REVIEW

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Comparative outcomes of hybrid versus conventional surgery for aortic dissection involving the aortic arch: A systematic review

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ABSTRACT

Introduction: Aortic arch involvement in acute aortic dissection is associated with substantial operative complexity and increased risks of mortality and neurological complications. While conventional open repair remains widely established, hybrid techniques integrating surgical reconstruction with thoracic endovascular aortic repair (TEVAR) have been increasingly utilized. Nevertheless, their comparative benefits and safety remain incompletely defined. This systematic review aimed to evaluate the outcomes of hybrid aortic arch repair compared with conventional open surgery specifically in patients with aortic dissection involving the aortic arch.

Methods: A systematic review was performed following PRISMA recommendations. PubMed/MEDLINE, ScienceDirect, ProQuest, and Google Scholar were searched from inception through June 2026. Comparative studies evaluating hybrid and conventional repair in adults with aortic arch dissection were eligible. Randomized controlled trials and comparative observational studies were included. Due to substantial variation in operative techniques, reported outcomes, and follow-up periods, a narrative synthesis was performed.

Results: A total of 478 records were identified, including three studies that fulfilled the inclusion criteria, comprising one randomized trial and two retrospective comparative cohorts published between 2013 and 2025. With a total of 810 patients, the analyzed studies included sample sizes ranging from 37 to 633 patients. Hybrid repair was associated with shorter aortic cross-clamp and cardiopulmonary bypass durations and demonstrated perioperative outcomes that were comparable or favorable relative to conventional surgery. Mortality, neurological events, postoperative recovery, and bleeding-related reintervention were generally similar or improved with hybrid treatment. However, interpretation was constrained by differences in methodology and varying risk of bias.

Conclusion: Hybrid aortic arch repair may represent a feasible alternative to conventional open surgery in appropriately selected patients with Stanford type A/DeBakey type I aortic dissection involving the arch. Potential benefits include improved operative efficiency without apparent compromise in early safety outcomes. However, limited evidence and inconsistent techniques and follow-up necessitate cautious interpretation. Further multicenter randomized studies with long-term follow-up are needed.

Keywords: aortic arch dissection, conventional surgery, hybrid procedure, outcomes.
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INTRODUCTION

Acute aortic dissection (AAD) is among the most catastrophic cardiovascular emergencies, and involvement of the aortic arch defines one of its most technically demanding and high-risk presentations. Because the arch gives rise to the supra-aortic branches supplying the brain and upper extremities, dissection extending into this segment threatens both aortic integrity and end-organ perfusion, and current international guidelines identify arch involvement as a major determinant of operative complexity and adverse outcome in Stanford type A/DeBakey type I dissection. Despite continuous refinement of surgical technique, arch repair remains associated with substantial early mortality and neurological morbidity, underscoring the ongoing need to define the optimal operative strategy for this population.[1–3]

Conventional open repair, most commonly performed as total or partial arch replacement with or without an elephant trunk extension, remains the established reference standard for arch dissection, but it carries several inherent limitations.[1,3,4] The procedure typically requires deep hypothermic circulatory arrest (DHCA) to permit a bloodless field during arch reconstruction, exposing

patients to cerebral and systemic ischemia and to coagulopathy, prolonged rewarming, and multi-organ dysfunction associated with extended arrest times.[4,5] Achieving complete arch replacement also necessitates prolonged cardiopulmonary bypass and aortic cross-clamp duration, both of which are independently linked to postoperative bleeding, respiratory failure, and renal impairment.[5,6] In addition, the technical complexity of reconstructing the arch and its branch vessels in a hypothermic, circulatory-arrested field demands considerable surgical expertise. It carries a non-negligible risk of stroke and spinal cord ischemia, particularly in elderly or hemodynamically unstable patients who are frequently poor candidates for extensive open reconstruction.[6,7] These limitations have driven interest in strategies capable of achieving comparable anatomical repair while reducing circulatory arrest time and overall physiological insult.

Hybrid aortic arch repair, which combines open surgical debranching of the supra-aortic vessels with thoracic endovascular aortic repair (TEVAR) of the distal arch and descending aorta, has emerged as an alternative capable of addressing several of these limitations.[8,9] By excluding the diseased arch segment endovascularly rather than through direct open replacement, hybrid techniques can shorten or even eliminate the need for DHCA, reduce cardiopulmonary bypass time, and extend the option of arch repair to patients considered high-risk for conventional surgery. Encouraging perioperative results from early case series and retrospective cohorts have supported its adoption in specialized aortic centers, and the recent publication of the first prospective randomized controlled trial directly comparing hybrid with conventional total arch replacement in acute Stanford type A dissection has further strengthened the evidence base for this approach.[10,11]

Nevertheless, the comparative outcomes of hybrid versus conventional arch repair remain incompletely defined. Prior systematic reviews and meta-analyses of hybrid arch repair, such as that by Yan et al., have generally pooled heterogeneous aortic arch pathologies, including aneurysmal and dissecting disease- and were based largely on retrospective, non-randomized comparisons that predate the recent randomized evidence.[12] Consequently, existing syntheses do not specifically isolate patients with aortic dissection, nor do they incorporate the 2025 randomized controlled trial by Zhao et al., which provides the first high-level evidence directly comparing perioperative outcomes between hybrid and conventional repair in this population.[10]

A systematic review focused specifically on aortic dissection with arch involvement, incorporating this recent trial alongside earlier comparative cohorts and centered on perioperative efficacy and safety outcomes, is therefore needed to provide clinicians with an updated, disease-specific synthesis of the evidence supporting hybrid repair. To address this gap, this systematic review aimed to evaluate the outcomes of hybrid aortic arch repair compared with conventional open surgery specifically in patients with aortic dissection involving the aortic arch, focusing on perioperative outcomes including mortality, neurological complications, operative duration, and reoperation for bleeding.

METHODS

Protocol Registration

This systematic review was prospectively registered in the PROSPERO international database (CRD420261481660) and was performed in accordance with the methodological recommendations outlined in the PRISMA 2020 guidelines.

Eligibility Criteria

Studies were included if they enrolled human patients diagnosed with aortic arch dissection, including acute, subacute, or chronic dissections involving the aortic arch confirmed by CT angiography, MRI, angiography, or intraoperative findings, with priority given to adult patients with acute aortic dissection and inclusion of mixed-age populations when relevant data were separately extractable. Eligible interventions comprised hybrid aortic arch procedures involving supra-aortic branch debranching and combined open surgical and endovascular repair, including thoracic endovascular aortic repair (TEVAR) or stent-graft placement. The comparator consisted of conventional open aortic arch procedures, such as total or partial arch replacement, elephant trunk procedures, open ascending–arch repair, or other standard open surgical techniques. Studies were required to report at least one relevant efficacy or safety outcome, including hospital or intensive care unit stay, 30-day mortality, long-term survival, stroke, spinal cord ischemia, renal failure, respiratory complications, bleeding or reoperation, reintervention, or major adverse cardiovascular or aortic events. Eligible study designs included randomized controlled trials, quasi-experimental studies, prospective or retrospective cohort studies, and comparative observational studies published as full-text, peer-reviewed articles in English. Studies were excluded if they involved aortic dissection without aortic arch involvement, evaluated isolated endovascular or open repair without a relevant hybrid-versus-conventional comparison, lacked a comparator group, or were case reports, reviews, conference abstracts, or non-English publications.

Search Strategy

A systematic literature search was conducted across PubMed/MEDLINE, ScienceDirect, ProQuest, and Google Scholar from database inception through June 2026 to identify relevant studies comparing hybrid and conventional approaches for aortic arch dissection. To enhance the comprehensiveness of study identification, the reference lists of all eligible articles and relevant clinical trial registries were also manually screened for additional studies. The search strategy incorporated both Medical Subject Headings (MeSH) and free-text terms, which were combined using Boolean operators and adapted according to the syntax requirements of each database. The primary search strategy for PubMed/MEDLINE was "efficacy" AND "hybrid" AND "conventional" AND ("aortic arch dissection" OR "DeBakey type I dissection"). In contrast, comparable search terms were applied in ScienceDirect, ProQuest, and Google Scholar using the Boolean combination "efficacy" AND "hybrid" AND "conventional" AND

("aortic arch dissection" OR "DeBakey type I dissection").

Study Selection and Data Extraction

Study selection was performed independently by two reviewers through sequential screening of titles, abstracts, and full-text articles according to the predefined eligibility criteria. All references retrieved from the electronic databases were imported into Zotero Reference Manager to facilitate citation management and identify duplicate records. Duplicate citations were initially detected using Zotero's automated matching function, followed by manual verification to ensure the accuracy of the deduplication process. Any disagreements regarding study eligibility were resolved through discussion until consensus was reached.

Data extraction was conducted independently by two reviewers using a standardized data collection form that had been pilot-tested before implementation. Information extracted from each study included study characteristics, participant demographics, intervention and comparator details, outcome measures, follow-up duration, and principal findings. When essential information was unavailable, attempts were made to obtain the missing data by contacting the corresponding authors of the original studies.

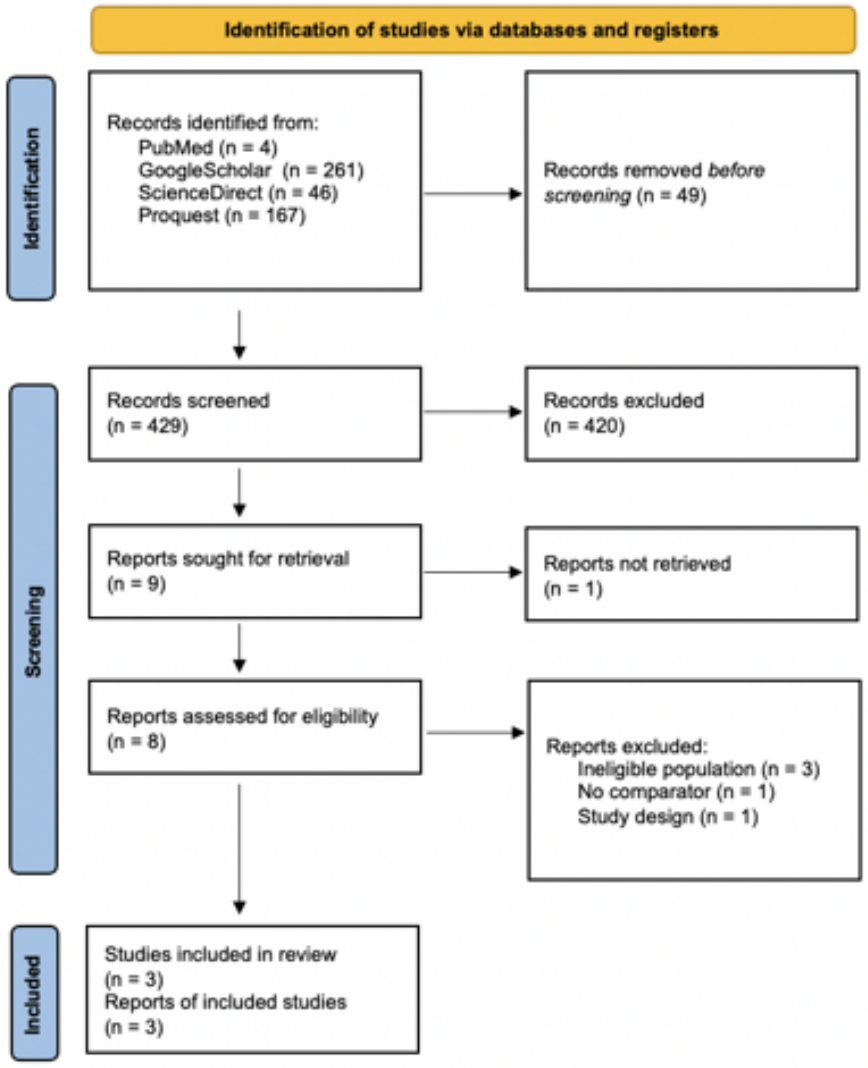


Figure 1. PRISMA flowchart

Risk of Bias Assessment

The methodological quality of the included studies was independently evaluated by four reviewers. Randomized controlled trials were assessed using the Cochrane Risk of Bias 2 (RoB 2) tool, which examines potential bias related to the randomization process, deviations from intended interventions, incomplete outcome data, outcome measurement, and selective reporting. Non-randomized studies were evaluated using the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) instrument, covering bias arising from confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement, and selective reporting of results. Any discrepancies between reviewers were resolved through discussion, with consultation from a third reviewer when consensus could not be achieved. The terminology and assessment domains were reported according to the original guidance for each appraisal tool.

Data Synthesis and Analysis

Because substantial heterogeneity among the included studies was anticipated, the findings were synthesized narratively rather than quantitatively. Results were summarized in evidence tables and organized according to intervention type and reported clinical outcomes. Variations across studies, including differences in disease characteristics, intervention strategies, comparator techniques, outcome measures, and duration of follow-up, were explored descriptively to identify potential sources of heterogeneity.

RESULTS

Data Searching

The literature search was performed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. During the identification phase, a total of 478 records were retrieved from four electronic databases, consisting of Google Scholar (n = 261), ProQuest (n = 167), ScienceDirect (n = 46), and PubMed (n = 4). Before the screening process, 49 records were removed, resulting in 429 records eligible for title and abstract screening. After screening, 420 records were excluded because they did not satisfy the predefined inclusion criteria, leaving 9 reports for full-text retrieval. Of these, 1 report could not be obtained, and the remaining 8

Table 1. Characteristics of included studies

Author (Year)	Country	Study Design	Study Period	N	Population	Type of Aortic Dissection	Dissection Phase	Type of hybrid procedure	Extent of Arch Replacement	Use of Circulatory Arrest	Cerebral Protection Strategy	Intervention	Comparator	Follow-Up Duration
Hofferberth et al., 2013	Australia	Retrospective comparative cohort study	January 2003 – December 2011	37	Patients with confirmed acute DeBakey type I (Stanford type A) aortic dissection undergoing surgical repair at a tertiary referral center	DeBakey type I (Stanford type A involving the arch and descending aorta)	Acute	Combination of open surgical and retrograde endovascular repair	Total arch replacement: 4 patients (Hybrid 2 ; Conventional 2) Hemi arch replacement: 17 patients (Hybrid 8 ; Conventional 9) No arch replacement : 16 patients (Hybrid 9 ; Conventional 7)	DHCA (Deep Hypothermic Circulatory Arrest) : 37 patients	Antegrade Cerebral Perfusion : 3 patients (Hybrid 2 ; Conventional 1) Retrograde Cerebral Perfusion : 4 patients (Hybrid 1 ; Conventional 3)	STABLE technique	Conventional proximal open surgical repair	Mean follow-up 50 months (Hybrid: 59 ± 34 months; Conventional: 41 ± 25 months)
Xie et al., 2021	China	Retrospective comparative cohort study	January 2016 – December 2018	633	Patients with confirmed DeBakey type I aortic dissection who underwent total arch replacement at Fuwai Hospital	DeBakey type I (Stanford type A)	Predominantly acute (85.3%); other are subacute (10.6%); chronic (4.1%)	Combination of open surgical and retrograde endovascular repair	Total arch replacement: 633 patients	DHCA (Deep Hypothermic Circulatory Arrest) : 511 patients (TAR+ FET : 431 ; ABP : 80) No Circulatory Arrest : 122 patients (HAR group)	Antegrade Cerebral Perfusion : 511 patients (TAR+ FET : 431 ; ABP : 80) No Cerebral Perfusion : 122 patients (HAR group)	Hybrid Aortic Arch Repair (HAR)	Total Arch Replacement with Frozen Elephant Trunk (TAR+FET) (primary comparator); additionally compared with Aortic Balloon Occlusion (ABO) technique	Early outcomes only (30-day follow-up); no long-term follow-up reported
Zhao et al. (2025)	China	RCT	January 2021 – December 2022	140	Adult patients (18–70 years) with imaging-confirmed acute Stanford type A aortic dissection involving the aortic arch and requiring total arch replacement	Stanford type A aortic dissection (TAAD) involving the aortic arch	Acute	Combination of open surgical and retrograde endovascular repair	Total arch replacement : 140 patients	DHCA (Deep Hypothermic Circulatory Arrest) : 70 patients (conventional group) Moderate Hypothermic Circulatory Arrest : 70 patients (hybrid group)	Antegrade Cerebral Perfusion : 140 patients	One-stop hybrid total arch repair	Conventional total arch replacement with stented elephant trunk (Sun's procedure) performed under DHCA	3 months (clinical follow-up and CTA/MRI at 1 and 3 months; 30-day survival also evaluated)

Table 2. The outcomes and main findings of the included studies

Author (Year)	Procedure	Aortic Cross Clamp Time (min)	Cardiopulmonary Bypass Time (min)	Early Mortality	Neurological	Hospital & ICU stay (days)	Re-operation for bleeding	Main Findings
Hofferberth et al., 2013	Hybrid vs Open repair	Similar (104 ± 49 vs 130 ± 42, p = 0,11)	Similar (213 ± 82 vs 237 ± 67, p = 0,36)	Similar (5% vs 11%, p = 0,6)	Similar risk of stroke (11% vs 18%, p = 0,65), but ↓ malperfusion syndrome (0% vs 22%, p = 0,04)	Similar duration of hospital (21 ± 13 vs 19 ± 15, p = 0,69) and ICU (6 ± 6 vs 7 ± 6, p = 0,54)	Similar (11% vs 3%, p = 1)	Hybrid reduced short term complication more than conventional procedure with comparable perioperative outcome and survival.
Xie et al., 2021	HAR vs TAR+FET vs ABO	↓ duration of cross clamp time (80,33 ± 34,88 vs 104,61 ± 34,92 vs 125,96 ± 34,86, p < 0,001)	↓ duration of CPB time (144,66 ± 53,66 vs 166,01 ± 46,56 vs 190,18 ± 51,81 , p < 0,001)	Similar (8% vs 6,1% vs 5,8%, p = 0,783)	Similar risk of stroke (4% vs 3,1% vs 1,8%, p = 0,104)	Similar duration of hospital (14,87 ± 8,76 vs 13,95 ± 7,22 vs 13,46 ± 6,25 , p = 0,520) and ICU (7,6 ± 3,87 vs 7,98 ± 4,18 vs 9,14 ± 6,16 , p = 0,221	Similar (2,8% vs 3,9% vs 7,0, p = 0,313)	Hybrid significantly reduced perioperative outcome with comparable short term complication and survival
Zhao et al., 2025	Hybrid vs Sun's procedure	↓ duration of cross clamp time (55,34 ± 8,25 vs 98,58 ± 13,64, p < 0,001)	↓ duration of CPB time (135,46 ± 15,25 vs 185,21 ± 23,72, p < 0,001)	↓ with Hybrid (8,6% vs 21,4%, p = 0,024)	↓ Stroke (4,3% vs 14,3%, p = 0,045), but similar risk SCI (1,4% vs 4,3%, p = 0,621)	↓ duration of hospital (10,8 ± 2,9 vs 15,3 ± 4,2, p < 0,001) and ICU (4,6 ± 1,3 vs 7,2 ± 2,1, p < 0,001)	↓ number of re-operation (2,9% vs 11,4%, p = 0,038)	Hybrid significantly improved perioperative outcomes, short term complication and early survival.

full-text articles underwent eligibility assessment. During this stage, 5 reports were excluded for the following reasons: ineligible population (n = 3), absence of a comparator (n = 1), and inappropriate study design (n = 1). Consequently, 3 studies fulfilled all eligibility criteria and were included in the final systematic review. The number of included reports corresponded to the total number of studies analyzed (n = 3) (**Figure 1**).

Characteristics of The Included Studies

Based on the literature search and study selection process, three studies met the eligibility criteria and were included in this systematic review. The included studies were published between 2013 and 2025 and were conducted in Australia (n = 1) and China (n = 2). Among the three included studies, two studies employed retrospective comparative cohort designs, while only one study was a randomized controlled trial (RCT). The total sample size across the included studies ranged from 37 to 633 participants. All studies enrolled adult patients with Stanford type A (DeBakey type I) aortic dissection involving the aortic arch who underwent surgical treatment. Most studies primarily included patients with acute aortic dissection, although one study also enrolled patients with subacute and chronic disease.

The interventions evaluated were various forms of hybrid aortic arch repair, including conventional surgical repair combined with thoracic endovascular aortic repair (TEVAR), hybrid arch repair using supra-aortic debranching with endovascular stent-graft implantation, and one-stop hybrid total arch replacement. These procedures were compared with conventional open surgical techniques, including proximal open repair, total arch replacement with a frozen elephant trunk (TAR + FET), aortic balloon occlusion (ABO), and Sun's procedure. The duration of follow-up varied considerably among studies, ranging from 30 days to a mean of 50 months, depending on the study design and clinical objectives (**Table 1**).

The Outcomes and Main Findings of the Included Studies

The findings of this systematic review suggest that hybrid aortic arch repair is a feasible alternative to conventional open surgical techniques for the management of acute Stanford type A (DeBakey type I) aortic dissection with involvement of the aortic arch. Across the included studies, hybrid approaches consistently demonstrated comparable or lower early mortality than conventional procedures while maintaining similar neurological outcomes. In the retrospective study by Hofferberth et al., hybrid repair using the STABLE technique achieved a lower hospital mortality rate than conventional open repair (5% vs. 11%). However, the difference was not statistically significant. Importantly, the hybrid approach eliminated postoperative malperfusion syndrome, significantly reduced distal aortic reinterventions, and promoted superior aortic remodeling characterized by greater true lumen expansion and increased false lumen thrombosis. Long-term survival was comparable between treatment groups, but hybrid repair substantially decreased late thoracoabdominal aneurysm formation and secondary distal aortic interventions.

Comparison among Hybrid Aortic Arch Repair (HAR), Total Arch Replacement with Frozen Elephant Trunk (TAR + FET), and Aortic Balloon Occlusion (ABO) demonstrated that all three surgical strategies produced similar short-term clinical outcomes. Xie et al. reported no significant differences in 30-day mortality, stroke, paraplegia, continuous renal replacement therapy, or re-exploration for bleeding among the three procedures. The only significant difference observed was a higher tracheotomy rate in the ABO group. Because only perioperative outcomes were evaluated, no conclusions could be drawn regarding long-term survival, reintervention rates, or aortic integrity. The authors therefore emphasized that procedure selection should be individualized according to patient characteristics, anatomical complexity, and surgeon expertise while awaiting further long-term comparative evidence.

The prospective randomized controlled trial by Zhao et al. further demonstrated the clinical advantages of one-stop hybrid total arch repair combined with retrograde thoracic endovascular aortic repair (TEVAR) compared with the conventional Sun's procedure. Hybrid surgery significantly reduced 30-day mortality and was associated with lower incidences of stroke, acute kidney injury, pulmonary infection, severe hypoxemia, postoperative delirium, and reoperation for bleeding. Furthermore, patients undergoing hybrid repair experienced superior early aortic remodeling, higher short-term survival, and better postoperative quality of life. These findings indicate that avoiding prolonged deep hypothermic circulatory arrest while combining open surgical reconstruction with endovascular stent-graft implantation may improve perioperative recovery without compromising procedural safety.

Overall, the available evidence indicates that hybrid arch repair provides perioperative outcomes that are at least comparable to conventional open surgery and may offer additional benefits in selected patients, particularly through reductions in postoperative malperfusion, systemic complications, and distal aortic reinterventions, together with improved early aortic remodeling. Although the current evidence supports the safety and efficacy of hybrid approaches, the limited number of prospective studies and the lack of long-term comparative follow-up highlight the need for larger randomized trials to determine the durability of these favorable outcomes and their impact on long-term survival and freedom from reintervention (**Table 2**).

Risk of Bias

The methodological quality of the included studies was evaluated using the Cochrane Risk of Bias 2 (RoB 2) tool for the randomized controlled trial and the ROBINS-I tool for the two non-randomized studies. Overall, the quality of the evidence varied according to study design and methodological rigor. The randomized controlled trial by Zhao et al. demonstrated a low risk of bias in the randomization process, as an appropriate computer-generated random sequence and allocation concealment were reported. Nevertheless, the study raised concerns regarding deviations from the intended interventions because an intention-to-treat analysis was not clearly described. A high risk of bias was identified in the missing outcome data domain, as several follow-up outcomes were evaluated only among surviving participants without appropriate methods to address missing data. Additional concerns were noted in the measurement of outcomes and the selection of reported results due to the absence of information regarding blinded outcome assessment and a pre-specified statistical analysis plan. Consequently, the overall risk of bias for this trial was judged to be high (**Figures 2** and **3**).

The two observational studies were assessed using the ROBINS-I tool. The retrospective comparative study evaluating hybrid and conventional surgical repair demonstrated a serious overall risk of bias, primarily because treatment allocation was determined by surgeon preference rather than randomization. This design introduced a substantial risk of confounding, while the retrospective single-center setting and incomplete radiological follow-up further increased the potential for bias. However, the classification of interventions, adherence to intended interventions, and outcome measurement were considered to have a low risk of bias because surgical procedures and clinical outcomes were clearly defined and objectively assessed.

Similarly, the retrospective cohort study by Xie et al. demonstrated an overall moderate risk of bias. Although the investigators minimized measured confounding through a matching weight method that improved baseline comparability between treatment groups, residual confounding from unmeasured clinical factors could not be excluded. The remaining methodological domains, including participant selection, intervention classification, deviations from intended interventions, missing outcome data, and outcome measurement, were considered to have a low risk of bias. Moderate concern remained regarding selective reporting because no published study protocol or pre-specified statistical analysis plan was available for comparison (**Figures 4** and **5**).

Overall, the risk-of-bias assessment indicates that the principal methodological limitations among the included studies

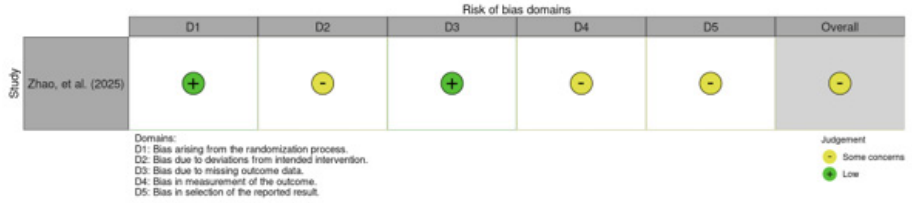


Figure 2. Risk of bias summary (Cochrane RoB 2 tool for RCTs)

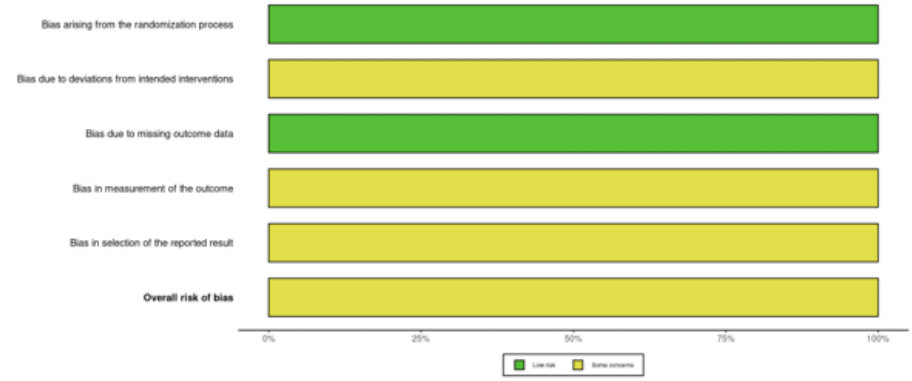


Figure 3. Risk of bias graph (Cochrane RoB 2 tool for RCTs)



Figure 4. Risk of bias summary (ROBINS-I tool for non-randomized studies)

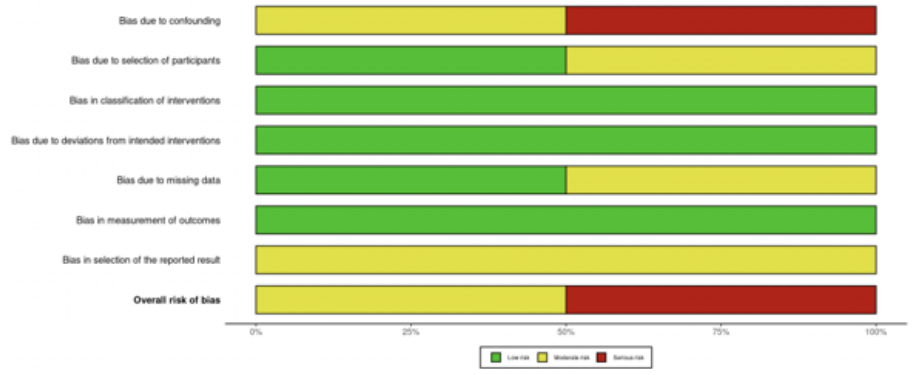


Figure 5. Risk of bias graph (ROBINS-I tool for non-randomized studies)

were related to confounding inherent to non-randomized designs and incomplete reporting of analytical methods. Despite these limitations, the studies generally employed objective clinical outcomes and clearly defined interventions, providing evidence of sufficient methodological quality to support qualitative synthesis. Nevertheless, the findings should be interpreted with appropriate caution due to the potential influence of residual confounding and incomplete follow-up in some studies.

DISCUSSION

This systematic review suggests that hybrid aortic arch repair (HAR) may be a reasonable alternative to conventional open surgery for selected patients with Stanford type A (DeBakey type I) aortic dissection involving the aortic arch. Across the three included comparative studies, hybrid repair demonstrated perioperative outcomes that were generally comparable with conventional approaches, with potential advantages in operative duration, postoperative recovery, and selected early clinical outcomes. However, the available evidence does not establish that hybrid repair is superior to conventional surgery. Rather, the findings support HAR as a patient-selection-dependent strategy that may provide specific perioperative advantages in appropriately selected anatomical and clinical settings. This interpretation is consistent with contemporary ACC/AHA, ESC, and EACTS recommendations, which emphasize individualized treatment according to patient characteristics, aortic anatomy, operative risk, and institutional expertise.[1–3]

The potential advantages of HAR may be related to its combination of limited open surgical reconstruction with thoracic endovascular aortic repair (TEVAR). Depending on the technique, this approach may reduce the extent of distal arch reconstruction and potentially shorten the duration of circulatory arrest, myocardial ischemia, and cardiopulmonary bypass (CPB) exposure.[13–18] Previous reports have described hybrid approaches as a means of reducing the physiological burden associated with extensive open arch reconstruction, particularly in patients considered to be at increased operative risk.[13–16] However, these potential physiological advantages should not be interpreted as evidence of overall clinical superiority because the durability and long-term consequences of different hybrid strategies remain incompletely defined.[11,17,19,20]

An important consideration in interpreting these findings is the possibility of selection bias and confounding by indication. Two of the three included studies were retrospective comparative cohorts, in which treatment

allocation was not randomized. In these settings, the decision to perform hybrid or conventional repair may have been influenced by patient age, comorbidities, anatomical complexity, malperfusion status, surgeon preference, or institutional experience.[8,16] Consequently, observed differences in outcomes may partly reflect baseline differences between treatment groups rather than the effect of the surgical strategy itself.

Selection bias may operate in either direction. High-risk patients may preferentially undergo hybrid repair because surgeons seek to minimize the physiological burden associated with extensive open arch surgery. Conversely, HAR may be preferentially offered to patients with favorable anatomy or to patients treated at centers with substantial endovascular expertise.[13–16] Surgical expertise and institutional volume may therefore act as important effect modifiers that are difficult to separate from the treatment effect in observational studies. These considerations reinforce that HAR should be regarded as an individualized treatment strategy rather than a universal replacement for conventional surgery.[1,3,14,21]

The included studies generally demonstrated shorter aortic cross-clamp times with hybrid repair, although Hofferberth et al. did not identify a statistically significant difference. The reduction observed in the other studies may reflect decreased technical complexity during distal arch reconstruction and the ability to complete part of the repair through an endovascular approach.[8,10,16] Shorter cross-clamp exposure may reduce myocardial ischemic burden and potentially decrease postoperative cardiac complications.[7–10] Nevertheless, cross-clamp duration should not be interpreted in isolation when selecting an operative technique.

Previous studies have similarly described reduced operative complexity as one potential advantage of hybrid arch strategies.[13–16] Shorter operative duration may be beneficial during the perioperative period, particularly in patients with substantial comorbidity or limited physiological reserve. However, treatment decisions must also consider anatomical suitability, long-term durability, endovascular-related complications, and the potential need for secondary intervention.[17,19,20,22–24] Thus, the shorter cross-clamp times observed in some studies support a potential procedural advantage but do not independently establish superiority of HAR.

Hybrid repair was associated with shorter CPB times in the comparative studies by Xie et al. and Zhao et al., whereas Hofferberth et al. reported no statistically significant difference.[8,10,16] Reduced CPB duration may be clinically relevant because prolonged extracorporeal circulation is associated with systemic inflammatory activation, coagulation abnormalities, and ischemia-reperfusion injury.[7–10] Consequently, reduced CPB exposure may contribute to improved perioperative recovery.

Previous studies have also identified shorter operative and bypass times as potential advantages of hybrid arch procedures.[10,15,17] However, the relationship between CPB duration and clinical outcomes is influenced by surgical complexity, patient condition, cerebral protection strategy, and institutional expertise. Therefore, shorter CPB time should be considered a potential procedural advantage rather than evidence that hybrid surgery provides superior overall outcomes.

Early mortality was generally comparable between hybrid and conventional procedures in the included studies, although Zhao et al. reported a significantly lower 30-day mortality with one-stop hybrid total arch repair.[10] These findings suggest that hybrid repair can achieve acceptable early survival in selected patients, but they do not establish a consistent mortality benefit. The potentially favorable early mortality observed with HAR may be related to reduced operative duration, lower physiological stress, and fewer postoperative complications.[13,17] However, interpretation should remain cautious because observational studies are particularly susceptible to confounding by indication. Patients selected for hybrid repair may differ systematically from those undergoing conventional surgery, while experienced centers may preferentially perform complex hybrid procedures.[8,16] Furthermore, the limited number of studies and relatively short follow-up in some cohorts prevent reliable assessment of long-term survival.[11,17,20]

Neurological complications are a major determinant of morbidity following aortic arch surgery. In this review, stroke rates were generally comparable between hybrid and conventional procedures, while Zhao et al. reported a lower stroke incidence following hybrid repair without a significant difference in spinal cord ischemia.[8,10,16] These findings suggest that HAR can achieve neurological outcomes comparable with conventional surgery in selected patients.

One possible explanation is that some hybrid techniques reduce the duration of circulatory arrest and cerebral ischemic exposure.[13–16] However, neurological outcomes are also strongly influenced by cerebral protection strategies, supra-aortic vessel anatomy, embolic burden, operative technique, and perioperative management.[1–3] Therefore, the reduction in stroke reported in one study should not be generalized to all hybrid procedures. Rather, the available evidence indicates that HAR may provide acceptable neurological outcomes when appropriate patient selection and cerebral protection strategies are applied.

The effect of hybrid repair on postoperative length of stay was inconsistent across the included studies. Zhao et al. reported significantly shorter hospital and ICU stays with hybrid repair, whereas Hofferberth et al. and Xie et al. found no significant differences.[8,10,16] The shorter stay observed in the randomized study may be related to reduced CPB and cross-clamp duration and lower rates of selected postoperative complications.[10] Previous literature has also suggested that hybrid procedures may facilitate postoperative recovery and reduce healthcare resource utilization.[14,17,25] However, hospital and ICU stay are influenced by institutional discharge protocols, rehabilitation pathways, ICU capacity, and patient comorbidities. Therefore, while HAR may facilitate earlier recovery in selected patients, current evidence is insufficient to conclude that it consistently reduces hospitalization compared with conventional surgery.

Reoperation for bleeding was generally comparable between treatment

groups, although Zhao et al. reported a significantly lower rate of re-exploration following hybrid repair.[10] A potential explanation is that reduced CPB duration and less extensive open reconstruction may decrease hypothermia-associated coagulopathy, platelet dysfunction, and consumption of coagulation factors.[7–10] Nevertheless, postoperative bleeding is influenced by emergency presentation, preoperative coagulation status, operative complexity, and institutional transfusion and hemostatic protocols. Therefore, the lower reoperation rate observed in one study should be interpreted as a potential benefit rather than a consistent effect of hybrid repair. Larger comparative studies using standardized definitions of bleeding and re-exploration are required to determine whether HAR genuinely reduces bleeding-related morbidity.

The findings of this review support HAR as an individualized treatment option rather than a replacement for conventional open arch surgery. Current international recommendations emphasize that treatment selection should incorporate patient characteristics, aortic anatomy, extent of arch involvement, operative risk, and institutional expertise.[1–3] Conventional total arch replacement remains an important strategy, particularly in younger patients, those with connective tissue disorders, and patients in whom long-term anatomical durability is prioritized.[1–3,7,12,15,18,21] Conversely, HAR may be considered when reducing CPB duration, cross-clamp exposure, or circulatory arrest is clinically desirable and when the anatomy is suitable for endovascular treatment.[17,18]

In clinical practice, appropriate patient selection should begin with detailed preoperative imaging to assess the primary entry tear, supra-aortic vessel involvement, landing-zone anatomy, and distal aortic pathology. Multidisciplinary evaluation involving cardiovascular surgeons, vascular or endovascular specialists, anesthesiologists, and radiologists may help determine whether a hybrid or conventional strategy provides the most appropriate balance between immediate operative risk and long-term durability.[2,14,21] Treatment in experienced aortic centers is particularly important because procedural outcomes may depend substantially on operator experience and institutional expertise.

Patients undergoing hybrid repair also require continued postoperative surveillance because endovascular components may be associated with late complications, including endoleak, stent-graft-related complications, progressive distal aortic dilatation, and secondary intervention. Serial computed tomography angiography or magnetic resonance imaging may therefore be required to evaluate aortic remodeling and identify delayed complications.[17,19,20] Overall, the current evidence supports HAR as one component of a contemporary, individualized treatment strategy, while conventional open repair remains an essential treatment option.

Future research should focus on determining which patients derive the greatest benefit from hybrid repair. Large multicenter randomized controlled trials comparing contemporary HAR with standardized conventional arch procedures are needed to reduce the influence of treatment-selection bias and surgeon preference. Such studies should incorporate detailed baseline anatomical and clinical characteristics to allow appropriate adjustment for factors such as age, malperfusion, connective tissue disease, comorbidity, and aortic anatomy.

Long-term outcomes should also receive greater emphasis. In addition to early mortality and neurological complications, future studies should evaluate long-term survival, freedom from reintervention, distal aortic enlargement, false-lumen thrombosis, aortic remodeling, endoleak, quality of life, and healthcare costs.[17,19,20]

Standardized definitions and longer follow-up would improve comparability between studies and clarify whether the perioperative advantages of hybrid repair translate into meaningful long-term benefits.

Further technological development may influence the future role of HAR. Improvements in branched and fenestrated endovascular devices, imaging technologies, hybrid operating rooms, and cerebral protection strategies may expand the range of anatomically suitable patients.[18] However, technological progress should be accompanied by rigorous evaluation of durability and late complications before broader indications are adopted.

This review has several strengths. First, the literature search and study selection were conducted using predefined eligibility criteria and a PRISMA-based approach, with independent screening and standardized data extraction. Second, risk of bias was formally evaluated using appropriate tools for both randomized and observational studies, allowing methodological limitations to be incorporated into the interpretation of the findings. Third, the review specifically focused on Stanford type A (DeBakey type I) dissection involving the aortic arch, rather than combining multiple unrelated aortic pathologies. Finally, several clinically relevant outcomes were evaluated, including operative duration, mortality, neurological complications, postoperative recovery, and reoperation for bleeding.

Several limitations should be considered. First, only three comparative studies met the eligibility criteria, limiting statistical power and certainty of the conclusions and preventing quantitative meta-analysis. Second, the included studies differed substantially in hybrid and conventional surgical techniques, patient characteristics, and follow-up duration, limiting direct comparison across studies. The hybrid procedures included the STABLE technique, supra-aortic debranching with TEVAR, and one-stop hybrid total arch repair, while conventional comparators included proximal open repair, TAR+FET, ABO, and Sun's procedure.

Third, two studies were retrospective comparative cohorts and were therefore susceptible to confounding and selection bias. In particular, treatment allocation could have been influenced by surgeon preference, anatomical suitability, patient risk, and institutional expertise. Although propensity-based adjustment was used in one study, residual confounding from unmeasured variables could not be excluded. Fourth, the included randomized trial also had methodological concerns, including incomplete reporting of deviations from the intended

intervention, missing outcome data, and limitations in prespecified statistical analysis. Consequently, the overall certainty of evidence remains limited.

Finally, long-term comparative evidence remains insufficient. Although some studies have reported favorable long-term aortic remodeling and reintervention outcomes following hybrid repair, the available evidence remains heterogeneous and limited in duration. Therefore, the findings of this review should be interpreted as supporting the potential role of HAR in selected patients rather than demonstrating its superiority over conventional open surgery.

CONCLUSION

This systematic review suggests that hybrid aortic arch repair may be a feasible alternative to conventional open surgery in selected patients with Stanford type A (DeBakey type I) aortic dissection involving the arch, with shorter aortic cross-clamp and cardiopulmonary bypass times and generally comparable perioperative outcomes. However, current evidence remains insufficient to establish superiority because of the limited number of comparative studies, heterogeneity in surgical techniques and patient selection, and limited long-term follow-up. Treatment selection should therefore be individualized based on patient characteristics, anatomy, operative risk, and institutional expertise, while further multicenter studies with standardized approaches and longer follow-up are needed to clarify long-term durability and optimal patient selection.

DISCLOSURES

ETHICAL CONSIDERATION

This study does not require ethical approval because the data used were obtained exclusively from previously published studies.

CONFLICT OF INTEREST

The authors have no conflict of interest

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AUTHOR CONTRIBUTION

All authors contributed to the study design, conceptualization, and content development. The literature search strategy was conducted by PAWS, IMY, and IGBAAK. Data analysis was performed by PAWS, INRS, and AVP. All authors contributed to the preparation, revision, and finalization of the manuscript for publication.

USE OF ARTIFICIAL INTELLIGENCE GENERATED CONTENT

The researchers used AI solely to assist with improving the writing and refining word choice. It was ensured that no research data were obtained or generated from AI.

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