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External wrapping of the ascending aorta versus ascending aorta replacement: Systematic review and meta-analysis

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ABSTRACT

Background: In the treatment of a moderately dilated ascending aorta, external wrapping of the ascending aorta may represent an alternative to the gold standard ascending aorta replacement. Concerns regarding the safety and long-term durability of external wrapping of the ascending aorta have limited its widespread adoption.

Methods: We conducted a systematic review and meta-analysis comparing external wrapping of the ascending aorta with ascending aorta replacement. The primary outcome was 30-day mortality, defined as 30-day and/or in-hospital mortality, and midterm mortality, as reported by the source studies. Secondary outcomes included intensive care unit and hospital length of stay, cardiopulmonary bypass time, cardiac crossclamp time, reoperation for bleeding, stroke, acute kidney injury, wound infection, concomitant surgeries, and midterm outcomes. Between-group differences were quantified using standardized mean difference. Effect estimates were expressed as odds ratios for binary outcomes, incidence rate ratios for time-dependent mortality, and standardized mean differences for continuous outcomes, each with 95% confidence intervals.

Results: Eight comparative studies comprising 851 patients were identified. A total of 433 patients (50.9%) underwent external wrapping of the ascending aorta, and 418 (49.1%) underwent ascending aorta replacement. The mean follow-up duration was 3.9 years (95% confidence interval, 1.8–8.4 years). No statistically significant differences were observed in 30-day mortality (odds ratio, 0.61; 95% confidence interval, 0.24–1.56), midterm mortality (incidence rate ratio, 0.97; 95% confidence interval, 0.57–1.66), acute kidney injury (odds ratio, 0.66; 95% confidence interval, 0.22–1.96), stroke (odds ratio, 0.67; 95% confidence interval, 0.23–1.93), wound infection (odds ratio, 1.37; 95% confidence interval, 0.41–4.53), concomitant aortic valve replacement (odds ratio, 0.92; 95% confidence interval, 0.42–2.00), coronary artery bypass grafting (odds ratio, 0.86; 95% confidence interval, 0.37–1.99), mitral valve procedures (odds ratio, 0.71; 95% confidence interval, 0.20–2.56), reoperation for bleeding (odds ratio, 0.48; 95% confidence interval, 0.15–1.58), proximal ascending aorta diameter (standardized mean difference, 0.19; 95% confidence interval, −0.21 to 0.59) or midascending aorta diameter at follow-up (standardized mean difference, −0.53; 95% confidence interval, −1.67 to 0.60). External wrapping of the ascending aorta was associated with shorter cardiopulmonary bypass time (unweighted mean absolute difference, 42.4 minutes; standardized mean difference, −2.46; 95% confidence interval, −3.49 to −1.43), crossclamp time (unweighted mean absolute difference, 30.6 minutes; standardized mean

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difference, −2.12; 95% confidence interval, −3.18 to −1.07), intensive care unit length of stay (unweighted mean absolute difference, 22.6 hours; standardized mean difference, −0.58; 95% confidence interval, −0.81 to −0.36), and hospital length of stay (unweighted mean absolute difference, 2.4 days; standardized mean difference, −0.36; 95% confidence interval, −0.63 to −0.10).

Conclusion: Thirty-day and midterm mortality did not significantly differ between external wrapping of the ascending aorta and ascending aorta replacement. In addition, external wrapping of the ascending aorta was associated with shorter cardiopulmonary bypass and crossclamp times and reduced intensive care unit and hospital length of stay. However, this study did not establish the clinical equivalence of external wrapping of the ascending aorta. Ascending aorta replacement remains the gold standard surgical technique for a moderately dilated ascending aorta. The retrospective design, limited follow-up, heterogeneous patient selection, and inconsistent outcomes reporting of the included studies limit the applicability of these findings to clinical practice.

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Introduction

The 2022 American College of Cardiology/American Heart Association (ACC/AHA) guideline defines an ascending aorta (AA) measuring 40–44 mm as moderately dilated and considers a diameter ≥45 mm as aneurysmal.[1] Relative to an AA diameter ≤34 mm, the Multi-Ethnic Study of Atherosclerosis by Paruchuri et al[2] reported that an AA diameter of 40–44 mm was already associated with an 89-fold increased relative risk of aortic dissection, increasing to 6,305-fold at diameters ≥45 mm. Although AA diameter remains an important determinant of risk, guidelines recommend individualized decision-making that incorporates valve morphology, genetic predisposition, growth rate, family history, body size, and the need for concomitant cardiac surgery, leaving the optimal management of moderate AA dilation an area of ongoing debate.

In patients with early aneurysmal disease, medical therapy along with aggressive control of modifiable risk factors remains central to slowing aortic enlargement.[3–5] When surgical intervention is indicated, ascending aorta replacement (AAR) represents the gold standard surgical approach. Historically, more conservative procedures have also been proposed. External wrapping of the ascending aorta (EWAA), first described by Bahnson and Nelson in 1956,[6] uses a vascular graft to reduce the AA diameter and reinforce the native wall, with the aim of limiting redilation and reintervention (Figure 1).[8] Robicsek et al[9] subsequently described reduction ascending aortoplasty (RAA) with external wrapping, in which a portion of the dilated aorta is excised to restore a normal diameter and then reinforced through an external graft.

Multiple surgical teams have performed EWAA, with or without concomitant RAA, with acceptable outcomes, including relatively low mortality and low late ruptures during follow-up.[7,10–32]

Nevertheless, EWAA has not gained widespread adoption, largely because of concerns regarding its potential long-term effects on the native aortic wall after wrapping.[17,20,33,34] Reported complications include prosthesis migration, focal wall erosion caused by chronic prosthesis-aorta interaction, and late redilation of untreated segments.[20] Moreover, external constraint may alter stress distribution along the aorta, potentially increasing mechanical load in adjacent downstream segments.[35] For these reasons, the role of EWAA remains a topic of discussion. We therefore performed a systematic review and meta-analysis of comparative studies evaluating postoperative and midterm outcomes after EWAA versus AAR.

Methods

Institutional review board approval for this study was not required. This systematic review and meta-analysis was registered in the International Prospective Register of Systematic Reviews (PROSPERO ID: CRD420251158932) and conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (Supplementary Figure S1).[36]

Search strategy

PubMed, Embase, and Web of Science were searched from inception through October 2025 in collaboration with a medical librarian (J.L.). The keywords utilized were "Ascending aorta dissection" or "aortic aneurysm" combined with "wrapping" or "girdling" in surgical patients. The complete database-specific strategies are provided in Supplementary Table S1. Two investigators (N.S., K.O.) independently performed data extraction employing a 2-step screening strategy in Covidence,[37] and the integrity of the data was verified by the authors (M.D., M.B., B.T., and G.F.). Extracted variables included study characteristics, patient demographics, operative details, and postoperative and follow-up outcomes. English-language human studies were eligible. Studies from the same center were included. Animal studies, abstracts, case reports, commentaries, editorials, expert opinions, conference presentations, pediatric studies, and studies without a relevant comparator or outcome were excluded. Non-English studies were consistently excluded to ensure accurate data extraction and minimize the risk of bias.

Full texts were independently assessed for eligibility by the authors (M.D., I.K., A.A., M.V., and A.K.). A total of 8 comparative studies were included. The most recent study was published in 2022,[7] and the study with the largest sample size included 499 patients.[13] The risk of bias of the included studies was assessed using the Newcastle-Ottawa Risk of Bias Assessment Scale (Supplementary Table S2). Articles reporting aortic valve surgery alone were included if they reported EWAA and AAR in separate study groups. Potential cohort overlap was assessed by comparing institutions, recruitment periods, eligibility criteria, study designs, sample sizes, interventions, and baseline characteristics. When overlap was suspected, the most comprehensive contemporary data set would be retained. No definite duplicate populations were identified. Indications and selection criteria for aortic intervention, operative urgency, differences in operative time and length of stay (LOS), absolute mortality events with reported causes of death, secondary outcome events, reoperation events, preoperative and follow-up proximal- and mid-AA diameters, and follow-up imaging and surveillance protocols were extracted when available. These variables were summarized descriptively rather than pooled given the inconsistency in reporting them. Using the "snowball technique," references for articles selected were also reviewed for relevant studies not captured by the original search.

Outcomes

The primary outcome was mortality (defined as 30-day/in-hospital/early and midterm). Secondary outcomes included hospital LOS, intensive care unit (ICU) stay, concomitant surgeries (aortic valve replacement [AVR], coronary artery bypass grafting [CABG], and mitral valve procedures), cardiopulmonary bypass (CPB) time, crossclamp (CXC) time, reoperation for bleeding, stroke, acute kidney injury (AKI), and wound infection. Midterm outcomes (defined as >30-day) included midaortic diameter, proximal aortic diameter, and midterm all-cause mortality.

Descriptive outcomes included indications and selection criteria for aortic intervention, operative urgency, absolute difference in operative times and LOS, absolute mortality events with reported causes of death, secondary outcome events, reoperation details, preoperative and follow-up proximal- and mid-AA diameters, and follow-up imaging and surveillance protocols (Supplementary Tables S3–S10).

Statistical analysis

Statistical analysis was performed for outcomes reported in ≥50% of studies or representing at least half of the pooled population. In order to mitigate variability in baseline continuous variables reported across studies, values were normalized to a common mean and standard deviation using the approach for unknown non-Gaussian distributions described by Cai et al.[38] Pooled estimates were weighted according to study sample size. Between-group differences were quantified using standardized mean difference (SMD).

For comparative analyses, effect measures were expressed as odds ratios (ORs) for binary outcomes and SMD for continuous outcomes, each with corresponding 95% confidence intervals (CIs). For time-dependent outcomes, Poisson regression was applied to account for heterogeneity in follow-up duration, under the assumption of a constant hazard over time. Total person-time was estimated from the number of observed events and the mean follow-up period.[39] Incidence rate ratios (IRRs) were obtained after logarithmic transformation, incorporating random effects. Between-study variability was addressed using a random-effects inverse-variance model with the DerSimonian-Laird estimator. The replacement cohort served as the reference group in all comparisons. When zero-event studies were encountered, a continuity correction was applied.

Statistical heterogeneity was assessed using Cochran's Q statistic and the I^2 metric. Publication bias was evaluated through visual inspection of funnel plot symmetry. Given the small number of included studies (<10), formal assessment of publication bias with Egger's test was not undertaken. Leave-one-out (LOO) sensitivity analyses were conducted to evaluate the robustness of the pooled estimates.

Univariable metaregression analyses were conducted to further explore the primary and statistically significant outcomes. For categorical variables, the results were reported as OR with corresponding 95% CI and P value. For continuous variables, estimates were presented as beta coefficients with standard error and P value. Exploratory metaregression bubble plots were constructed to explore the relationship between baseline study-level characteristics and the SMD of the significant outcomes.

All statistical computations were performed in R (version 4.5.1) using the RStudio interface. Statistical significance was defined as a 2-sided P value <.05.

Results

The initial search identified 1,270 studies. After deduplication, 773 unique studies were retrieved. A total of 680 were found to be irrelevant, and 93 studies were assessed for eligibility. Upon further review, 85 studies did not meet eligibility criteria for the following reasons: 40 lacked a comparison group or outcomes of

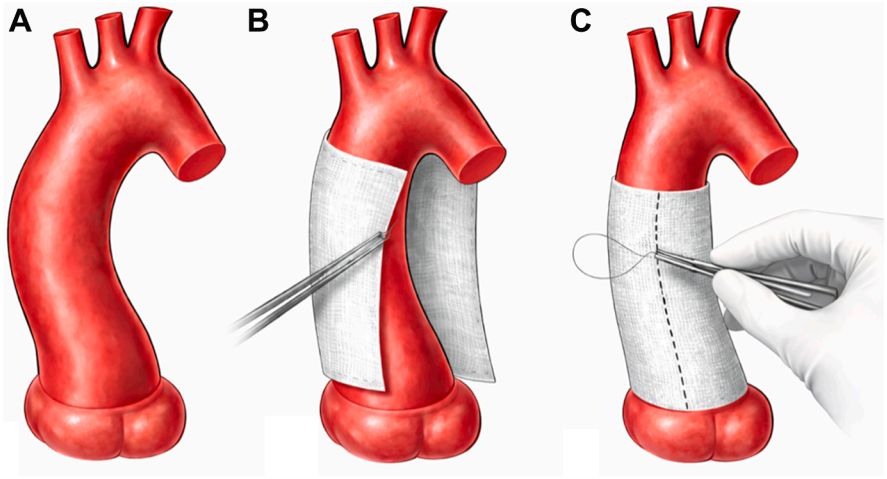


Figure 1. External ascending aorta wrapping and surgical technique. (A) Moderately dilated ascending aorta (AA). (B) External aortic wrapping technique with a tailored prosthetic graft placed around the AA. (C) Completed external aortic wrap with a central longitudinal suture line, restoring physiologic aortic diameter while preserving the native aortic wall. External wrapping of the ascending aorta (EWAA) is performed through full or reduced sternotomy with complete dissection of the AA from the sinotubular junction (STJ) to the right brachiocephalic artery (RBCA). Careful separation from the pulmonary artery and posterior pericardial reflection is required, and this step is often facilitated after initiation of CPB, when the pulmonary artery is decompressed. The objective is to restore a physiologic aortic diameter, typically <35 mm, using an external prosthetic support. A longitudinally opened polyester graft or synthetic mesh (32–34 mm) is placed around the AA from the STJ to the BCA to reduce and reinforce the aortic wall while preserving compliance. The graft is trimmed to the appropriate length and carefully approximated to avoid excessive tension or folds, and final stabilization is achieved with 4-0 polypropylene sutures reinforced with Teflon pledgets, ensuring secure fixation and complete coverage of the AA. A technical video by Kim et al can be observed at: https://www.aats.org/resources/aorta-wrapping-procedure-for-ascending-aorta-aneurysm.[7]

Table I
Summary of included studies

Study	Year of publication	Country	Patients	Study design	Follow-up, mean (y)	Extracted outcomes	Aortic diameter considered dilation
Belov et al[11]	2009	Russia	Total $n = 79$ Wrapping $n = 32$ Replacement $n = 47$	Cohort	Wrapping: 6.9 ± 3.9 Replacement: 6.8 ± 3.5	30-day mortality Hospital LOS ICU stay Reoperation for bleeding Aortic diameter at follow-up Midterm mortality	≥50 mm
Laux et al[12]	2020	Germany	Total $n = 235$ Wrapping $n = 144$ Replacement $n = 91$	Cohort	Overall: 4.7 ± 2.9	30-day mortality Postoperative stroke Renal failure Wound infection Aortic diameter at follow-up Midterm mortality	50 mm
Kim et al[7]	2022	Korea	Total $n = 140$ Wrapping $n = 70$ Replacement $n = 70$	Cohort	Overall: 7.1 [IQR: 3.9–11.2]	30-day mortality Hospital LOS ICU stay Postoperative stroke Postoperative Afib Respiratory failure Renal failure LCOS Wound infection GI bleeding Reoperation for bleeding and dissection or rupture Aortic diameter at follow-up Midterm mortality	40-55 mm
Zhang et al[15]	2011	China	Total $n = 71$ Wrapping $n = 32$ Replacement $n = 39$	Cohort	Overall: 3.3	30-d mortality Hospital LOS ICU stay Postoperative stroke IABP use Respiratory failure Renal failure Reoperation for bleeding Aortic diameter at follow-up Midterm mortality	50 mm for degenerative aneurysms, 40 mm for BAV disease
Abe et al[10]	2017	Japan	Total $n = 40$ Wrapping $n = 20$ Replacement $n = 20$	Cohort	Overall: 4.9	30-d mortality ICU stay Postoperative stroke Postoperative Afib Renal failure Midterm mortality	≥50 mm or ≥45 mm with BAV
Zhu et al[16]	2020	China	Total $n = 119$ Wrapping $n = 49$ Replacement $n = 70$	Cohort	Overall: 1.0	30-d mortality Hospital LOS Postoperative LVEF Wound infection Aortic diameter at follow-up Midterm mortality	40-45 mm
Matsuyama et al[14]	2016	Japan	Total $n = 145$ Wrapping n = 19 Replacement $n = 11$ AVR alone $n = 115$	Cohort	Wrapping: 4.8 ± 0.9 Replacement: 5.6 ± 3.0	30-d mortality Aortic-related mortality Midterm mortality	40–50 mm for wrapping, >50 mm for replacement
Lee et al[13]	2013	Korea	Total $n = 499$ Wrapping $n = 67$ Replacement $n = 70$ AVR alone $n = 362$	Cohort	Wrapping: 3.1 ± 1,8 Replacement: 2.2 ± 1.8	30-d mortality Postoperative stroke Renal failure LCOS Aortic-related mortality Reoperation for bleeding Aortic diameter at follow-up Midterm mortality	40–55 mm

Afib, atrial fibrillation; *AVR*, aortic valve replacement; *BAV*, bicuspid aortic valve; *GI*, gastrointestinal; *IABP*, intra-aortic balloon pump; *ICU*, intensive care unit; *LCOS*, low cardiac output syndrome; *LOS*, length of stay; *LVEF*, left ventricular ejection fraction.

interest, 21 had an ineligible design, 15 presented an ineligible intervention, 7 were abstracts, 1 had an ineligible setting, and 1 had an ineligible indication.

Eventually, 8 comparative studies were included for meta-analytic purposes (Supplementary Figure S1). We identified a total of 851 patients: 433 (50.9%) underwent EWAA and 418 (49.1%) underwent AAR. Study sample sizes ranged from 40 to 499 patients, with a median sample size of 129.5 (interquartile range [IQR], 75–190). The isolated AVR group from Matsuyama et al and Lee et al were excluded from analysis. Study

Table II
Summary of wrapping technique for included studies

Study	Wrapping technique	Wrapping material	Indication for surgery
Belov et al	Reduction aortoplasty with external wrapping of the AA ± concomitant cardiac procedures	Prosthetic graft—not specified	Moderately sized AA aneurysm without dissection
Laux et al	Aortic prosthetic wrapping ± AVR	Dacron	Transverse aortic diameter between 45 and 55 mm, frail condition, absence of significant elongation of aorta
Kim et al	Aortic prosthetic wrapping + AVR	PTFE or double velour	AA aneurysm 40–55 mm
Zhang et al	Reinforced reduction aortoplasty + AVR	Dacron	AA aneurysm >50 mm (>40 mm for BAV)
Abe et al	AA wrapping + AVR	Dacron	AA aneurysm >50 mm (>45 mm for BAV)
Zhu et al	AVR for BAV stenosis + treatment of AA	Dacron	AA aneurysm 40–45 mm
Matsuyama et al	AVR for BAV ± treatment of AA	Prosthetic graft—not specified	AA aneurysm 40–50 mm
Lee et al	AA wrappping + AVR	Prosthetic graft—not specified	AA aneurysm 40–55 mm

AA, ascending aorta; *AVR*, aortic valve replacement; *BAV*, bicuspid aortic valve; *PTFE*, polytetrafluoroethylene.

characteristics are presented in Table I. EWAA techniques and operative indications are summarized in Table II and Supplementary Table S3.

Patient characteristics

The reported baseline characteristics demonstrated clinically relevant differences between groups. Patients undergoing EWAA were older than those undergoing AAR (61.8 ± 9.3 vs 59.2 ± 10.7 years; SMD, 0.261). The proportion of women was similar (39.3% vs 35.9%; SMD, −0.070), as were the reported prevalences of hypertension (49.8% vs 47.9%; SMD, −0.037), diabetes (12.6% vs 10.6%; SMD, −0.063), chronic kidney disease (CKD) (7.2% vs 6.7%; SMD, −0.019), and preoperative left ventricular ejection fraction (LVEF; 57.2 ± 9.4% vs 58.5 ± 7.8%; SMD, 0.096). However, the EWAA group had a smaller baseline AA diameter (48.6 ± 4.5 vs 52.7 ± 7.4 mm; SMD, 0.664) and a lower prevalence of bicuspid aortic valve (BAV) disease (51.6% vs 65.0%; SMD, 0.273). Aortic annular diameter was slightly larger in the EWAA group (34.5 ± 3.8 vs 33.6 ± 4.8 mm; SMD, 0.214). These differences support caution when comparing outcomes between the nonrandomized cohorts. Baseline characteristics are summarized in Table III.

Table III
Baseline characteristics

Characteristic	Wrapping	Replacement	SMD
Age, y, mean (SD)	61.8 (9.3)	59.2 (10.7)	0.261
Female sex, *n* (%)	170/433 (39.3)	150/418 (35.9)	−0.070
Hypertension, *n* (%)	206/414 (49.8)	195/407 (47.9)	−0.037
Diabetes, *n* (%)	48/382 (12.6)	38/360 (10.6)	−0.063
CKD, *n* (%)	24/333 (7.2)	20/298 (6.7)	−0.019
Preoperative LVEF, %, mean (SD)	57.2 (9.4)	58.5 (7.8)	0.096
Aortic diameter, mean (SD)	48.6 (4.5)	52.7 (7.4)	0.664
Aortic annulus diameter, mean (SD)	34.5 (3.8)	33.6 (4.8)	0.214
BAV, n (%)	207/401 (51.6)	241/371 (65.0)	0.273

BAV, bicuspid aortic valve; *CKD*, chronic kidney disease; *LVEF*, left ventricular ejection fraction; *SD*, standard deviation; *SMD*, standardized mean difference.

Primary outcome

Thirty-day mortality did not differ significantly between EWAA (n = 433) and AAR (n = 418) (OR, 0.60; 95% CI, 0.27–1.30; $I^2 = 0\%$) (Table IV, Figure 2). Similarly, among 623 patients, postoperative AKI (OR, 0.66; 95% CI, 0.22–1.96; $I^2 = 0\%$) (Supplementary Figure S2) and stroke (OR, 0.67; 95% CI, 0.23–1.93; $I^2 = 0\%$) (Supplementary Figure S3) also did not differ significantly. The mean duration of follow-up across the studies was 3.9 years (95% CI, 1.8–8.4 years) (Table I). Median follow-up was 4.8 years (IQR, 3.3–5.4) for EWAA and 4.8 years (IQR, 3.0–5.9) for AAR. At follow-up, midterm mortality did not differ significantly between EWAA and AAR (IRR, 0.97; 95% CI, 0.57–1.66; $I^2 = 0\%$; $\tau^2 = 0.086$; $P = .47$) (Figure 3).

Surgical urgency was incompletely reported. Laux et al, Abe et al, Zhu et al, and Lee et al included exclusively elective procedures, with no urgent or emergency cases in either group. Belov et al, Kim et al, Zhang et al, and Matsuyama et al did not report operative urgency (Supplementary Table S4).

Causes of death were heterogeneously reported. Belov et al reported 30-day mortality only after AAR, with 2 deaths attributable to multiorgan failure, whereas Laux et al reported 4 deaths after EWAA compared and 6 after AAR without cause-specific attribution. Kim et al, Zhang et al, Abe et al, Zhu et al, and Matsuyama et al reported no 30-day mortality, whereas Lee et al reported 1 death after EWAA and none after AAR. Midterm mortality occurred in 1 EWAA and 3 AAR patients in Belov et al, 21 and 12, respectively, in Laux et al, 4 and 6 in Kim et al, 3 and 5 in Zhang et al, 4 and 3 in Abe et al, none and 1 in Zhu et al, 1 and none in Matsuyama et al, and 6 and 7 in Lee et al. Midterm mortality causes were generally unspecified. Only Zhang et al provided complete attribution and reported no aortic-related deaths (Supplementary Table S5).

Secondary outcomes

Among 616 patients (EWAA, $n = 289$; AAR, $n = 327$), EWAA was associated with significantly shorter CPB time (unweighted mean absolute difference [UMAD], 42.4 minutes; SMD, −2.46; 95% CI, −3.49 to −1.43) (Supplementary Figure S4) and aortic CXC time (UMAD, 30.6 minutes; SMD, −2.12; 95% CI, −3.18 to −1.07) (Supplementary Figure S5, Supplementary Table S6). Both analyses showed substantial between-study heterogeneity (CPB: $I^2 = 96.0\%$; CXC: $I^2 = 96.4\%$), although the direction of effect consistently favored EWAA in each study.

Among 330 patients (EWAA, $n = 154$; AAR, $n = 176$), ICU LOS was shorter after EWAA (UMAD, 22.6 hours; SMD, −0.58; 95% CI, −0.81 to −0.36), with no observed heterogeneity ($I^2 = 0\%$) (Supplementary Figure S11). Similarly, among 409 patients (EWAA, $n = 183$; AAR, $n = 226$), hospital LOS was also significantly shorter after EWAA (UMAD, 2.4 days; SMD, −0.36; 95% CI, −0.63 to −0.10), with moderate heterogeneity ($I^2 = 43\%$) (Supplementary Figure S12). Across studies, the direction of effect consistently favored EWAA (Supplementary Table S6).

Wound infection among 494 patients (OR, 1.37; 95% CI, 0.41–4.53; $I^2 = 0\%$) (Supplementary Figure S10) and reoperation for bleeding among 427 patients (OR, 0.48; 95% CI, 0.15–1.58; $I^2 = 0\%$)

Table IV
Outcomes

Outcome		No. of patients	Effect [95% CI], *P* value	Heterogeneity (I^2, *P* value)
30-d mortality	8	851	OR, 0.60 [0.27–1.30], .196	0.0%, .960
LOS	4	409	SMD, −0.36 [−0.63 to −0.10], .0073	43.0%, .153
ICU stay	4	330	SMD, −0.58 [−0.81 to −0.36], <.001	0.0%, .469
Concomitant AVR	8	851	OR, 0.92 [0.42–2.00], .841	0.0%, >.999
Concomitant CABG	5	467	OR, 0.86 [0.37–1.99], .732	0.0%, .968
Concomitant mitral	5	449	OR, 0.71 [0.20–2.56], .599	0.0%, .995
CPB time	7	616	SMD, −2.46 [−3.49 to −1.43], <.001	96.0%, <.001
CXC time	7	616	SMD, −2.12 [−3.18 to −1.07], <.01	96.4%, <.001
Reoperation for bleeding	4	427	OR, 0.48 [0.15–1.58], .228	0.0%, .718
Stroke	5	623	OR, 0.67 [0.23–1.93], .459	0.0%, .521
AKI	5	623	OR, 0.66 [0.22–1.96], .451	0.0%, .601
Wound infection	3	494	OR, 1.37 [0.41–4.53], .609	0.0%, .913
Late outcomes				
Midaortic diameter	4	565	SMD, −0.53 [−1.67 to 0.60], 0.357	97.2%, <.001
Proximal aortic diameter	3	446	SMD, 0.19 [−0.21 to 0.59], 0.352	74.7%, .019
Midterm mortality	8	851	IRR, 0.97 [0.57–1.66] 0.921	0.0%, .468

AKI, acute kidney injury; *AVR*, aortic valve replacement; *CABG*, coronary artery bypass grafting; *CI*, confidence interval; *CXC*, crossclamp; *CPB*, cardiopulmonary bypass; *ICU*, intensive care unit; *IRR*, incidence rate ratio; *LOS*, length of stay; *OR*, odds ratio; *SMD*, standardized mean difference.

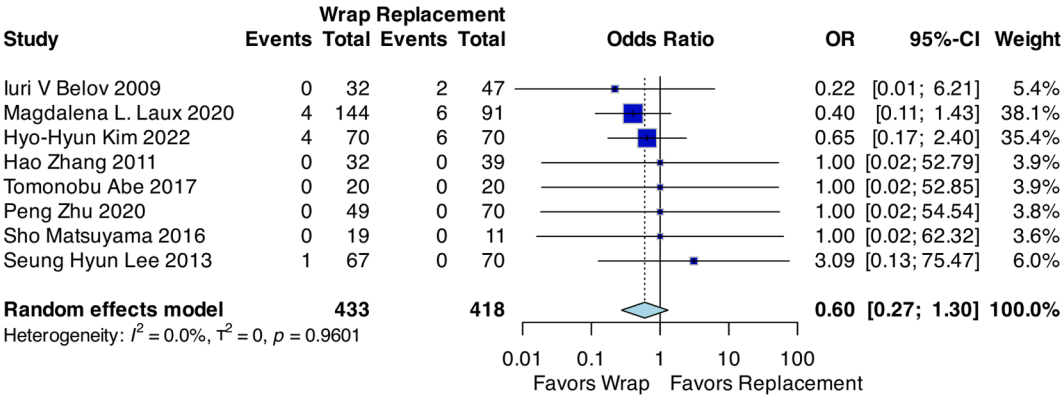


Figure 2. Forest plot of 30-day mortality comparing wrapping versus replacement. *CI*, confidence interval; *OR*, odds ratio.

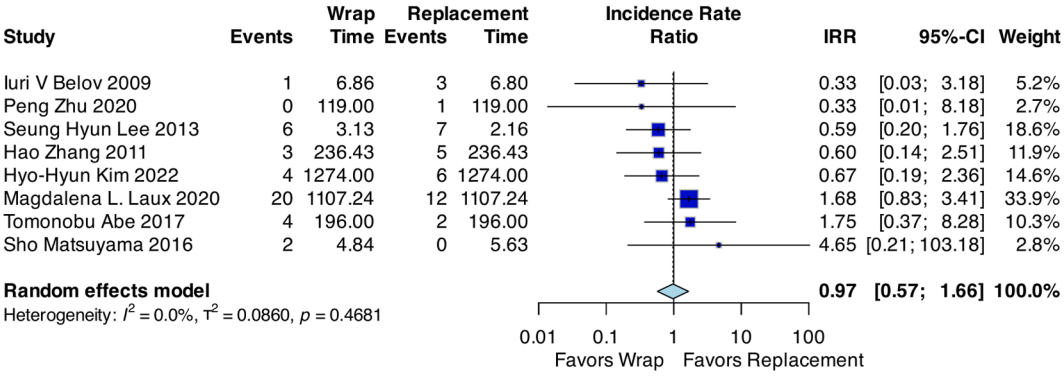


Figure 3. Forest plot of midterm mortality comparing wrapping versus replacement. *CI*, confidence interval; *IRR*, incidence rate ratio.

(Supplementary Figure S9) did not differ significantly. Reoperation for bleeding was reported by Belov et al (EWAA, 0/32; AAR, 3/47), Kim et al (1/70 versus 1/70), Zhang et al (2/32 vs 3/39), and Lee et al (1/67 vs 4/70). Laux et al reported rethoracotomy for bleeding or tamponade in 16.9% of the EWAA group and 14.9% of the AAR group. Other reported events included reoperation for sinus of Valsalva dilation (Abe et al, 1/20 vs 0/20; Matsuyama et al, 0/19 vs 1/11) and reoperation of the AA or arch (Kim et al, 8/70 vs 4/70) (Supplementary Table S8).

The frequency of concomitant procedures was also not significantly different. Concomitant AVR was assessed in all 851 patients (OR, 0.92; 95% CI, 0.42–2.00; $I^2 = 0\%$) (Supplementary Figure S6), CABG in 467 patients (OR, 0.86; 95% CI, 0.37–1.99; $I^2 = 0\%$) (Supplementary Figure S7), and mitral-valve procedures in 449

patients (OR, 0.71; 95% CI, 0.20–2.56; $I^2 = 0\%$) (Supplementary Figure S8). No statistical heterogeneity was observed for these analyses. Study-level secondary-outcome events are reported in Supplementary Table S7.

Among 446 patients (EWAA, $n = 246$; AAR, $n = 200$), follow-up proximal AA diameter did not differ significantly between groups (SMD, 0.19; 95% CI, −0.21 to 0.59), with substantial heterogeneity ($I^2 = 74.7\%$; $\tau^2 = 0.0915$; $P = .019$) (Supplementary Figure S13). Similarly, among 565 patients (EWAA, $n = 295$; AAR, $n = 270$), follow-up mid-AA diameter (95% CI, 1.8–8.4 years) did not differ significantly between groups (SMD, −0.53; 95% CI, −1.67 to 0.60), with considerable heterogeneity ($I^2 = 97.2\%$; $\tau^2 = 1.2837$; $P < .001$) (Supplementary Figure S14). The mean follow-up duration for these analyses was 3.9 years. Preoperative and follow-up measurements are provided in Supplementary Table S9.

Follow-up imaging strategies varied across studies. Belov et al used transthoracic echocardiography (TTE) performed at local clinics, supplemented by telephone follow-up. Laux et al used routine computed tomography (CT) surveillance, whereas Kim et al used protocol-based echocardiography (not specified if TTE or transesophageal echocardiography [TEE]) and CT before discharge, at 6 months, and annually thereafter. Zhang et al and Abe et al reported serial CT assessment, although whether imaging was routinely scheduled or symptom driven was not specified. Zhu et al used echocardiography (not specified if TTE or TEE) and cardiac CT extracted from clinical records without a clearly defined imaging schedule. Matsuyama et al primarily used CT with outpatient surveillance, whereas Lee et al performed TTE before discharge, at 6 months, 1 year, and every 2 years thereafter (Supplementary Table S10).

Sensitivity analyses

Overall, LOO analyses supported the stability of most pooled estimates. For early postoperative outcomes, including 30-day mortality (OR range, 0.54–0.76; overall OR, 0.60; 95% CI, 0.27–1.30) (Supplementary Figure S15), stroke (OR range, 0.50–1.04; overall OR, 0.67; 95% CI, 0.23–1.93), AKI (OR range, 0.50–1.41; overall OR, 0.66; 95% CI, 0.22–1.96), bleeding (OR range, 0.34–0.63; overall OR, 0.48; 95% CI, 0.15–1.58), and wound infection (OR range, 1.20–1.63; overall OR, 1.37; 95% CI, 0.41–4.53), remained stable across iterations, with $I^2 = 0\%$ in all models. Similarly, for midterm mortality, sequential exclusion of individual studies did not alter the pooled estimate (IRR range, 0.73–1.11; overall IRR, 0.97; 95% CI, 0.57–1.66), with negligible heterogeneity (I^2, 0%–2.4%) (Supplementary Figure S16). LOO analyses remained stable also for the other variables considered and are presented in Supplementary Figures S17–S26.

For resource utilization, ICU LOS remained consistently reduced with EWAA (SMD range, −0.62 to −0.43; overall SMD, −0.58; 95% CI, −0.81 to −0.36; $I^2 = 0\%$), whereas hospital LOS showed modest variability but preserved significance (SMD range, −0.45 to −0.29; overall SMD, −0.36; 95% CI, −0.63 to −0.10; $I^2 = 43\%$). In contrast, operative times demonstrated substantial variability despite persistent significance (CPB SMD range, −2.90 to −1.34; overall SMD, −2.46; 95% CI, −3.49 to −1.43; $I^2 = 96\%$; CXC SMD range, −2.45 to −1.60; overall SMD, −2.12; 95% CI, −3.18 to −1.07; $I^2 = 96.4\%$).

With respect to aortic remodeling, proximal diameter estimates remained nonsignificant and stable (SMD range, 0.01–0.34; overall SMD, 0.19; 95% CI, −0.21 to 0.59; $I^2 = 74.7\%$), whereas midascending diameter analyses demonstrated marked instability (SMD range, 0.49 to −0.94; overall SMD, −0.53; 95% CI, −1.67 to 0.60; $I^2 = 97.2\%$), reflecting substantial between-study heterogeneity.

Funnel plots across outcomes did not demonstrate consistent evidence of small-study effects; however, given the limited number of studies, formal assessment of publication bias remains underpowered.

Metaregression

Metaregression was performed to explore the association between baseline characteristics and postoperative outcomes. Metaregression outcomes are reported in Supplementary Table S11 and Supplementary Table S12.

For continuous outcomes, an association with longer CPB time was found for increasing age (beta [b] = 0.672 ± 0.159; $P < .001$), female sex (b = 0.326 ± 0.087; $P < .001$), diabetes (b = −0.062 ± 0.016; $P < .001$), larger AA diameter (b = -0.4934 ± 0.095; $P < .001$), and higher preoperative LVEF (b = 0.089 ± 0.039; $P = .021$). CXC time was significantly associated with hypertension (b = −0.062 ± 0.024; $P = .009$), diabetes (b = −0.128 ± 0.024; $P < .001$), and BAV prevalence (b = −0.036 ± 0.011; $P = .001$). No baseline variables were significantly associated with ICU stay or hospital LOS. Data on CKD were insufficient to evaluate its association with LOS outcomes.

For categorical outcomes, no significant associations were observed between baseline characteristics and stroke, AKI, or 30-day mortality.

Overall, the bubble plots suggested no clear linear relationship between baseline clinical characteristics and CPB- and CXC-associated effect size across studies (Supplementary Figures S27–S35). The relatively compact dispersion of bubbles along the SMD axis indicates good consistency between studies and supports the robustness of the pooled estimate without evidence of a strong small-study effect.

Discussion

In this meta-analysis of 851 patients, EWAA, with or without RAA, was compared with AAR. The primary finding was no significant difference in 30-day mortality (OR, 0.60; 95% CI, 0.27–1.30) or midterm mortality (IRR, 0.97; 95% CI, 0.57–1.66). In addition, no significant differences were observed in stroke (OR, 0.67; 95% CI, 0.23–1.93), AKI (OR, 0.66; 95% CI, 0.22–1.96), wound infection (OR, 1.37; 95% CI, 0.41–4.53), concomitant AVR (OR, 0.92; 95% CI, 0.42–2.00), CABG (OR, 0.86; 95% CI, 0.37–1.99), or mitral valve surgery (OR, 0.71; 95% CI, 0.20–2.56). Although EWAA was associated with shorter CPB time (42.4 minutes) and CXC time (30.6 minutes) and reduced ICU LOS (22.6 hours) and hospital LOS (2.4 days), these differences likely reflect the greater complexity of AAR and duration of concomitant procedures. Follow-up aortic dimensions also did not differ, including mid-AA diameter (SMD, −0.53; 95% CI, −1.67 to 0.60) and proximal AA diameter (SMD, 0.19; 95% CI, −0.21 to 0.59), although surveillance protocols, imaging modalities, measurement locations, and follow-up duration varied across studies. Reoperation for bleeding was not significant between groups (OR, 0.48; 95% CI, 0.15–1.58; $I^2 = 0\%$). Further indications for reintervention were heterogeneous and inconsistently reported. Accordingly, these findings should be considered exploratory and not interpreted as evidence of clinical equivalence. AAR remains the gold standard for patients meeting guideline-based criteria for intervention. Nevertheless, EWAA may represent a selective alternative in patients with moderate AA dilation undergoing concomitant cardiac surgery, particularly those with BAV or fusiform aneurysm, or when advanced age,

frailty, comorbidity burden, or procedural complexity makes AAR less favorable.

This meta-analysis is the first to include exclusively comparative studies. Previously, Plonek et al analyzed 722 patients, including descriptive studies, and reported favorable outcomes with isolated EWAA. Specifically, 30-day mortality was 0.4% in patients undergoing EWAA alone ($n = 272$), with no aortic-related deaths in either early or midterm follow-up. Midterm outcomes also demonstrated low rates of significant aortic redilation (0.7%) and aortic reoperation (0.7%).[34] In our meta-analysis, 30-day mortality was 1.2% and midterm mortality was 9.2% after EWAA. Follow-up aortic dimensions and reoperation rates were also comparable, although aortic-related mortality and reintervention could not be reliably quantified because of inconsistent reporting.

A key determinant in successful EWAA is patient selection. Current ACC/AHA recommendations support concomitant AAR at diameters ≥45 mm in BAV and ≥50 mm in tricuspid aortic valve.[1] In high-risk patients with moderate AA dilation undergoing concomitant cardiac surgery, EWAA may represent a considerable alternative to AAR.[1] According to Plonek et al,[40] EWAA stabilizes the AA wall and reduces wall stress and technical complexity of AAR. Furthermore, Zhang et al[15] found decreased rates of packed red blood cell transfusions in patients undergoing EWAA with RAA compared with AAR (3.5 ± 1.7 vs 4.8 ± 2.1, $P = .01$). Accordingly, this approach may benefit high-risk populations such as the elderly, those with significant comorbidities or undergoing concomitant cardiac surgery, patients deemed ineligible for AAR, or presenting at centers where routine AAR is not performed.[8,41] Suematsu et al demonstrated in 43 high-risk patients (mean age, 79.1 ± 6.8 years; EuroSCORE 64% ± 12%) a hospital mortality of 2.3%, major complications in 4.6%, and 1- and 3-year survival of 95.3% and 91%, respectively, with no aortic-related deaths and high rates of complete (85.7%) or partial (14.3%) aortic remodeling.[42] In a smaller case series, Carrel et al[43] reported 100% procedural survival in 5 frail patients, with ICU stay ≤2 days, no postoperative complications, and no aortic events at 18 months.

Another critical criterion for EWAA is the anatomic phenotype of the AA aneurysm. EWAA is most appropriate for poststenotic fusiform dilation and is generally not recommended in the setting of diffuse or severely diseased AA or in cases with aortic root involvement.[44,45] EWAA may be particularly suitable in BAV-associated aortopathy with progressive dilation but should be avoided in severe aortic valve insufficiency because of the risk of root enlargement and graft displacement. However, as reported by Pecoraro et al,[46] moderate aortic valve insufficiency related to sinotubular junction dilation may improve with EWAA. In our cohort, however, most patients with BAV underwent AAR, and no significant difference was noted between the 2 groups.

From a biomechanical standpoint, EWAA may restore physiologic aortic mechanics by reducing wall stress, improving distensibility and systolic deformation, and preserving native pulsatile energy transmission through the Windkessel effect.[8,47–50] In addition, it offers a technically simpler alternative to AAR. However, EWAA is associated with potentially severe complications. Neri et al reported adverse histologic changes in reoperated patients, including aortic wall thinning, loss of normal layered architecture, and inflammatory infiltration consistent with a foreign-body reaction, whereas nonreinforced segments remained unaltered. These findings have been attributed to impaired vasa vasorum perfusion, chronic inflammation, and sustained external compression, potentially rendering the aorta a passive, graft-like conduit. These alterations appeared less pronounced with macroporous Dacron mesh compared with more rigid prosthetic conduits, likely because of greater material elasticity.[48] Prapas et al[51] demonstrated that EWAA with fresh autologous pericardium may mitigate adverse structural changes by preserving aortic elasticity and accommodating physiologic deformation. Among the included studies, Dacron was the predominant graft material (4 studies), whereas 3 studies did not report the prosthetic graft type, and 1 study used polytetrafluoroethylene (PTFE). Although Dacron is associated with rare but severe complications, currently, it represents a pragmatic option for EWAA, as radical pericardial harvesting may cause further postoperative morbidity.[52,53]

Additional potential complications of EWAA include aortic wall erosion secondary to chronic prosthesis-related friction or compression, as well as focal stress concentration resulting from graft folding or plication that may predispose to localized aortic wall injury.[20,52,54] Further concerns include prosthesis migration, inadequate reinforcement with recurrent dilation, and aortic biomechanics alterations, which may increase wall stress in adjacent segments, predisposing to distal aneurysm formation and eventually, dissection.[20,48,54] Concerns persist regarding aortic redilation and long-term durability of EWAA.

Aortic graft dilation occurs early after AAR because of immediate pressurization, with Dacron grafts demonstrating greater diameter expansion than PTFE, particularly in knitted (20%) compared with woven (10%) configurations.[55] Mostly, dilation occurs within the first weeks with limited progression thereafter. However, late graft dilation can reach a 30% diameter increase at 5–8 years and 60%–70% at 10–15 years.[55] Comparable long-term data for EWAA remain limited. In a cohort of 204 patients (median follow-up, 7.1 years), Kim et al reported no significant redilation at the annulus, sinuses of Valsalva, or AA after either EWAA or AAR. However, a modest but significant increase in proximal arch diameter was observed after EWAA (≈0.34 mm/y), particularly in patients with larger baseline aortic size.[7] Madjarov et al[56] further challenged the interpretation of these findings, suggesting that proximal arch enlargement may reflect altered flow patterns and turbulence at the transition zone rather than intrinsic degeneration of the EWAA, underscoring how late remodeling remains a concern. Similarly, Arsan et al,[19] in their study of 62 patients undergoing EWAA with RAA (mean follow-up, ≈3.3 years), demonstrated significant initial reduction in aortic diameter with low mortality (1.6%) and no major early complications, but observed a statistically significant increase in aortic size during follow-up, albeit remaining within normal limits, underscoring the need for continued surveillance. No significant differences in midterm mortality or follow-up aortic dimensions were observed between EWAA and AAR. However, these findings should be interpreted considering heterogeneity in surveillance protocols, imaging modalities, anatomic measurement locations, and follow-up duration across studies.

Practically, AAR remains the gold standard for patients with moderately dilated AA. EWAA may have a selective role in patients with moderate, fusiform AA dilation or BAV, undergoing concomitant cardiac surgery, particularly when advanced age, frailty, comorbidity burden, or operative complexity makes AAR less favorable. EWAA should not be considered equivalent to AAR, and its role in contemporary practice remains to be defined. Hybrid approaches, combining EWAA with endovascular or minimally invasive techniques, may represent a promising future direction. Prospective multicenter studies with standardized patient selection, preoperative risk assessment, EWAA technique, imaging surveillance, and longer follow-up are needed to identify patients most likely to benefit and establish the comparative effectiveness and durability of EWAA relative to the gold standard AAR.

Limitations

This study presents several limitations. First, the available comparative evidence was limited to 8 retrospective observational studies. Treatment allocation was not randomized and reflected operative indication, comorbidity burden, surgeon preference, and institutional practice. Accordingly, the EWAA and AAR cohorts should not be considered clinically equivalent. In the present analysis, patients undergoing EWAA were older but had smaller baseline AA diameters and a lower prevalence of BAV, suggesting that both patient-level risk and anatomic suitability may have influenced treatment selection. Moreover, important variables, including Society of Thoracic Surgeons score, EuroSCORE, frailty, functional status, pulmonary reserve, nutritional status, urgency of surgery, surgeon-specific selection criteria, and detailed anatomic features beyond aortic diameter, were inconsistently reported. Because only aggregate study-level data were available and adjusted or propensity-matched estimates were not uniformly provided, residual confounding could not be addressed. Therefore, the absence of statistically significant differences in mortality, perioperative morbidity, or aortic remodeling should not be interpreted as evidence of clinical equivalence or comparable durability between strategies.

Second, clinical and methodologic heterogeneity limited the precision and generalizability of the findings. The included studies captured a selected subset of the broader EWAA experience, involving patients with BAV or undergoing concomitant cardiac surgery and center-specific criteria for choosing EWAA versus AAR. In addition, isolated external wrapping and RAA with external reinforcement were pooled because of the limited number of comparative studies, although these procedures differ technically and may have distinct biomechanical and clinical implications. Imaging assessment was also heterogeneous, with inconsistent reporting of imaging modality, measurement location, timing of follow-up, and whether surveillance was routine or symptom driven. Cause-specific mortality was incompletely reported, precluding reliable assessment of the proportion of late deaths attributable to aortic pathology. Reoperation was also inconsistently defined and reported, with variable timing and indications, precluding reliable comparison of reintervention risk between EWAA and AAR.

Third, assessment of long-term durability remains limited. Although the pooled mean follow-up was 3.9 years, follow-up duration varied substantially across studies, and late adverse aortic events were uncommon. The included studies may therefore be underpowered to detect differences in redilation, aortic reintervention, progressive remodeling, or delayed complications related to EWAA. Similarly, the aggregate-data metaregression analyses were limited by low statistical power and potential ecological bias.

Taken together, these limitations warrant cautious interpretation of the results and underscore the need for prospective, adequately powered studies with standardized patient selection, operative technique, imaging surveillance, and long-term follow-up.

In conclusion, in this meta-analysis of 8 retrospective comparative studies, neither 30-day nor midterm mortality differed significantly between EWAA and AAR. Stroke, AKI, wound infection, concomitant surgeries, and follow-up aortic dimensions were also similar, whereas EWAA was associated with shorter CPB and CXC times and reduced ICU and hospital LOS. However, nonrandomized treatment allocation, baseline clinical differences, heterogeneous operative and surveillance protocols, and limited follow-up preclude conclusions regarding clinical equivalence or long-term durability of EWAA. AAR remains the gold standard, whereas EWAA may be considered selectively in patients with moderate AA dilation undergoing concomitant cardiac surgery, particularly those with BAV or fusiform aneurysm, or when advanced age, frailty, comorbidity burden, or procedural complexity makes AAR less favorable.

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Conflict of Interest/Disclosure

The authors declare no conflicts of interest related to this study.

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Supplementary materials

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