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Evolving Strategies in Vascular Trauma: From Open Repair to Endovascular Techniques

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ABSTRACT

Vascular trauma can cause rapid exsanguination and limb-threatening ischemia, and its management is shifting from routine open repair toward endovascular techniques. This narrative review compares open and endovascular management across anatomical regions using evidence published between 2021 and 2026. PubMed was searched for studies combining terms for vascular injury, open repair and endovascular procedures, supplemented by reference-list checking, and 14 studies were purposively selected and synthesized narratively by theme. In lower-extremity arterial injury, a meta-analysis of 32 studies associated endovascular therapy with less major amputation (OR 0.42) and less fasciotomy or compartment syndrome, with similar mortality. In axillosubclavian injury, open surgery was associated with higher short-term mortality than endovascular repair (OR 2.07), but the difference was lost when studies at high risk of bias were excluded. In blunt thoracic aortic injury, thoracic endovascular aortic repair achieved 98% technical success and 5% 30-day mortality with rare late reintervention, and repair within 24 hours was associated with higher mortality than delayed repair. The only randomized trial of resuscitative endovascular balloon occlusion of the aorta was stopped early for harm, and a 2025 guideline conditionally recommends against its use in unstable patients with subdiaphragmatic bleeding. Most comparative evidence is retrospective and prone to selection bias. Endovascular repair is now first-line treatment for blunt thoracic aortic injury and a useful option for selected peripheral and junctional injuries, while open surgery remains essential for unstable patients and many penetrating injuries. Prospective studies with long-term follow-up, including in low- and middle-income settings, are needed.

Keywords: vascular system injuries; endovascular procedures; open surgical repair; thoracic endovascular aortic repair; resuscitative endovascular balloon occlusion of the aorta; trauma

INTRODUCTION

Vascular trauma is a high-stakes injury pattern, because damage to a major vessel can cause rapid exsanguination, limb-threatening ischemia, or both. Penetrating and blunt mechanisms account for most of these injuries [1], and their management depends on fast, effective decisions made under difficult conditions [2]. Outcomes are shaped not only by the injury itself but by how quickly bleeding is controlled and perfusion is restored.

For most of the modern surgical era, vascular injuries were treated with open surgery, and techniques such as temporary vascular shunts were developed to support damage-control strategies [2,3]. Open repair remains the most common approach for penetrating non-aortic arterial injuries today [4]. However, it can require extensive exposure in anatomically difficult regions and carries its own morbidity. In one recent meta-analysis, intraoperative nerve injury was reported only after open repair of lower-extremity arteries, with a pooled incidence of 15% [5].

Over the past few decades, endovascular techniques have changed this picture. Stent grafts, temporary shunts, and balloon occlusion now give surgeons fewer invasive ways to control hemorrhage, particularly in junctional and torso injuries [3]. The shift is clearest in blunt thoracic aortic injury, where thoracic endovascular aortic repair (TEVAR) is now

recommended as first-line treatment [6,7]. Endovascular repair is also increasingly used in other vascular beds. It accounted for more than 40% of axillosubclavian arterial repairs in a multicenter registry [8], was associated with lower amputation and fasciotomy rates in lower-extremity arterial injuries [5] and was linked to lower in-hospital mortality in blunt inferior vena cava injuries [9].

Despite this progress, important questions remain. Most comparative data come from retrospective studies vulnerable to selection and publication bias [4,10]. The optimal timing of intervention is still debated: a systematic review supporting the Society for Vascular Surgery guidelines found higher mortality with early (<24 hours) than with delayed TEVAR [11]. Resuscitative endovascular balloon occlusion of the aorta (REBOA) also remains controversial, and the Eastern Association for the Surgery of Trauma conditionally recommends against its use in unstable patients with subdiaphragmatic bleeding [12]. In addition, endovascular repair depends on trained operators and suitable facilities, and current European guidelines support its use in selected patients when this expertise is available [13]. Such resources are not available in every setting.

This review therefore aimed to synthesize recent evidence, published between 2021 and 2026, on how the management of vascular trauma has evolved from open repair to endovascular techniques. It addressed two questions. First, how do the outcomes of open and endovascular management compare across the main anatomical regions? Second, where does the evidence remain uncertain, and what does this mean for clinical practice?

MATERIALS AND METHODS

Study Design

This article is a narrative literature review. No protocol was prepared or registered. Reporting was guided by the Scale for the Assessment of Narrative Review Articles (SANRA), which covers the importance and aims of a review, the description of the literature search, referencing, scientific reasoning and the presentation of data [14]. The quality of individual studies was not formally appraised. The evidence was organized into four themes: (1) extremity and other peripheral arterial injuries, (2) axillosubclavian, venous and other difficult-to-access injuries, (3) blunt thoracic aortic injury (BTAI) and (4) resuscitative endovascular balloon occlusion of the aorta (REBOA).

Literature Search

PubMed was searched on 4 September 2026 for English-language articles on human subjects published between September 2021 and September 2026. The search combined three groups of terms with the Boolean operator AND: terms for vascular injury (for example, "Vascular System Injuries"[Mesh], "vascular trauma" and "arterial injury"), terms for open repair (for example, "Vascular Surgical Procedures"[Mesh], "open repair", "temporary shunt" and "damage control") and terms for endovascular techniques (for example, "Endovascular Procedures"[Mesh], "stent graft", "embolization", "REBOA" and "TEVAR"). The full search string is given in Supplementary Table S1. The search retrieved 325 records. It was supplemented by searches in Google Scholar and by checking the reference lists of relevant reviews and guidelines.

Selection of Literature

One author screened titles and abstracts and then full texts, without independent second screening. Studies were eligible if they (i) were published between September 2021 and September 2026, (ii) reported outcomes of open repair, endovascular repair or both in patients with traumatic vascular injury and (iii) were available in English. Case reports, editorials and studies of non-traumatic vascular disease were excluded. Because the aim was a narrative synthesis rather than complete coverage, studies were selected purposively. Where several studies addressed the same question, systematic reviews, meta-analyses, randomized trials and large registry or database analyses were preferred. Fourteen studies were included (Table 1). Other publications cited in the Introduction and Discussion provided context and were not part of the included studies.

Data Extraction and Synthesis

For each included study, one author recorded the design, setting, sample and main findings in a standard extraction table (Table 1). Full texts were used where they were available; for nine studies, only abstract-level information was available (marked * in Table 1). Numerical results were transcribed as reported by the original authors. Findings were synthesized narratively by theme. A meta-analysis was not attempted because the included studies differed widely in design, population and outcomes.

RESULTS

Overview of the Included Studies

Fourteen studies were included (Table 1). Ten were systematic reviews, most of which included a meta-analysis and one of which formed the basis of a practice management guideline; three were retrospective analyses of national trauma databases in the United States; and one was a randomized controlled trial. Four studies addressed extremity and other peripheral arterial injuries, three addressed axillosubclavian, venous and other difficult-to-access injuries, five addressed BTAI and two addressed REBOA. Apart from the single randomized trial, the comparative evidence came almost entirely from observational studies.

TABLE 1: Summary of the Fourteen Included Studies, Ordered by Theme.

No	Author, year	Study design	Sample	Main findings
1	Abdou et al., 2022 [15]	Retrospective NTDB analysis (noninferiority design)	3,698 adults with isolated popliteal artery injury, 2002–2016	Endovascular repair was used in 6.7% of blunt and 3.5% of penetrating injuries. Amputation after blunt injury was 15.7% with open and 14.2% with endovascular repair; compartment syndrome after penetrating injury was 14.9% and 5.4%. Endovascular repair may be noninferior for limb preservation.
2	Al Tannir et al., 2024 [4]	Systematic review and meta-analysis	8 studies, 8,369 patients with penetrating non-aortic arterial injury	Only 15% had endovascular repair. Endovascular repair was associated with lower in-hospital or 30-day mortality (OR 0.72) and less compartment syndrome (OR 0.29). Overall risk of bias was moderate.
3	Qi et al., 2024 [5]	Systematic review and meta-analysis	32 studies of traumatic lower-extremity arterial injury	Endovascular therapy was associated with less major amputation (OR 0.42), less fasciotomy or compartment syndrome (OR 0.31) and a shorter stay, with similar mortality (OR 1.11). Nerve injury was reported only after open repair (15%).
4	Vaidya et al., 2024 [10]*	Systematic review	Studies of popliteal artery injury published 2010–2023	Endovascular management was associated with several favorable outcomes, but open surgery served only as a historical reference. Prospective data are needed.
5	Tsai et al., 2026 [16]	Systematic review and meta-analysis	12 retrospective studies, 2,854 patients with axillosubclavian arterial injury	Open surgery had higher short-term mortality than endovascular repair (OR 2.07; moderate certainty). Amputation, thrombosis and stroke did not differ (very low certainty). The mortality difference was lost when high-risk-of-bias studies were excluded (OR 0.92).
6	O'Connor et al., 2024 [9]	Retrospective TQIP analysis	1,334 patients with inferior vena cava injury, 2017–2020	5% had endovascular repair. Repair type did not affect outcomes after penetrating injury. After blunt injury, endovascular repair was associated with lower in-hospital mortality (aOR 0.35) but higher odds of venous thromboembolism.
7	Otaibi et al., 2024 [17]	Retrospective TQIP analysis	170 adolescents (<18 years) with subclavian or iliac artery injury, 2017–2020	Blunt injury (n = 60): no difference by repair type. Penetrating injury (n = 110): endovascular repair had lower morbidity (19% vs 41%) and mortality (3.7% vs 21%).
8	Nana et al., 2024 [6]	Systematic review	35 retrospective studies, 991 patients treated with TEVAR for BTAI	Technical success 98%, 30-day mortality 5%, spinal cord ischemia 1% and stroke 2%. At about 29 months, mortality was 2% and reintervention 1%.
9	Jubouri et al., 2024 [7]	Systematic review and meta-analysis	27 studies, 1,498 patients treated with TEVAR for BTAI	Survival was 91% at 6 months, 90% at 1 year and 88% at 5 years; pooled reintervention was 6.4%.
10	Gennai et al., 2023 [18]	Systematic review and meta-analysis	11 studies, 389 patients surviving >30 days after TEVAR; mean follow-up 8.2 years	Late reintervention was 2.1% and late survival 95.6%. A bird-beak configuration was seen in 38.7%.
11	Rudra et al., 2023 [19]	Systematic review and meta-analysis	7 studies, 4,177 patients with BTAI	TEVAR within 24 hours had higher short-term mortality than delayed TEVAR (RR 1.86) but a shorter ICU stay.

No	Author, year	Study design	Sample	Main findings
12	Firwana et al., 2026 [11]	Systematic review commissioned for SVS guidelines	21 studies addressing 7 key questions	Early (<24 h) TEVAR was associated with higher mortality than delayed repair (RR 2.04; moderate certainty). For grade 1–2 injuries, TEVAR had higher aortic-related mortality than nonoperative management (RR 8.11).
13	Jansen et al., 2023 [20]	Randomized clinical trial (UK-REBOA)	90 patients with exsanguinating torso hemorrhage at 16 UK major trauma centers	Stopped early for harm. 90-day mortality was 54% with REBOA plus standard care and 42% with standard care alone (OR 1.58).
14	Harfouche et al., 2025 [12]	Systematic review, meta-analysis and EAST guideline	31 studies	No mortality difference with REBOA in unstable subdiaphragmatic bleeding (OR 0.86); higher mortality with REBOA in pelvic fracture (OR 2.15). Conditional recommendation against REBOA in this population.

Extremity and Other Peripheral Arterial Injuries

The largest synthesis for the lower limb included 32 cohort studies and case series with a low or moderate risk of bias [5]. Compared with open surgical repair, endovascular therapy was associated with a lower risk of major amputation (odds ratio [OR] 0.42, 95% confidence interval [CI] 0.21–0.85) and of fasciotomy or compartment syndrome (OR 0.31, 95% CI 0.20–0.50), and with a hospital stay about five days shorter. All-cause mortality did not differ between the two approaches (OR 1.11, 95% CI 0.75–1.64). Intraoperative nerve injury was reported only in patients who had open repair, with a pooled incidence of 15% [5].

For penetrating non-aortic arterial injuries, a meta-analysis of eight studies including 8,369 patients found that only 15% of patients were treated endovascularly [4]. Endovascular repair was associated with lower in-hospital or 30-day mortality (OR 0.72, 95% CI 0.55–0.95) and less compartment syndrome (OR 0.29, 95% CI 0.12–0.71). However, patients who received endovascular repair were less likely to have a concurrent venous injury (OR 0.41), and the overall risk of bias was moderate [4].

The popliteal artery is a particularly demanding site. Among 3,698 adults with isolated popliteal injury in the National Trauma Data Bank, endovascular repair was used in only 6.7% of blunt and 3.5% of penetrating injuries [15]. Amputation rates after blunt injury were similar with open and endovascular repair (15.7% and 14.2%), and compartment syndrome after penetrating injury was less frequent after endovascular repair (5.4% compared with 14.9%), which led the authors to suggest that endovascular repair may be noninferior for limb preservation [15]. A systematic review of studies published from 2010 to 2023 reached a similar but cautious conclusion: endovascular management was associated with several favorable outcomes, but open surgery could serve only as a historical reference, and prospective data are needed to identify which patients benefit [10].

Axillosubclavian, Venous and Other Difficult-to-Access Injuries

Axillosubclavian injuries are difficult to expose surgically, which makes them an obvious target for endovascular repair. A 2026 meta-analysis of 12 retrospective studies including 2,854 patients found that open surgery was associated with higher short-term mortality than endovascular repair (OR 2.07, 95% CI 1.46–2.93), with moderate certainty of evidence [16]. Amputation, thrombosis of the repair and stroke did not differ, but the certainty for these outcomes was very low. Importantly, the mortality difference disappeared when studies at high risk of bias were excluded (OR 0.92, 95% CI 0.24–3.57), and nine of the 12 studies came from the United States [16].

Venous injuries show a similar pattern. Among 1,334 patients with traumatic inferior vena cava injury in the American College of Surgeons Trauma Quality Improvement Program (TQIP) database, only 5% were repaired endovascularly [9]. The type of repair did not affect outcomes after penetrating injury. After blunt injury, however, endovascular repair was associated with lower in-hospital mortality (adjusted OR [aOR] 0.35) and lower non-thromboembolic morbidity (aOR 0.41), at the cost of higher odds of venous thromboembolism [9]. In 170 adolescents with subclavian or iliac artery injury from the same database, endovascular repair was associated with lower morbidity (19% compared with 41%) and mortality (3.7% compared with 21%) after penetrating injury, whereas the type of repair made no difference after blunt injury [17].

Blunt Thoracic Aortic Injury

Thoracic endovascular aortic repair (TEVAR) has become the standard treatment for BTAI, and recent reviews describe its results in detail. A systematic review of 35 retrospective studies with 991 patients reported 98% technical success, 5% mortality at 30 days, spinal cord ischemia in 1% and stroke in 2% [6]. At a follow-up of about 29 months, mortality was 2% and reintervention 1% [6]. A meta-analysis of 27 studies with 1,498 patients reported survival of 91% at 6 months, 90% at 1 year and 88% at 5 years, with a pooled reintervention rate of 6.4% [7]. Long-term durability appears good: among 389 patients followed for a mean of 8.2 years, late reintervention was needed in only 2.1%, and overall late survival

was 95.6%, although a bird-beak configuration of the stent graft was seen in 38.7% [18].

The main unresolved question is timing. A meta-analysis of seven studies with 4,177 patients found higher short-term mortality when TEVAR was performed within 24 hours than when it was delayed (relative risk [RR] 1.86, 95% CI 1.26–2.74), although intensive care stays were shorter after early repair [19]. The systematic review commissioned for the Society for Vascular Surgery (SVS) guidelines, which included 21 studies, reached the same conclusion with moderate certainty (RR 2.04, 95% CI 1.45–2.86) [11]. In patients with concurrent traumatic brain injury, repair within 9 hours was associated with higher mortality than later repair (12.9% compared with 6.5%), although with low certainty. The same review found that for grade 1 and 2 injuries, TEVAR was associated with higher aortic-related mortality than nonoperative management (RR 8.11, 95% CI 1.25–52.57), and that intraoperative heparin was associated with lower mortality (RR 0.41, 95% CI 0.23–0.71) [11].

Resuscitative Endovascular Balloon Occlusion of the Aorta

REBOA is the endovascular technique with the least favorable recent evidence. In the UK-REBOA trial, 90 patients with exsanguinating torso hemorrhage at 16 major trauma centers in the United Kingdom were randomized to REBOA plus standard care or to standard care alone [20]. The trial was stopped early because its prespecified rule for harm was met. Mortality at 90 days was 54% with REBOA and 42% with standard care alone (OR 1.58), with an 86.9% posterior probability that REBOA increased mortality [20]. The 2025 guideline of the Eastern Association for the Surgery of Trauma (EAST), based on a meta-analysis of 31 studies, found no difference in mortality between REBOA and no REBOA in unstable patients with subdiaphragmatic bleeding (OR 0.86, 95% CI 0.37–2.04), and higher mortality with REBOA in patients with pelvic fractures (OR 2.15, 95% CI 1.35–3.42) [12]. The guideline therefore conditionally recommends against REBOA for hemodynamically unstable trauma patients with suspected subdiaphragmatic hemorrhage [12].

DISCUSSION

Summary of Findings

This review found three main things. First, the shift from open to endovascular repair is clearest in BTAI, where TEVAR combines high technical success with good long-term durability. Second, for peripheral, junctional and venous injuries, endovascular repair is associated with fewer limb complications and, in some analyses, lower mortality, but these associations are weakened by selection bias. Third, REBOA has not shown a survival benefit, and the only randomized trial suggests harm.

Interpreting the Shift Toward Endovascular Repair

The evidence for TEVAR in BTAI is the most consistent of the four themes, although it also comes from retrospective series rather than randomized trials [6,7,18]. A recent narrative review reached the same overall conclusion: TEVAR has largely replaced open surgery for BTAI in hemodynamically stable patients, whereas open repair remains the main approach for most peripheral arterial injuries [21].

For peripheral and junctional injuries, the favorable associations with endovascular repair need careful interpretation. Patients chosen for endovascular repair often differ from those treated with open surgery; for example, they were less likely to have a concurrent venous injury [4]. In the axillosubclavian meta-analysis, the survival advantage of endovascular repair was no longer seen when studies at high risk of bias were excluded [16]. Not all large studies favor endovascular repair. In a propensity-matched analysis of peripheral arterial injuries, endovascular repair was associated with more in-hospital complications, higher 30-day readmission (11% compared with 7%) and open reoperation (6% compared with 2%) rates, and higher costs [22]. Together, these findings suggest that part of the apparent benefit reflects patient selection rather than the technique itself.

The Continuing Role of Open Repair

Open surgery remains essential. It is still the most common approach for penetrating non-aortic injuries [4], and it gives direct control of bleeding in hemodynamically unstable patients and in complex injuries [16]. In penetrating abdominal vascular trauma with severe active bleeding, the role of endovascular techniques is limited, although hybrid operating rooms allow temporary balloon control, embolization or stenting to be combined with open surgery [2]. Open vascular skills, including the use of temporary shunts and damage-control techniques, therefore need to be maintained alongside endovascular skills [3].

Timing, Durability and the REBOA Controversy

The timing data for TEVAR are notable because they challenge the earlier preference for urgent repair. Both meta-analyses found higher mortality with repair within 24 hours [11,19]. Although the early and delayed groups in one analysis had similar presenting profiles [19], these are observational comparisons, and residual confounding cannot be excluded. The SVS review concluded that delayed intervention appears beneficial when feasible, particularly in patients with concurrent injuries [11].

Durability differs by region. For TEVAR, follow-up beyond five years is reassuring [18]. For peripheral stent grafts, long-term data are much more limited: earlier studies of axillosubclavian stent grafts reported occlusion rates of 14% to 58%, and the comparative data in this review covered mainly short-term outcomes [16].

The REBOA findings show that a less invasive technique is not automatically a safer one. UK-REBOA was small and stopped early, so its estimates are imprecise, but it is the only randomized evidence, and its direction is consistent with the EAST meta-analysis [12,20]. Current evidence therefore does not

support the routine use of REBOA in unstable patients with subdiaphragmatic bleeding.

Implications for Practice

The findings suggest six implications. (1) TEVAR should be the first-line treatment for BTAI that requires repair, and in stable patients, particularly those with traumatic brain injury, delaying repair beyond 24 hours appears reasonable [6,11]. (2) Grade 1 and 2 aortic injuries can often be managed nonoperatively [11]. (3) For peripheral, junctional and venous injuries, the choice between open and endovascular repair should be based on hemodynamic status, injury pattern and local expertise, with endovascular repair as a reasonable option for stable patients with suitable anatomy [13,16]. (4) Open vascular and damage-control skills must be maintained [3]. (5) REBOA should not be used routinely in unstable patients with subdiaphragmatic bleeding [12,20]. (6) Trauma systems should aim for rapid revascularization; the 2025 European guidelines recommend restoring perfusion to an ischemic limb within one hour of admission [13].

These implications are relevant to low- and middle-income countries, including Indonesia. No included study was conducted in Indonesia, and most data came from high-income countries, particularly the United States [9,15–17]. The European guidelines also note that high-quality evidence on vascular trauma is scarce, including for low- and middle-income settings [13]. Where hybrid operating rooms and trained endovascular operators are not available in every hospital, open repair and damage-control techniques remain the basis of care, and the timely transfer of selected patients to centers with endovascular capability should be planned within regional trauma systems.

Gaps in the Evidence

Several gaps remain. None of the included studies was a randomized comparison of open and endovascular repair, and most comparative data come from registries in which the surgeon chose the treatment. Long-term outcomes after peripheral stent grafting, including patency, limb function and quality of life, are poorly described [16]. Data from low- and middle-income countries are scarce [13]. Future research should use prospective multicenter registries with standardized definitions, adjustment for injury severity and long-term follow-up, and should include trauma centers in settings such as Indonesia.

Limitations

This review has several limitations. The systematic search was limited to PubMed, supplemented informally by Google Scholar and reference lists; studies were selected purposively, no protocol was registered and study quality was not formally appraised, so selection bias is possible. Screening and data extraction were performed by one author without independent verification. Only English-language studies were considered. Several of the included reviews on BTAI probably share primary studies, so their findings are not independent. For nine studies, only abstract-level information was available. Finally, the five-year window excluded older landmark studies, which were cited only for context.

CONCLUSIONS

The management of vascular trauma has moved from routine open repair toward a selective, injury-specific use of endovascular techniques. The shift is most complete in blunt thoracic aortic injury, where TEVAR is the first-line treatment, shows good long-term durability and may be safer when delayed in stable patients. For peripheral, junctional and venous injuries, endovascular repair is associated with fewer limb complications and possibly lower mortality, but selection bias limits these conclusions, and open repair remains essential for unstable patients and many penetrating injuries. REBOA has not shown a survival benefit. Prospective multicenter studies with long-term follow-up, including studies from low- and middle-income countries, are needed to define which patients benefit most from each approach.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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