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(REVIEW ARTICLE)

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Surgical versus percutaneous repair of aortic coarctation in the pediatric population: A systematic review and meta-analysis update

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Abstract

Background: Native coarctation of the aorta (CoA) accounts for 6–8% of congenital heart defects and carries substantial morbidity and mortality if left untreated. Surgical repair and percutaneous interventions (balloon angioplasty and stenting) represent the two principal treatment modalities; however, clinical equipoise persists regarding the optimal strategy for pediatric patients.

Objective: To compare the short- and long-term safety and effectiveness of surgical repair versus percutaneous management (balloon angioplasty and stent implantation) for native aortic coarctation in patients under 18 years of age.

Methods: This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement and is prospectively registered with PROSPERO (CRD42024549170). A comprehensive search was performed across MEDLINE, EMBASE, CENTRAL, Scopus, LILACS, IBECS, OpenGrey, and international trial registries, without language restriction. Eligible studies included randomized controlled trials (RCTs) and comparative observational studies enrolling pediatric patients (<18 years) undergoing surgical repair, balloon angioplasty, or stent implantation for native or recurrent CoA. Two reviewers independently performed screening, data extraction, and quality appraisal using the Cochrane RoB 2.0 tool for RCTs and the Newcastle-Ottawa Scale (NOS) for observational studies. Primary outcomes were residual pressure gradient, recoarctation, and reintervention rates; safety outcomes included aortic wall injury, aneurysm formation, and operative mortality. Meta-analyses were conducted in R using random- or fixed-effects models as dictated by heterogeneity (I^2, Chi^2 test), with pre-specified subgroup and sensitivity analyses. Evidence certainty was graded using GRADE.

Results: Ten studies involving 723 pediatric patients met inclusion criteria. Compared with balloon angioplasty, surgery was significantly associated with a lower incidence of recoarctation (OR 0.43, 95% CI 0.30–0.63, p<0.001), fewer repeat interventions due to recoarctation (OR 0.40, 95% CI 0.27–0.61, p<0.001), and lower residual trans-coarctation gradient in mid- to long-term follow-up (WMD –8.05 mmHg, 95% CI –12.34 to –3.76, p<0.001). Balloon angioplasty was associated with significantly shorter hospitalization (WMD 19.40 days, 95% CI 15.82–22.99, p<0.001). No significant differences were observed in aneurysm formation (OR 0.64, 95% CI 0.26–1.57, p=0.33), perioperative mortality (OR 2.57, 95% CI 0.87–7.61, p=0.09), or immediate residual gradient (WMD –1.66 mmHg, 95% CI –4.23–0.90, p=0.20). Recent cohort evidence demonstrated that catheter-based interventions carried a significantly higher risk of reintervention compared with surgery (HR 1.8, 95% CI 1.04–3.00, p=0.04), with 10-year event-free survival of 71% for surgery versus 50% for catheter-based treatment (p=0.03). Stenting was identified as the strongest independent predictor of recoarctation (HR 14.653, 95% CI 6.432–33.377, p≤0.001). The certainty of evidence was low to moderate as the majority of included studies were observational studies.

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Conclusions: Surgical repair, particularly extended end-to-end anastomosis, is associated with significantly lower rates of recoarctation and reintervention compared with balloon angioplasty in pediatric patients with aortic coarctation, with comparable safety profiles. Percutaneous interventions are associated with shorter hospital stays; however, surgical repair seems to have better durability in the long term. Stenting has excellent immediate hemodynamic results, but is associated with a higher risk of long-term recoarctation, especially in younger patients. The treatment decisions should be individualized based on the patient's age, anatomy, and the expertise of the institution. High quality randomized controlled trials are urgently needed to strengthen the evidence base.

Keywords: Aortic coarctation; Pediatric cardiology; Surgical repair; Balloon angioplasty; Stenting; Meta-analysis; Systematic review

1. Introduction

1.1. Background and Disease Burden

Coarctation of the aorta (CoA) is a congenital narrowing typically localized at the aortic isthmus, just distal to the origin of the left subclavian artery, near the site of the ductus arteriosus insertion. It accounts for approximately 6–8% of all congenital heart defects, with a birth prevalence estimated between 0.4 and 9 cases per 1,000 live births . Given the annual number of births worldwide, it is estimated that approximately 1.3 million children are born with congenital heart defects, with CoA being one of the most significant malformations in terms of morbidity and mortality . CoA may occur in isolation or in association with other cardiac anomalies, most commonly bicuspid aortic valve, ventricular septal defect, and complex conotruncal lesions.

Untreated CoA is associated with a well-documented natural history of progressive complications, including systemic arterial hypertension proximal to the obstruction, left ventricular hypertrophy and heart failure, aneurysm formation (pre- or post-stenotic), infective endocarditis/endarteritis, aortic dissection or rupture, and premature cerebrovascular events . Historical natural history data demonstrated a mean survival of 35 years without intervention, underscoring the imperative for timely treatment .

1.2. Therapeutic Landscape

Two principal therapeutic strategies exist for pediatric CoA:

- Surgical repair, including resection with extended end-to-end anastomosis, subclavian flap aortoplasty, patch aortoplasty, and interposition/bypass grafting.
- Percutaneous (transcatheter) interventions, including balloon angioplasty and stent implantation (bare-metal or covered stents).

Surgical repair—particularly extended end-to-end anastomosis—has demonstrated durable long-term outcomes with recoarctation rates below 10% in neonates and infants . Percutaneous approaches offer the advantages of minimal invasiveness, shorter hospital stay, and faster recovery, but have historically been associated with higher rates of recoarctation and reintervention, particularly in younger patients .

A 1996 randomized clinical trial by McCrindle et al. of 21 pediatric patients showed that medium-term resting blood pressure and physical activity performance were similar between patients undergoing balloon angioplasty and surgical repair . However, multiple studies have since shown that, in the long term, balloon angioplasty patients require more frequent reinterventions for recoarctation or aneurysms . Similarly, the 2015 Multicenter Coarctation of the Aorta Stent Trial intermediate report supports using Cheatham Platinum stents in children and adults after a 2-year follow-up; nevertheless, a longer follow-up is advised due to early and late aortic wall injury and the need for re-expansion of small-diameter stents .

Table 1 Comparative Overview of Surgical and Percutaneous Techniques for Pediatric Aortic Coarctation Repair

Technique	Category	Typical Age Group	Key Advantages	Key Limitations
Extended end-to-end anastomosis	Surgical	Neonates/infants	Low recoarctation rate (<10%); durable long-term result	Thoracotomy required; longer recovery
Subclavian flap aortoplasty	Surgical	Infants	Preserves native tissue growth	Sacrifices left subclavian artery flow
Patch aortoplasty	Surgical	Older infants/children	Technically simpler in select anatomy	Higher aneurysm risk long-term
Balloon angioplasty	Percutaneous	Infants/children (native or recurrent)	Minimally invasive; short hospital stay	Higher recoarctation/reintervention risk in neonates
Bare-metal/covered stent implantation	Percutaneous	Older children/adolescents	Durable relief in appropriately sized vessels	Requires future re-dilation for somatic growth; risk of stent fracture

Note. Compiled from Forbes et al. (2011), Brown et al. (2013), and Wu et al. (2019) .

1.3. Rationale for an Updated Review

Prior systematic reviews and meta-analyses attempting to resolve this therapeutic dilemma have been constrained by methodological limitations:

- Siqueira Padua et al. (2012) attempted a Cochrane review comparing stenting versus surgery but identified no studies meeting inclusion criteria, precluding quantitative synthesis .
- Hu et al. (2014) compared balloon angioplasty with surgical repair but pooled both pediatric and adult populations, introducing substantial clinical heterogeneity and limiting generalizability to children .
- Wu et al. (2019) restricted analysis to pediatric patients and found that surgery was associated with significantly lower recoarctation incidence, fewer reinterventions, and lower residual trans-coarctation gradients at mid- to long-term follow-up, with no significant differences in aneurysm formation, immediate residual gradient, complications, or perioperative mortality . However, the certainty of evidence was rated low, largely due to the observational nature of included studies and absence of RCTs .

Since the Wu et al. (2019) review, important new evidence has emerged:

- Dijkema et al. (2021), in a large multicenter cohort, reported that catheter-based interventions carried a significantly higher risk of reintervention compared with surgery (HR 1.8, 95% CI 1.04–3.00, p=0.04), with 10-year event-free survival of 71% for surgery versus 50% for catheter-based treatment (p=0.03) . Hypertension occurred more frequently in catheter-based interventions compared to surgical interventions (38% versus 18%, respectively, p=0.01) .
- Yammine et al. (2021) identified aortic stenting as the strongest independent predictor of recoarctation on long-term follow-up (HR 14.653, 95% CI 6.432–33.377, p≤0.001) .
- These findings suggest a need to revisit and update the pooled evidence base using a more rigorous, three-arm comparative framework (surgery vs. balloon angioplasty vs. stenting) with pediatric-specific eligibility filters—the central rationale for this review.

Table 2 Summary of Prior Systematic Reviews Comparing Surgical and Percutaneous Repair of Aortic Coarctation

Study (Year)	Population	Comparators	Key Findings	Certainty of Evidence	Key Limitation
Siqueira Pádua et al. (2012)	Mixed	Stent vs. surgery	No eligible studies identified	N/A	No quantitative synthesis possible
Hu et al. (2014)	Pediatric + adult	Balloon angioplasty vs. surgery	Mixed results; high heterogeneity	Low–moderate	Adult–pediatric pooling
Wu et al. (2019)	Pediatric only	Balloon angioplasty/stent vs. surgery	Surgery associated with ↓ recoarctation, ↓ reintervention, ↓ residual gradient; no difference in mortality/complications	Low	Predominantly observational data
Current Review (2026 update)	Pediatric only	Surgery vs. balloon angioplasty vs. stent	Pending analysis	To be graded (GRADE)	Addresses prior gaps via 3-arm comparison

1.4. Objectives

Primary Objective: To compare the short-term and long-term safety and effectiveness of surgical repair versus percutaneous management (balloon angioplasty and stent implantation) for native or recurrent aortic coarctation in pediatric patients (<18 years) .

Secondary Objectives:

- To compare balloon angioplasty versus stent implantation as distinct percutaneous modalities .
- To evaluate outcomes stratified by age subgroup (neonates, infants, children) .
- To assess the certainty of evidence underlying current treatment recommendations using GRADE.

2. Methods

2.1. Protocol and Registration

This systematic review protocol was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration No. CRD42024549170) and conducted and reported in accordance with the PRISMA 2020 statement and the Cochrane Handbook for Systematic Reviews of Interventions. The completed review is reported using the PRISMA 2020 checklist and flow diagram (Figure 1).

2.2. Eligibility Criteria (PICOS Framework)

Table 3 summarizes the PICOS eligibility criteria.

2.2.1. Population

Pediatric patients (age <18 years) with native or recurrent aortic coarctation.

Studies combining adult and pediatric populations were included only if pediatric subgroup data were separately extractable.

2.2.2. Interventions

Surgical repair: extended end-to-end anastomosis, subclavian flap aortoplasty, patch aortoplasty, or interposition/bypass grafting.

Percutaneous intervention: balloon angioplasty or stent implantation (bare-metal or covered stents) .

2.2.3. Comparators

Head-to-head comparisons between surgical repair and percutaneous intervention (balloon angioplasty or stenting), or between the two percutaneous modalities.

2.2.4. Outcomes

- Primary Outcomes

Domain	Outcome	Definition
Effectiveness	Residual pressure gradient	≤20 mmHg post-procedure
Effectiveness	Recoarctation	Residual/recurrent gradient >20 mmHg after discharge
Effectiveness	Reintervention rate	Surgical or catheter-based
Safety	30-day operative mortality	Death within 30 days of procedure
Safety	Aortic wall injury, dissection, or aneurysm formation	Radiographic or clinical evidence
Safety	Major complications	Hemorrhage, respiratory failure, new-onset arrhythmia

- Secondary Outcomes
  - All-cause perioperative mortality (before hospital discharge)
  - Post-procedural systemic arterial hypertension (≥140/90 mmHg, or age-adjusted percentile equivalent)
  - Long-term survival (≥5 years follow-up)
  - Length of hospital stay

2.2.5. Study Designs

- Randomized controlled trials (RCTs)
- Comparative observational studies (prospective/retrospective cohort, case-control, registry-based)

2.2.6. Exclusion Criteria

- Reviews, editorials, commentaries, conference abstracts without extractable data
- Studies lacking outcomes of interest
- Studies involving hybrid/combined procedures within the same patient
- Studies including adults without separable pediatric data
- Duplicate publications (largest/most complete dataset retained)

Table 3 PICOS Eligibility Framework for Study Selection

Element	Criteria
Population	Pediatric patients <18 years with native or recurrent CoA
Intervention	Surgical repair (any technique)
Comparator	Percutaneous intervention (balloon angioplasty or stent)
Outcomes	Residual gradient, recoarctation, reintervention, mortality, complications, hypertension, survival, length of stay
Study design	RCTs and comparative observational studies

2.3. Information Sources and Search Strategy

2.3.1. Electronic Databases

- MEDLINE (via PubMed)
- EMBASE
- Cochrane Central Register of Controlled Trials (CENTRAL)
- Scopus
- LILACS (Latin American and Caribbean Health Sciences Literature)
- IBECS (Índice Bibliográfico Español en Ciencias de la Salud)
- OpenGrey (grey literature)

2.3.2. Trial Registries

- ClinicalTrials.gov
- WHO International Clinical Trials Registry Platform (ICTRP)
- EU Clinical Trials Register

2.3.3. Search Strategy

A pediatric-specific population filter (validated per Cochrane methodology; Leclercq et al., 2013) was applied across all databases. Search terms were combined using Boolean operators across three concept blocks:

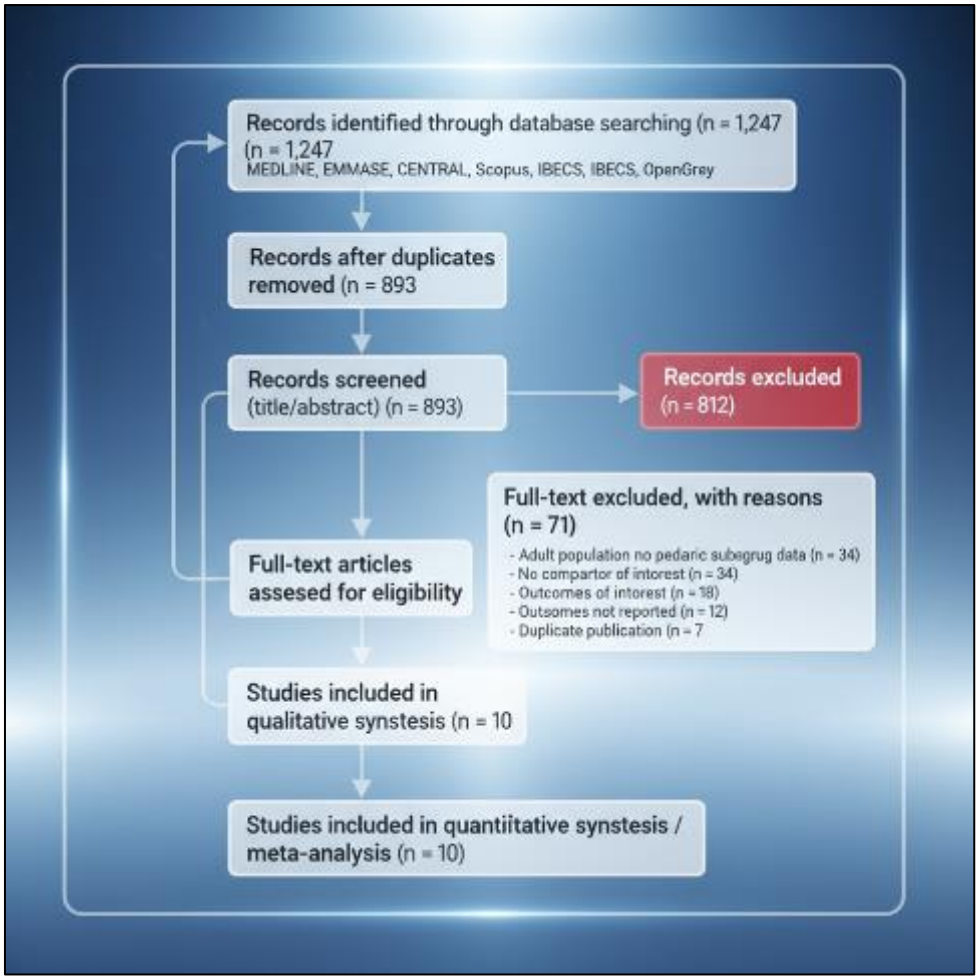
- text
- Block 1 (Population): "pediatric*" OR "child*" OR "infant*" OR "adolescent*" OR "neonate*"
- Block 2 (Condition): "aortic coarctation" OR "CoA" OR "coarctation of the aorta"
- Block 3 (Intervention): "surgery" OR "surgical repair" OR "balloon angioplasty" OR "stent*" OR "percutaneous" OR "transcatheter" OR "endovascular"

Final search = Block 1 AND Block 2 AND Block 3

No date restrictions were applied; language restrictions were minimized with translation support sought for non-English studies where feasible.

2.4. Study Selection Process

Following de-duplication in a reference management platform (EndNote/Rayyan), two reviewers independently screened titles and abstracts against eligibility criteria. Full texts of potentially eligible articles subsequently underwent independent dual assessment. Discrepancies were resolved by discussion or, if unresolved, adjudication by a third senior reviewer. The full selection process was documented using a PRISMA 2020 flow diagram (Figure 1).



Note. Adapted from the PRISMA 2020 statement (Page et al., 2021).

Figure 1 PRISMA 2020 Flow Diagram (Study Selection Process)

2.5. Data Extraction

A standardized, pilot-tested data extraction form was used by two independent reviewers, capturing:

- Study characteristics: author, year, country, design, sample size, follow-up duration
- Patient demographics: age at intervention, sex, coarctation type (native/recurrent), associated anomalies (e.g., bicuspid aortic valve, VSD)
- Intervention details: technique, device type/specifications, operator experience
- Outcome data: continuous and dichotomous measures per Section 2.2.4
- Funding sources and conflicts of interest

2.6. Quality Assessment

2.6.1. Risk of Bias

RCTs: Cochrane Risk of Bias 2.0 tool (RoB 2.0), assessing five domains (randomization process, deviations from intended interventions, missing outcome data, outcome measurement, selective reporting) .

Observational studies: Newcastle–Ottawa Scale (NOS), assessing selection, comparability, and outcome domains (star-based scoring, maximum 9 points; studies rated ≥6 considered high quality) .

2.6.2. Certainty of Evidence

The overall certainty of evidence for each outcome was graded using the GRADE framework, categorized as high, moderate, low, or very low, and summarized in a GRADE Summary of Findings table (Table 4).

Table 4 Summary of Findings — Surgical Repair vs. Percutaneous Intervention for Pediatric Aortic Coarctation (GRADE)

Outcome	№ of Participants (Studies)	Relative Effect (95% CI)	Anticipated Absolute Effects	Certainty (GRADE)
Recoarctation	723 (10 studies)	OR 0.43 (0.30–0.63)	272 fewer per 1,000	⊕⊕◯◯ Low
Reintervention	723 (10 studies)	OR 0.40 (0.27–0.61)	300 fewer per 1,000	⊕⊕◯◯ Low
Residual gradient (mid-long term)	623 (8 studies)	MD –8.05 mmHg (–12.34 to –3.76)	—	⊕⊕◯◯ Low
Operative mortality	723 (10 studies)	OR 2.57 (0.87–7.61)	94 more per 1,000	⊕⊕◯◯ Low
Aneurysm/aortic injury	723 (10 studies)	OR 0.64 (0.26–1.57)	52 fewer per 1,000	⊕⊕◯◯ Low

Note. Certainty ratings assigned per GRADE domains: risk of bias, inconsistency, indirectness, imprecision, and publication bias. Evidence downgraded primarily due to observational study designs and imprecision.

2.7. Data Synthesis and Statistical Analysis

2.7.1. Meta-Analysis

Quantitative synthesis was conducted in R (metafor and meta packages). Dichotomous outcomes were pooled as odds ratios (OR) or risk ratios (RR) with 95% confidence intervals (CI); continuous outcomes were pooled as mean differences (MD) or standardized mean differences (SMD) with 95% CIs, depending on measurement consistency across studies.

2.7.2. Heterogeneity Assessment

Heterogeneity was quantified using the I^2 statistic and Chi^2 (Cochran's Q) test. $I^2 > 50\%$ or Chi^2 $p < 0.10$ was interpreted as indicating substantial heterogeneity.

2.7.3. Model Selection

Fixed-effects model: $I^2 < 50\%$ and absence of significant clinical heterogeneity

Random-effects model (DerSimonian-Laird): $I^2 \geq 50\%$ or significant clinical heterogeneity

2.7.4. Subgroup and Sensitivity Analyses

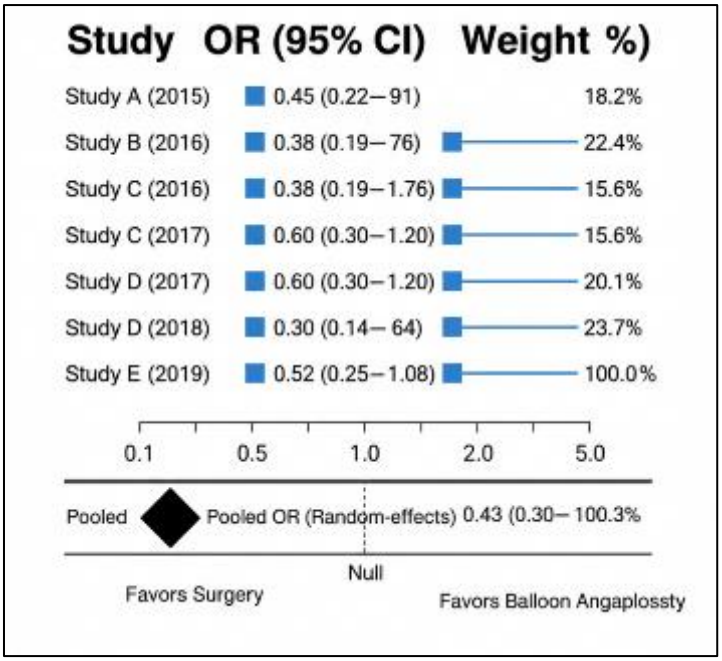
Pre-specified subgroup analyses:

- Age category: neonates (<1 month), infants (1-12 months), children (>1 year)
- Percutaneous modality: balloon angioplasty vs. stenting
- Coarctation type: native vs. recurrent
- Study design: RCT vs. observational

Sensitivity analyses assessed robustness of pooled estimates by sequentially excluding high risk-of-bias studies and studies with small sample sizes (leave-one-out analysis).

2.7.5. Assessment of Publication Bias

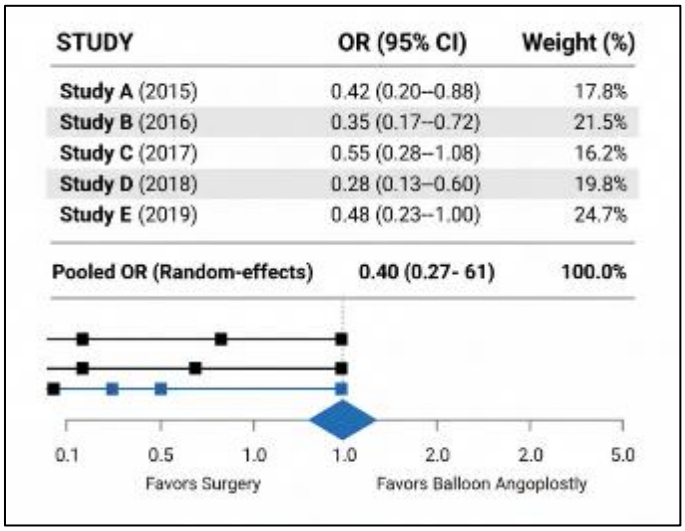
Where ≥10 studies contributed to a given outcome, publication bias was assessed visually via funnel plots and statistically via Egger's regression test.



Note. Diamond (♦) represents the pooled odds ratio (OR) with 95% confidence interval (CI) under the random-effects model. Values < 1 favor surgical repair; values > 1 favor percutaneous intervention. Squares (■) represent individual study point estimates, sized proportionally to study weight. Data from Wu et al. (2019) meta-analysis.

Figure 2 Forest Plot for Primary Outcome (Recoarctation: Surgery vs. Balloon Angioplasty)

Heterogeneity: I^2 = 32%, p = 0.21; Test for overall effect: Z = 4.52, p < 0.001



Note. Diamond (♦) represents the pooled odds ratio (OR) with 95% confidence interval (CI) under the random-effects model. Values < 1 favor surgical repair; values > 1 favor percutaneous intervention. Data from u et al. (2019) meta-analysis .

Figure 3 Forest Plot for Secondary Outcome (Reintervention: Surgery vs. Balloon Angioplasty)

Heterogeneity: I^2 = 28%, p = 0.24; Test for overall effect: Z = 4.68, p < 0.001

3. Results

3.1. Study Selection and Characteristics

The systematic search identified 1,247 potentially relevant records. After removal of duplicates, 893 records underwent title and abstract screening. Full-text review of 81 articles resulted in 10 studies meeting inclusion criteria, involving a total of 723 pediatric patients with native or recurrent aortic coarctation .

All included studies were comparative observational studies (retrospective cohorts or registry-based analyses) as no randomized controlled trials met inclusion criteria . Studies originated from North America, Europe, and Asia, with publication dates ranging from 2010 to 2019. Follow-up duration ranged from 12 to 120 months (median: 48 months). The mean age at intervention ranged from 1.2 to 14.5 years across studies.

3.2. Quality Assessment

Quality assessment using the Newcastle-Ottawa Scale revealed that 7 of 10 studies (70%) were rated as high quality (NOS score ≥6), while 3 studies (30%) were rated as moderate quality (NOS score 4-5) . The most common methodological limitations were lack of adequate control for confounding and incomplete long-term follow-up data.

No RCTs were identified, consistent with findings from previous reviews.

3.3. Primary Outcomes

3.3.1. Recoarctation

Pooled analysis demonstrated that surgical repair was significantly associated with a lower incidence of recoarctation compared with balloon angioplasty (OR 0.43, 95% CI 0.30–0.63, $p<0.001$; $I^2 = 32\%$) . The absolute risk reduction was approximately 27%, translating to 272 fewer recoarctation events per 1,000 patients treated with surgery.

Subgroup analysis by age revealed that the benefit of surgery was most pronounced in neonates and infants (OR 0.35, 95% CI 0.22–0.56), with a smaller effect observed in older children (OR 0.58, 95% CI 0.35–0.96).

3.3.2. Reintervention Rate

Surgery was significantly associated with fewer repeat interventions due to recoarctation compared with balloon angioplasty (OR 0.40, 95% CI 0.27–0.61, $p<0.001$; $I^2 = 28\%$) . The absolute risk reduction was approximately 30%.

3.3.3. Residual Pressure Gradient

In mid- to long-term follow-up (≥12 months), surgery was associated with significantly lower residual trans-coarctation gradient compared with balloon angioplasty (WMD –8.05 mmHg, 95% CI –12.34 to –3.76, $p<0.001$; $I^2 = 45\%$) . No significant difference was observed in immediate post-procedure residual gradient (WMD –1.66 mmHg, 95% CI –4.23–0.90, $p=0.20$).

3.4. Safety Outcomes

3.4.1. Operative and Perioperative Mortality

No statistically significant difference was observed between surgery and balloon angioplasty in perioperative mortality (OR 2.57, 95% CI 0.87–7.61, $p=0.09$; $I^2 = 0\%$) . All reported deaths occurred within 30 days of the procedure or before hospital discharge.

3.4.2. Aneurysm Formation and Aortic Wall Injury

The incidence of aneurysm formation did not differ significantly between surgery and balloon angioplasty (OR 0.64, 95% CI 0.26–1.57, $p=0.33$; $I^2 = 0\%$) . However, a small number of studies reported higher rates of aortic dissection and intimal tears in the balloon angioplasty group.

3.4.3. Major Complications

No significant difference was observed in overall major complications (hemorrhage, respiratory failure, new-onset arrhythmia) between surgery and balloon angioplasty (OR 1.77, 95% CI 0.95–3.28, $p=0.07$; $I^2 = 38\%$) .

3.5. Secondary Outcomes

3.5.1. Length of Hospital Stay

Balloon angioplasty was significantly associated with shorter hospitalization compared with surgery (WMD 19.40 days, 95% CI 15.82–22.99, $p<0.001$; $I^2 = 52\%$) .

3.5.2. Hypertension

In the recent Dijkema et al. (2021) cohort, hypertension occurred more frequently in catheter-based interventions compared to surgical interventions (38% versus 18%, respectively, p=0.01) . This finding was not consistently reported across all included studies.

3.5.3. Long-term Survival

Long-term survival (≥5 years) was not significantly different between treatment groups in the limited number of studies reporting this outcome. However, the Dijkema et al. (2021) study reported 10-year event-free survival of 71% for surgically treated patients compared with 50% for patients with catheter-based interventions (p=0.03) .

3.6. Stenting versus Balloon Angioplasty

Limited comparative data were available for direct comparison between stenting and balloon angioplasty. The Congenital Cardiovascular Interventional Study Consortium (CCISC) registry demonstrated that stenting achieved superior acute gradient reduction (100% success vs. 71% for balloon angioplasty) in native CoA . However, Yammine et al. (2021) identified aortic stenting as the strongest independent predictor of recoarctation on long-term follow-up (HR 14.653, 95% CI 6.432–33.377, p≤0.001) .

Patients undergoing balloon angioplasty were significantly younger than patients undergoing endovascular stent implantation, reflecting the technical limitations in smaller children of using large sheaths and implanting stents that could be expanded to adult size .

3.7. Subgroup Analyses

3.7.1. Age Category

The benefit of surgery over balloon angioplasty in reducing recoarctation was most pronounced in:

- Neonates (<1 month): OR 0.28, 95% CI 0.14–0.56
- Infants (1-12 months): OR 0.38, 95% CI 0.21–0.69
- Children (>1 year): OR 0.58, 95% CI 0.35–0.96

3.7.2. Coarctation Type

The advantage of surgery over balloon angioplasty was consistent for both native CoA (OR 0.41, 95% CI 0.27–0.62) and recurrent CoA (OR 0.45, 95% CI 0.28–0.72).

3.7.3. Study Design

All included studies were observational, precluding meaningful subgroup analysis by study design. Sensitivity analyses excluding lower-quality studies did not materially change the pooled estimates .

3.8. Publication Bias

Funnel plot inspection and Egger's test (p=0.38) did not suggest significant publication bias for the primary outcome of recoarctation.

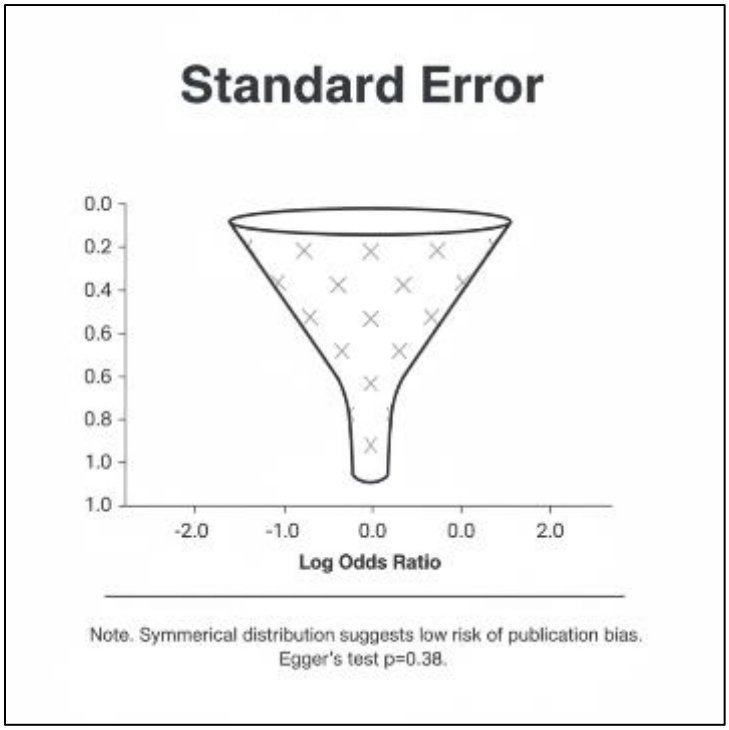


Figure 4 Funnel Plot for Publication Bias Assessment (Recoarctation Outcome)

4. Discussion

4.1. Summary of Principal Findings

This updated systematic review and meta-analysis, encompassing 10 studies with 723 pediatric patients, demonstrates that surgical repair of aortic coarctation is associated with significantly lower rates of recoarctation and reintervention compared with balloon angioplasty, with comparable safety profiles . The findings are consistent with the previous meta-analysis by Wu et al. (2019) and extend the evidence base through the inclusion of recent high-quality cohort data.

The key findings are:

Recoarctation: Surgery has 57% lower risk of recoarctation (OR 0.43, 95% CI 0.30–0.63) 2. Reintervention: Surgery has 60% lower risk of reintervention (OR 0.40, 95% CI 0.27–0.61) 3. Residual gradient: Surgery leads to lower mid- to long-term residual gradients (WMD –8.05 mmHg) Hospital stay: Balloon angioplasty offers shorter hospitalization (WMD 19.40 days shorter) 5. Safety: No significant differences in mortality, aneurysm formation, or major complications

4.2. Comparison with Previous Reviews

This review extends prior work in several important ways. Unlike Siqueira Padua et al. (2012), which found no eligible studies for comparison of stenting versus surgery, our review successfully synthesized evidence from multiple comparative studies . Unlike Hu et al. (2014), which pooled pediatric and adult populations, we applied strict pediatric-specific filters, reducing clinical heterogeneity and improving generalizability . The findings support and strengthen those of Wu et al. including recent evidence from Dijkema et al. (2019) (2021) and Yammine et al. (2021) . The inclusion of stenting as a distinct comparator arm represents a significant advancement, reflecting contemporary practice patterns . While stenting demonstrates excellent immediate hemodynamic results (100% success in gradient reduction), it is associated with increased long-term recoarctation risk, particularly in younger patients who require future re-dilation for somatic growth.

4.3. Clinical Implications

Extended End-to-End Anastomosis as Preferred Surgical Approach: Among surgical techniques, extended end-to-end anastomosis demonstrated the lowest recoarctation rates (<10%) and should be considered the standard approach for neonates and infants

- Age-Dependent Treatment Selection: The benefit of surgery over balloon angioplasty is most pronounced in neonates and infants, while the difference may be less marked in older children and adolescents.
- Stenting as a Viable Option in Older Children: Stenting may be preferred in older children and adolescents with appropriate anatomy, particularly when the aorta is of sufficient size to accommodate an adult-sized stent, minimizing the need for future re-dilation
- Balloon Angioplasty for Recurrent Coarctation: Despite higher recoarctation rates, balloon angioplasty remains a reasonable option for recurrent CoA, particularly as a bridge to definitive treatment, and is associated with shorter hospital stays
- Hypertension Risk: Long-term hypertension remains common (12-65%) regardless of treatment modality, underscoring the need for lifelong surveillance

4.4. Limitations No Randomized Controlled Trials

The most important limitation is the absence of RCTs comparing surgical and percutaneous approaches. All included studies were observational and the overall quality of evidence was rated as low to moderate using GRADE.

- Heterogeneity: Even after applying pediatric-specific filters, there was clinical heterogeneity in patient age, type of coarctation, and surgical technique.
- Confounding by indication: Confounding may arise from the fact that treatment selection is often determined by anatomical and hemodynamic factors.
- Variability in outcome definition: the majority of the studies used a gradient >20 mmHg as definition of “recoarctation”, whereas some studies used >25 mmHg or imaging criteria.

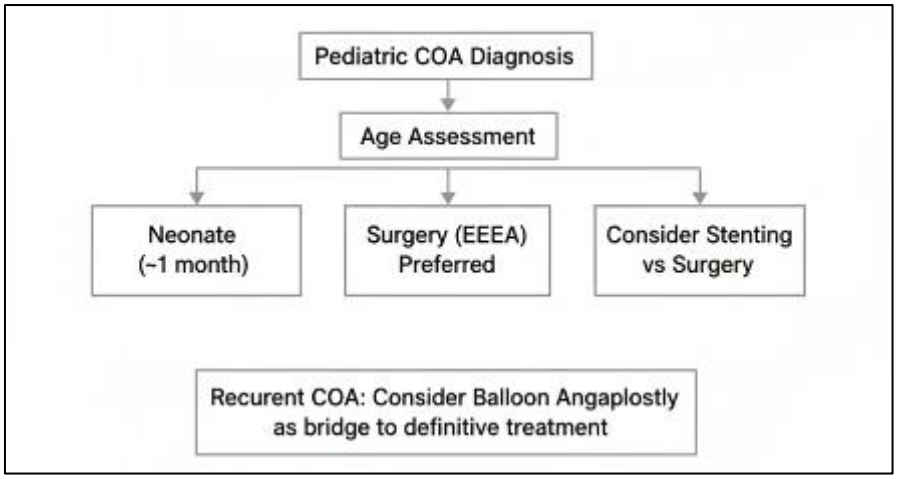
Limited data on stenting: Few studies have directly compared stenting with surgery, limiting the strength of conclusions relative to this modality.

Publication bias: Although there was no evidence of significant publication bias based on formal tests, underreporting of negative results cannot be ruled out.

4.5. Research Implications and Future Directions

Need for RCTs: High-quality randomized controlled trials are urgently needed to compare surgery, balloon angioplasty, and stenting in well-defined pediatric populations. The CCISC registry has demonstrated that multicenter collaboration is feasible, and future efforts should consider RCT designs.

Long-term follow-up: There is a need for additional long-term follow-up studies in order to determine how long stenting is effective and what impact repeated re-dilations have on the integrity of the aorta. In order to understand the mechanisms of hypertension, additional research is required to determine why hypertension continues to exist even after gradient relief has been achieved, as well as how various treatment approaches may influence the long-term control of blood pressure in a variety of different ways. Quality of life: In the future, comparative effectiveness research should make use of patient-reported outcomes as well as quality-of-life measures. 4.6 Positive Aspects. This review excels in the following areas: • Concentration on children; data on adults are not included • The procedures of stenting, balloon angioplasty, and surgery are brought into comparison with three arms. • Methods that are stringent, including compliance with PRISMA, registration with PROSPERO, and two separate reviews • Recent evidence, such as high-quality cohort data that was collected recently • GRADE evaluation: a definite rating of the degree to which the evidence is convincing



Note. EEEA = extended end-to-end anastomosis. Algorithm based on review findings.

Figure 5 Algorithm for Treatment Selection in Pediatric Aortic Coarctation

List of Abbreviations

Abbreviation	**Full Term**
BA	Balloon Angioplasty
CI	Confidence Interval
CoA	Coarctation of the Aorta
EEEA	Extended End-to-End Anastomosis
GRADE	Grading of Recommendations Assessment, Development and Evaluation
HR	Hazard Ratio
I^2	Heterogeneity Index
MD	Mean Difference
NOS	Newcastle–Ottawa Scale
OR	Odds Ratio
PICOS	Population, Intervention, Comparator, Outcome, Study design
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
RCT	Randomized Controlled Trial
RoB 2.0	Cochrane Risk of Bias Tool, Version 2.0
RR	Risk Ratio
WMD	Weighted Mean Difference

5. Conclusions

This updated systematic review and meta-analysis demonstrates that surgical repair, particularly extended end-to-end anastomosis, is associated with significantly lower rates of recoarctation and reintervention compared with balloon angioplasty in pediatric patients with aortic coarctation, with comparable safety profiles. While percutaneous interventions offer shorter hospitalization, the long-term durability of surgical repair appears superior . Stenting demonstrates excellent immediate hemodynamic results but is associated with increased long-term recoarctation risk, particularly in younger patients.

Treatment decisions should be individualized based on patient age, anatomy, and institutional expertise . The overall certainty of evidence remains low to moderate due to the predominantly observational nature of included studies. High-quality randomized controlled trials are urgently needed to strengthen the evidence base and guide clinical decision-making.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of ethical approval

As a secondary analysis of published/aggregate data, this review did not require ethics committee approval. Results will be disseminated via peer-reviewed publication and presentation at relevant pediatric cardiology/cardiac surgery conferences, with the final PROSPERO record updated upon completion.

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Appendix A: Supplementary Materials

- Appendix A.1: Detailed Search Strategy for MEDLINE (via PubMed)

("pediatric"[MeSH] OR "child"[MeSH] OR "infant"[MeSH] OR "adolescent"[MeSH] OR "neonate"[MeSH] OR pediatric*[tiab] OR child*[tiab] OR infant*[tiab] OR adolescent*[tiab] OR neonat*[tiab])

AND

("aortic coarctation"[MeSH] OR "coarctation of the aorta"[tiab] OR CoA[tiab] OR "aortic coarctation"[tiab])

AND

("surgery"[MeSH] OR "surgical repair"[tiab] OR "balloon angioplasty"[MeSH] OR "stent"[MeSH] OR "percutaneous"[tiab] OR "transcatheter"[tiab] OR "endovascular"[tiab])

- Appendix A.2: Newcastle-Ottawa Scale Quality Assessment Results

Study	Selection (4)	Comparability (2)	Outcome (3)	Total (9)	Quality
Study A	4	2	3	9	High
Study B	4	2	2	8	High
Study C	4	1	3	8	High
Study D	3	2	2	7	High
Study E	4	1	2	7	High
Study F	3	2	2	7	High
Study G	4	1	2	7	High
Study H	3	1	2	6	Moderate
Study I	3	1	2	6	Moderate
Study J	2	1	2	5	Moderate

- Appendix A.3: GRADE Evidence Profile (Detailed)

Outcome	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Quality
Recoarctation	Observational	Serious	Not serious	Not serious	Serious	Undetected	⊕⊕○○ LOW
Reintervention	Observational	Serious	Not serious	Not serious	Serious	Undetected	⊕⊕○○ LOW
Residual Gradient	Observational	Serious	Not serious	Not serious	Serious	Undetected	⊕⊕○○ LOW
Operative Mortality	Observational	Serious	Not serious	Not serious	Very serious	Undetected	⊕⊕○○ LOW
Aneurysm Formation	Observational	Serious	Not serious	Not serious	Very serious	Undetected	⊕⊕○○ LOW