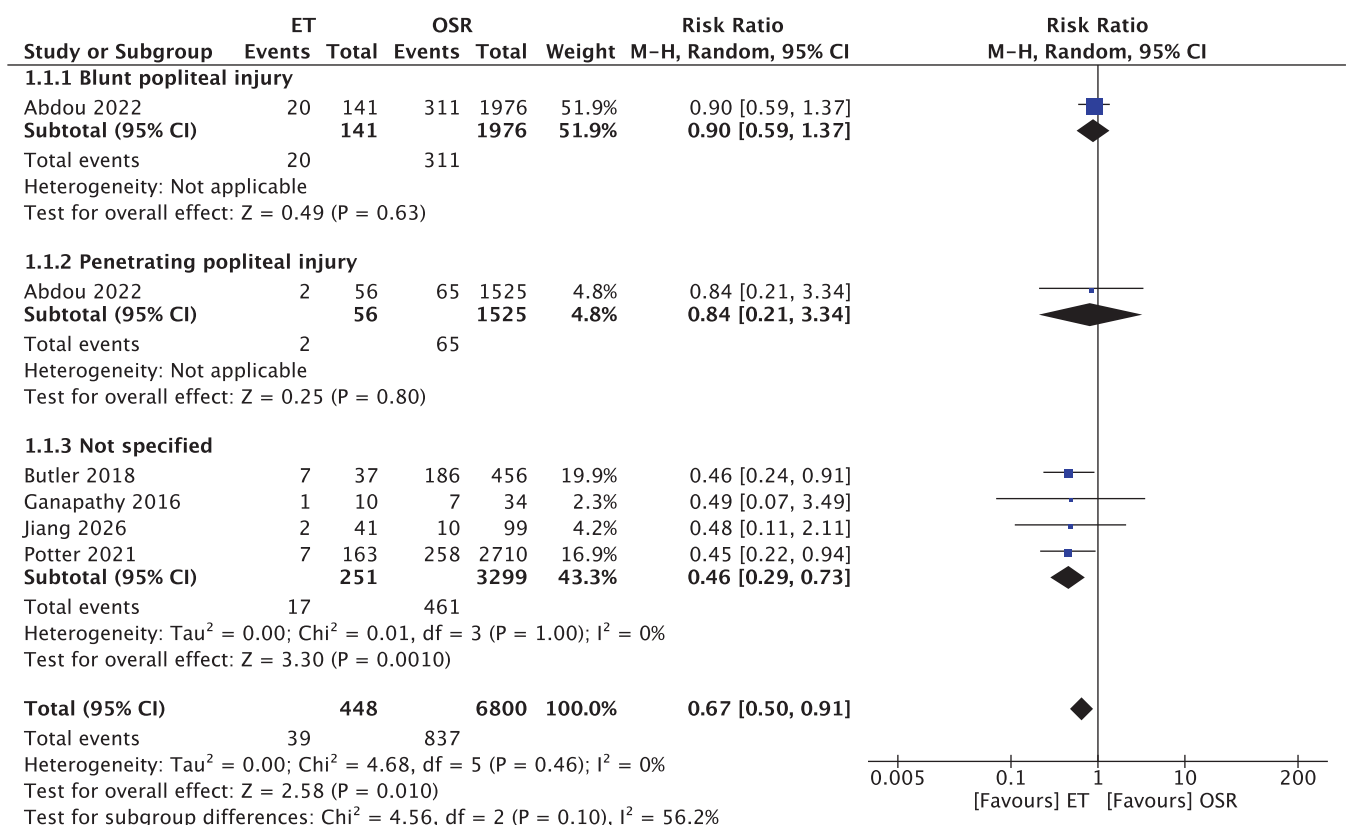
Study	Database	Artery	ET (n)	OSR (n)	Outcomes Reported
Abdou et al. [22]	USA / Trauma Database	Popliteal artery	Blunt: 141 Penetrating: 56	Blunt: 1,976 Penetrating: 1,525	Amputation; compartment syndrome
Degmetich et al. [23]	USA / National Inpatient Sample	Superficial femoral artery	390	1,865	Compartment syndrome; fasciotomy
Potter et al. [24]	USA / National Trauma Data Bank	Superficial femoral artery and/or popliteal artery	163	2,710	Amputation; compartment syndrome; fasciotomy
Ganapathy et al. [25]	USA / Duke University Medical Center Trauma Center	Superficial femoral artery, popliteal artery, tibioperoneal arteries	10	34	Amputation; fasciotomy
Butler et al. [26]	USA / California Office of Statewide Health Planning and Development	Popliteal artery	456	37	Amputation; fasciotomy
Jiang et al. [27]	China / The Third Hospital of Hebei Medical University	Popliteal artery	99	41	Amputation

Abbreviations: ET: endovascular therapy; OSR: open surgical repair.

Table 2 Baseline characteristics of patients undergoing endovascular therapy (ET) versus open surgical repair (OSR).

Study	Age (ET)	Age (OSR)	Male (%)	ISS (OSR)	Mechanism
Abdou et al. [22]	45	36	74.3	9	Blunt and penetrating
Degmetich et al. [23]	44.9	32.5	86.3	Not reported	Blunt, penetrating and unspecified
Potter et al. [24]	33	31	84	10	Blunt and penetrating
Ganapathy et al. [25]	38	25	41	Not reported	Penetrating and unspecified
Butler et al. [26]	50.9	36.3	80.4	12.5	Blunt, penetrating and unspecified
Jiang et al. [27]	44.8	42.1	79.2	Not reported	Blunt and penetrating

Abbreviations: ISS: injury severity score.

**Figure 2** Forest plot of amputation comparing endovascular therapy (ET) versus open surgical repair (OSR). Risk ratios with 95% confidence intervals (CIs) are presented using a random-effects model.

Squares represent study-specific estimates and horizontal lines indicate 95% CIs; the diamond represents the pooled effect estimate. Source: Prepared by the authors.

Fasciotomy

Four studies reported fasciotomy outcomes following vascular repair and were included in the quantitative synthesis [23–26]. Across included studies, ET was associated with a lower rate of fasciotomy compared with OSR; however, the magnitude of effect varied substantially between studies. The pooled analysis is shown in Figure 4.

Pooled meta-analysis demonstrated that ET was associated with a statistically significant reduction in the need for fasciotomy (RR 0.43, 95% CI 0.27–0.69; Figure 4). Notably, substantial statistical heterogeneity

was observed ($I^2 = 75\%$), indicating considerable variability in effect estimates across studies. The overall effect was statistically significant ($Z = 3.57$; $p = 0.0004$). This heterogeneity likely reflects differences in institutional thresholds for prophylactic fasciotomy, variations in injury severity and ischemia time, and database-specific reporting practices.

Other Prespecified Outcomes

Additional prespecified outcomes, including mortality, arterial patency, reintervention, thrombotic complications and follow-up, were variably reported across studies

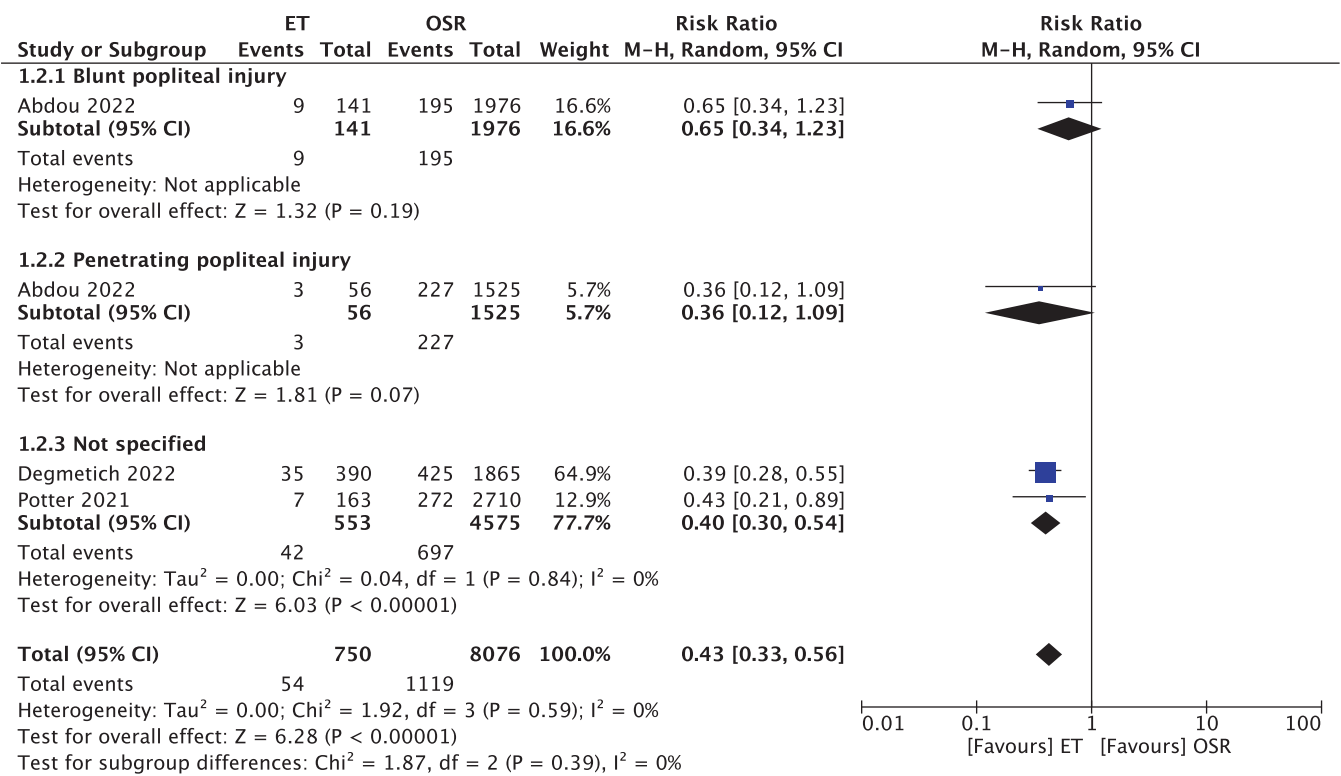


Figure 3 Forest plot of compartment syndrome comparing endovascular therapy (ET) versus open surgical repair (OSR). Risk ratios with 95% confidence intervals (CIs) are presented using a random-effects model.

Squares represent study-specific estimates and horizontal lines indicate 95% CIs; the diamond represents the pooled effect estimate. Source: Prepared by the authors.

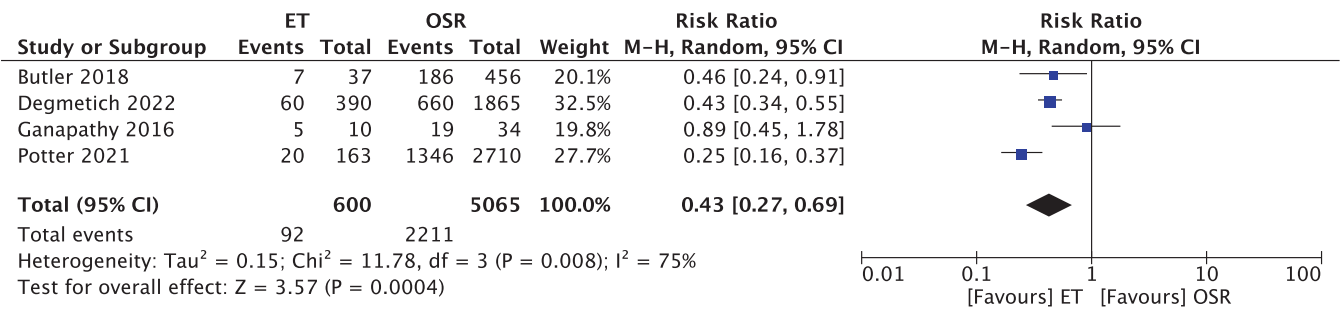


Figure 4 Forest plot of fasciotomy comparing endovascular therapy (ET) versus open surgical repair (OSR). Risk ratios with 95% confidence intervals (CIs) are presented using a random-effects model.

Squares represent study-specific estimates and horizontal lines indicate 95% CIs; the diamond represents the pooled effect estimate. Source: Prepared by the authors.

(Table 3). In-hospital mortality was reported in two large database studies, with comparable rates between ET and OSR in one study and higher mortality observed in the ET group in another [23, 24]. One population-based study additionally reported postdischarge mortality, demonstrating higher mortality in the ET cohort [26]. The availability of additional clinically relevant outcomes across included studies is summarized in Table 3.

Arterial patency and reintervention outcomes were reported in only one study with short-term follow-up

(up to six months) [27], precluding meaningful comparison or quantitative synthesis. Thrombotic complications were inconsistently reported and, when available [27], primarily reflected overall thromboembolic events rather than graft or stent thrombosis, further limiting interpretation of arterial repair durability.

Owing to heterogeneity in outcome definitions, reporting methods, and follow-up duration, these outcomes were not included in the quantitative meta-analysis.

Table 3 Availability of key outcomes across included studies.

Study	Mortality	Arterial Patency	Reintervention	Thrombotic complications	Follow-up
Abdou et al. [22]	Not reported	Not reported	Not reported	Not reported	Not reported
Degmetich et al. [23]	In-hospital ET: 15 (3.8%) OSR: 70 (3.8%)	Not reported	Not reported	Not reported	Not reported
Potter et al. [24]	In-hospital ET: 8 (5.1%) OSR: 27 (1.0%)	Not reported	Not reported	Not reported	Not reported
Ganapathy et al. [25]	Not reported	Not reported	Not reported	Not reported	Limb salvage: 30 (83%) No ambulation: 6 (18%)
Butler et al. [26]	All cause mortality ET: 3 (15%) OSR: 5 (2.4%)	Not reported	Not reported	Not reported	Amputation post-discharge ET: 4 (21.1%) OSR: 21 (10.4%)
Jiang et al. [27]	Not reported	One month: ET: 36 (87.8%) OSR: 90 (90.9%) Three month: ET: 34 (82.9%) OSR: 85 (85.8%) Six month: ET: 30 (73.17%) OSR: 78 (78.7%)	Not reported	ET: 3 (7.32%) OSR: 5 (5.05%)	6-month survival prognosis HR: 0.682 (95% CI 0.187–2.495, $p = 0.47$)

Abbreviations: ET: endovascular therapy; OSR: open surgical repair; HR: hazard ratio; CI: confidence interval.

Risk of Bias

Risk of bias across the included studies was assessed using the ROBINS-I framework [29]. All included studies were retrospective observational cohorts, primarily derived from trauma or administrative databases. Consequently, all studies were judged to have a serious risk of bias due to confounding, as treatment allocation was not randomized and likely influenced by injury severity, hemodynamic status, and anatomical suitability for ET. The overall risk of bias assessment is summarized in Figure 5.

Bias in the selection of participants was rated as moderate in most studies because inclusion was based on retrospective database identification. Classification of interventions was considered low risk, as ET and OSR were clearly identifiable procedural categories in the included databases.

Bias due to deviations from intended interventions was judged to be low, as the studies primarily evaluated procedural outcomes without crossover between treatment groups. Missing data bias was considered moderate owing to incomplete reporting of several clinical variables and outcomes across administrative datasets. Measurement of outcomes such as amputation, compartment syndrome, and fasciotomy was judged to be low risk, as these outcomes represent clearly documented clinical events. Selective reporting bias was considered moderate, given variability in outcome reporting across studies.

Overall, all included studies were judged to have a serious overall risk of bias, primarily driven by

confounding inherent to retrospective observational designs (Figure 5).

DISCUSSION

This systematic review and meta-analysis provides an updated synthesis of comparative evidence evaluating endovascular therapy versus open surgical repair for traumatic lower extremity arterial injury. The principal finding is that ET demonstrated a reduced risk of amputation in pooled analysis; however, subgroup analyses did not demonstrate consistent significance across all injury mechanisms [22]. These findings are clinically relevant in the context of evolving trauma systems that increasingly incorporate endovascular and hybrid treatment strategies. The limited number of included studies reflects the scarcity of contemporary comparative data directly evaluating endovascular and OSR techniques in traumatic lower limb vascular injuries. The search timeframe was restricted to contemporary studies (2016–2026) to reflect current endovascular techniques, device technology, and modern trauma system practices, as earlier studies might not accurately represent current clinical outcomes.

Endovascular Therapy and Limb Salvage

Historically, OSR has been regarded as the definitive treatment for traumatic lower extremity arterial injury, largely because of concerns regarding the durability and reliability of endovascular interventions in the acute trauma setting [1,2]. However, advances in endovascular

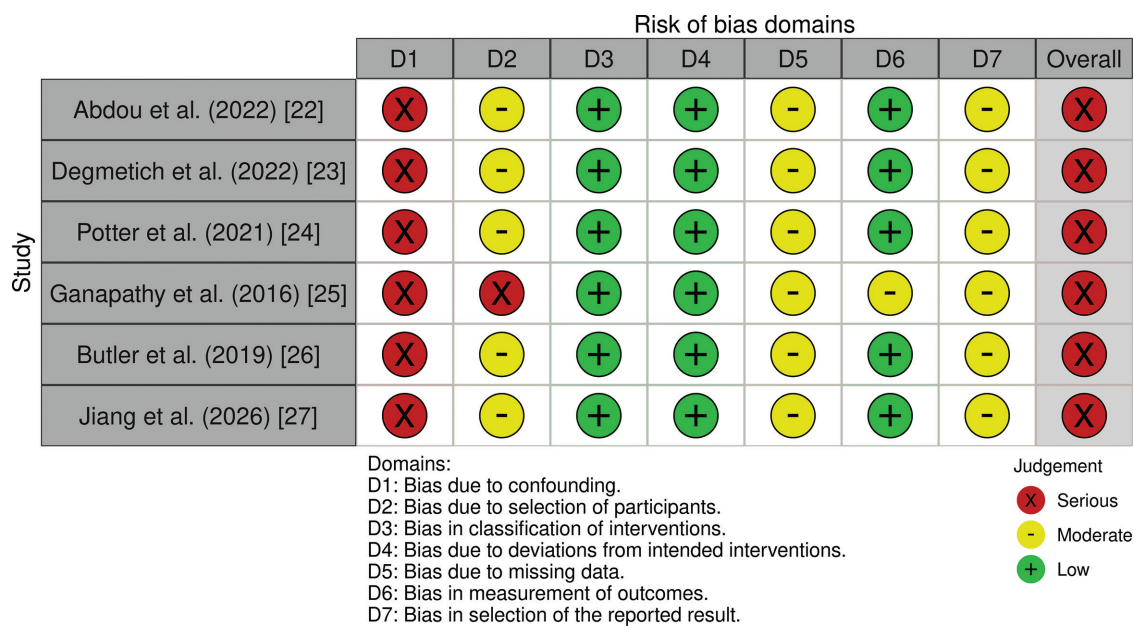


Figure 5 Risk of bias assessment using ROBINS-I (Risk Of Bias In Non-randomized Studies of Interventions).

Source: Prepared by the authors.

technology, improvements in imaging modalities, and increasing operator experience have progressively expanded the role of ET in contemporary trauma care [3–5]. In the present meta-analysis, ET was associated with a reduced risk of amputation in pooled analysis; however, subgroup analyses did not demonstrate consistent significance across all injury mechanisms, with negligible statistical heterogeneity ($I^2 = 0\%$), suggesting that endovascular approaches might not compromise limb salvage when applied in appropriately selected patients. Collectively, these findings suggest that ET might be associated with reduced amputation risk compared with traditional OSR in patients with traumatic lower extremity arterial injury.

These findings are consistent with contemporary database analyses and institutional series reporting non-inferior limb salvage outcomes following ET for femoral and popliteal artery injuries [11–14]. Importantly, the absence of an increased amputation risk in the ET group challenges earlier concerns regarding endovascular durability in trauma and suggests that early technical failure or device-related complications might not translate into worse definitive limb outcomes in the acute setting, particularly when timely conversion or adjunctive interventions are available [9].

Ischemia-related Morbidity and Compartment Syndrome

One of the most consistent findings of this meta-analysis is the reduction in postoperative compartment syndrome associated with ET (RR 0.43, 95%

CI 0.33–0.56; $I^2 = 0\%$). Compartment syndrome following vascular trauma is a well-recognized consequence of ischemia–reperfusion injury, prolonged ischemic time, extensive soft tissue dissection, and concomitant venous injury [6,11,14].

ET might attenuate these pathophysiologic mechanisms through rapid intraluminal revascularization, avoidance of prolonged arterial clamping, and relative preservation of collateral blood flow, compared with open surgical repair [9,18]. Prior studies have demonstrated that shorter ischemic durations and reduced soft tissue manipulation are independently associated with lower rates of compartment syndrome and secondary limb morbidity following vascular injury [5,16]. The absence of heterogeneity suggests relatively consistent findings across included studies, although residual confounding cannot be excluded.

Fasciotomy and Practice Variability

Similarly, ET was associated with a significantly lower requirement for fasciotomy compared with open surgical repair (RR 0.43, 95% CI 0.27–0.69), although substantial statistical heterogeneity was observed ($I^2 = 75\%$). The pooled analysis for fasciotomy demonstrated substantial heterogeneity, which limits the interpretability of this finding. Several factors might contribute to this variability, including differences in institutional protocols for prophylactic fasciotomy, variation in injury severity and ischemia duration, and inconsistencies in coding practices across trauma and administrative databases. In particular, the decision to perform fasciotomy

is often influenced by surgeon judgment and local practice patterns rather than standardized criteria, further contributing to heterogeneity. As a result, the observed reduction in fasciotomy associated with ET should be interpreted with caution, as it might not represent a consistent or reliable treatment effect across different clinical settings [7,14,28].

Previous studies have demonstrated considerable variation in fasciotomy practices following vascular trauma, even among high-volume trauma centers, underscoring the influence of surgeon judgment, institutional protocols, and local practice patterns [31,32]. Accordingly, the observed heterogeneity should be interpreted not as inconsistency in the direction of treatment effect, but rather as a reflection of real-world variability in clinical decision-making surrounding fasciotomy after vascular repair.

Summary of Findings

Overall, pooled analyses demonstrated that ET might provide limb salvage outcomes comparable to OSR, while being associated with significantly lower rates of ischemia-related morbidity, particularly postoperative compartment syndrome and the need for fasciotomy. Statistical heterogeneity was low for amputation outcomes and absent for compartment syndrome, indicating consistent effects across studies, whereas substantial heterogeneity was observed for fasciotomy outcomes, likely reflecting variability in injury severity, institutional practice patterns, and prophylactic fasciotomy thresholds.

Although several clinically important outcomes were reported in individual studies, including mortality, short-term patency, and thrombotic complications, these data were sparse and highly heterogeneous. Mortality was reported using different methodologies, including in-hospital mortality and postdischarge survival, while patency data were limited to a single study with follow-up restricted to six months. Importantly, reintervention and thrombosis outcomes were not consistently defined, and available thrombotic data largely reflected general thromboembolic events rather than graft- or stent-specific failure. As a result, these outcomes could not be meaningfully synthesized. These endpoints are particularly relevant for evaluating the durability of endovascular repair in traumatic vascular injury. As a result, although the present analysis suggests comparable limb salvage and lower ischemia-related morbidity with endovascular therapy, the long-term durability and functional outcomes of these approaches remain uncertain. Future studies with standardized reporting of patency, reintervention, and long-term limb function are necessary to better define the comparative effectiveness of endovascular and OSR strategies.

Relevance to Damage Control and Endovascular Resuscitation

From a trauma systems perspective, the findings of this study align closely with established principles of damage control surgery and endovascular resuscitation. Endovascular approaches facilitate rapid hemorrhage control and timely revascularization while minimizing additional physiologic insult, which is particularly relevant in polytrauma patients with limited physiologic reserve [3,20,21]. The observed reductions in ischemia-related morbidity, especially compartment syndrome and the need for fasciotomy, are consistent with these principles.

The increasing availability of hybrid operating rooms, portable fluoroscopic imaging, and trauma surgeons with endovascular expertise has further enabled the early integration of ET into vascular trauma management algorithms [17–19]. In this context, the present findings provide empirical support for the selective use of ET, particularly in hemodynamically stable or transiently responsive patients with anatomically suitable injuries, without compromising definitive limb salvage outcomes.

Risk of Bias and Methodological Considerations

All included studies were retrospective observational cohorts, introducing inherent risks of selection bias and unmeasured confounding (Figure 5). Although the study protocol prespecified risk-of-bias assessment using ROBINS-I, formal application was limited by incomplete reporting of key domains, particularly confounding, intervention classification, and outcome ascertainment, which are common limitations of large trauma and administrative databases [29,30]. Accordingly, a narrative assessment of methodological quality was undertaken to enhance transparency without assigning potentially misleading summary bias judgments. An important methodological consideration is confounding by indication. In clinical practice, ET is not randomly assigned but is typically selected for patients with more favorable anatomical and clinical characteristics. These might include more accessible vascular lesions, less severe soft-tissue destruction, preserved distal runoff, and shorter ischemia times.

Conversely, patients undergoing OSR are more likely to present with complex injuries, including extensive tissue damage, hemodynamic instability, or prolonged ischemia, which inherently increase the risk of adverse outcomes such as amputation and compartment syndrome. These differences in baseline injury characteristics might substantially influence the observed treatment effects. Therefore, the apparent benefits of ET, particularly in reducing ischemia-related morbidity, should be interpreted with caution, as they might partly reflect underlying differences in patient selection rather than

the intrinsic superiority of the intervention. Future studies incorporating detailed injury severity and ischemia duration are needed to better clarify the independent effect of treatment strategy.

Despite these limitations, the consistent direction of effect across outcomes, together with low or absent statistical heterogeneity for key endpoints, particularly compartment syndrome, supports the internal coherence and robustness of the observed findings.

Rationale for Not Applying GRADE

Although certainty-of-evidence assessment using GRADE was prespecified in the study protocol, it was not applied in the final analysis. Within the GRADE framework, observational studies begin at low certainty and are frequently downgraded further for risk of bias, imprecision, and inconsistency—especially in meta-analyses comprising a limited number of studies [33,34]. In the present context, formal GRADE classification was unlikely to provide additional discriminatory value and risked obscuring clinically relevant effect estimates. Instead, certainty of evidence was addressed narratively, an approach consistent with editorial expectations in trauma and surgical journals.

Clinical Implications and Patient Selection

The findings of this meta-analysis support ET as a complementary strategy, rather than a replacement, for OSR in traumatic lower extremity arterial injury. Appropriate patient selection remains critical. ET appears most suitable for focal arterial injuries with preserved distal runoff, limited soft tissue contamination, and relative hemodynamic stability, whereas OSR remains indispensable in cases of complex arterial disruption, extensive contamination, associated skeletal or soft tissue injury, or when endovascular resources and expertise are unavailable [2,7,35]. These results underscore the importance of institutional capability and multidisciplinary decision-making in optimizing vascular trauma outcomes.

Limitations

Several limitations of this study should be acknowledged. First, all included studies were retrospective observational analyses and are therefore susceptible to selection bias and residual confounding. Second, the reliance on large administrative and trauma databases limited the availability of detailed anatomic, physiologic, and procedural information. Third, although selected studies reported additional outcomes such as mortality and short-term patency, these were limited in number, inconsistently defined, and restricted to short follow-up durations, which limits conclusions regarding long-term durability (Table 3). Consequently,

future studies with more detailed reporting of arterial segment-specific outcomes are needed to better evaluate differences in prognosis and treatment patterns between SFA and popliteal artery injuries. Additionally, the pooled analysis for fasciotomy demonstrated substantial heterogeneity, which might reflect variations in institutional prophylactic fasciotomy protocols, injury severity, ischemia time, and database coding practices. Therefore, this finding should be interpreted cautiously and might not represent a consistent treatment effect across different settings. Finally, deviation from the pre-specified ROBINS-I and GRADE assessments represents a methodological limitation, although this decision was prospectively justified and transparently reported. These limitations reflect a broader gap in the current trauma literature rather than a methodological shortcoming of the present study.

CONCLUSION

Despite these limitations, this meta-analysis suggests that ET might provide limb salvage outcomes comparable to OSR, while being associated with a significant reduction in ischemia-related morbidity, particularly postoperative compartment syndrome and the need for fasciotomy. These findings reinforce the expanding role of endovascular strategies in contemporary trauma care and highlight the importance of institutional readiness, endovascular expertise, and judicious patient selection in optimizing outcomes for patients with traumatic lower extremity vascular injury.

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Ethics Statement

- (1) All the authors mentioned in the manuscript have agreed to authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.
- (2) The authors declare that they have read and abided by the JEVTM statement of ethical standards including rules of informed consent and ethical committee approval as stated in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Author Contributions

Conceptualization: all authors; protocol development: MRS, K; data extraction and analysis: MRS, K; manuscript drafting: MRS; critical revision: ED, NR; final approval: all authors.

Data Availability

All data generated or analyzed during this study are included in this published article and its supplementary materials. Additional data are available from the corresponding author upon reasonable request.

Declaration of the Use of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT (OpenAI) to improve readability, structure, and language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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