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Aortic Arch Repair Using Open and Hybrid Techniques: A Systematic Review

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Abstract

Early surgical intervention is critical for treatment of aortic arch aneurysms and dissections, but limited comprehensive data exist to define the optimal approach for surgical management with respect to postoperative outcomes. We conducted a systematic review of the 2 most common surgical approaches—total arch replacement and hybrid arch repair. We referenced the electronic PubMed database reporting on outcomes for these surgical approaches from inception to June 2022. Our initial search query returned a total of 2,517 records. All records were independently screened for adherence to our inclusion criteria and a total of 12 retrospective cohort studies were identified as appropriate for inclusion. Across the included studies, a total of 618 patients underwent hybrid repair, as compared to 2,104 patients who underwent total arch replacement. We found that most of the literature supported the findings of similar rates of permanent neurologic dysfunction, acute kidney injury, and short-term mortality between approaches and higher postoperative reintervention rates following hybrid repair. Reported outcomes of studies included in this review often conflicted regarding midterm and long-term survival, as well as hospital and intensive care unit length of stay following open and hybrid repair. Future studies should address midterm and long-term survival with a prospective study design.

Central Message

This systematic review on the optimal approach to the surgical management of the aortic arch found comparable short-term outcomes between conventional open and hybrid surgical-endovascular aortic arch repair.

Keywords

total arch replacement, hybrid arch repair, aortic arch, endovascular

Introduction

Thoracic aortic aneurysms have an estimated incidence of 5.3 per 100,000 individuals per year and are commonly associated with high rates of morbidity and mortality if left untreated.[1] Surgical intervention is required for treatment of thoracic aortic aneurysms, although the complexity of surgical intervention varies greatly based on the aortic segments involved. Aneurysms of the aortic arch comprise approximately 10% of thoracic aortic aneurysms and entail a greater number of surgical considerations, given the added complexity of managing cerebrovascular circulation.[2] Untreated aortic arch aneurysms can acutely cause dissection or rupture of the aortic wall, a highly lethal outcome that can be mitigated by early detection and timely surgical repair. Aortic aneurysm treatment has advanced by integrating less invasive modalities with better long-term solutions during a single intervention.

Aneurysms of the aortic arch are presently managed via several approaches, including conventional open total aortic arch replacement or hybrid surgical-endovascular intervention. Total aortic arch replacement has been the standard approach for treating aortic arch aneurysms for the past 4 decades.[3] While advancements have been made in open arch replacement, morbidity remains significant.[4] The hybrid approach aims to reduce the duration of operative time, hypothermic cooling, and cardiopulmonary bypass by combining features of the surgical approach with endovascular technology. This is achieved through a single or staged approach, in which only the proximal portion of the aortic arch is reconstructed using an open surgical technique while endovascular stent grafts are used for more distal portions of the arch. Several studies have compared conventional open repair to isolated endovascular repair,[5,6] but few studies compare conventional repair to hybrid repair.[7–9] Randomized controlled trial data comparing these techniques do not currently exist,[10,11] although studies are under way.[12]

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Despite clear differences in the technical and perioperative requirements of these treatment approaches, both have been associated with increasingly favorable long-term outcomes. We conducted a systematic review comparing short-term and long-term outcomes of conventional open arch repair to hybrid arch repair among adult patients undergoing aortic arch surgery for dissection or aneurysm.

Methods

In accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), our systematic review of the literature regarding surgical management of aortic arch aneurysms and dissections was conducted referencing the electronic PubMed database. To holistically identify literature pertaining to the topic, search query terms included the following: (aortic arch OR aortic arch repair OR aortic arch replacement OR arch) AND (open OR total) AND (hybrid or endovascular) AND (aneurysm OR dissection). Our search query was conducted in June 2022, and all records were independently screened by 1 reviewer to identify records that adhered to the inclusion criteria.

Given our investigative desire to ascertain the optimal approach to surgical management of the aortic arch—with respect to both short-term and long-term postoperative outcomes—inclusion criteria were narrowly restricted to full-text articles that were available in English and offered direct comparisons of postoperative outcomes associated with open versus hybrid surgical management of the aortic arch. Specifically, inclusion criteria were restricted to records that adhered to the following: (1) indication of aneurysm or dissection involving the aortic arch, (2) management with either the open or hybrid surgical approach, and (3) adult patients ≥18 years old. Open surgical management was restricted to total aortic arch replacement, excluding hemiarch, elephant trunk, and frozen elephant trunk techniques, since hemiarch has important differences compared to total arch replacement,[13,14] and elephant trunk techniques are hybrid surgical-endovascular procedures. Hybrid approach included type I, II, and III approaches according to standard definitions.[15] Complete endovascular management with branched or fenestrated thoracic endovascular aortic repair was not evaluated as part of this comparison.

No date confinements were established. Preliminary identification of records adherent to these inclusion criteria was achieved by an independent reviewer's objective screening of all titles and abstracts retrieved through the search query. Records nonadherent to the inclusion criteria, or that aligned with referenced exclusion criteria, were omitted from further review (Table 1). All studies deemed acceptable for inclusion were screened for bias referencing the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) and assigned a certainty rating. Studies assigned a GRADE certainty rating of "High" indicate higher levels of confidence in the reported outcomes than those assigned a "Moderate" GRADE certainty rating.

Table 1. Exclusion Criteria.

Exclusion criteria were articles that:
1. Did not adhere to inclusion criteria, OR that
2. Were unavailable in full text, OR that
3. Were unavailable in English, OR that
4. Referenced pathologic anomalies that did not involve the aortic arch (including type B dissections and abdominal aortic aneurysms), OR that
5. Focused on type III hybrid repair of the aortic arch, OR that
6. Solely presented a case report/series, commentary, or systematic review, OR that
7. Did not pertain to surgical management of aortic arch aneurysms/dissections, OR that
8. Pertained to reoperation of the aortic arch, OR that
9. Pertained to pediatric patient population (<18 years)

Results

Search Outcome

Our initial search query on the electronic PubMed database returned 2,517 full-text records that were independently investigated for pertinent insights to our review. All titles and abstracts were screened for adherence to our inclusion criteria, and 83 records were identified for full-text review. After full-text review, 8 studies were deemed suitable for inclusion (Fig. 1). Bibliography and reference sections for each of these 8 records were also independently reviewed and 4 additional articles were identified as adherent to our inclusion criteria and included in our review. All 12 articles were retrospective cohort studies, while 3 also included risk-adjusted analysis. Pertinent findings identified within these records were manually aggregated and appropriately stratified for comparative analysis of postoperative outcomes (Table 2). Both short-term and long-term postoperative outcomes were investigated referencing the following measures: (1) permanent neurologic dysfunction (PND) where studies clearly defined dysfunction as permanent or stroke, (2) acute kidney injury (AKI), (3) length of stay (LOS), (4) short-term mortality, (5) midterm and long-term survival, and (6) reintervention at 1, 3, and 5 years (Table 2).

Permanent Neurologic Dysfunction

Postoperative PND, or stroke, has been identified as an independent risk factor for long-term mortality in patients undergoing open or type III hybrid procedures.[16] In this review, 7 of 12 studies (Table 3) directly compared PND between patients undergoing open or hybrid aortic arch operations.[17–23] Most studies found no difference in postoperative PND at the time of discharge between groups.[17–19,21–23] However, Joo et al. found that among 174 patients

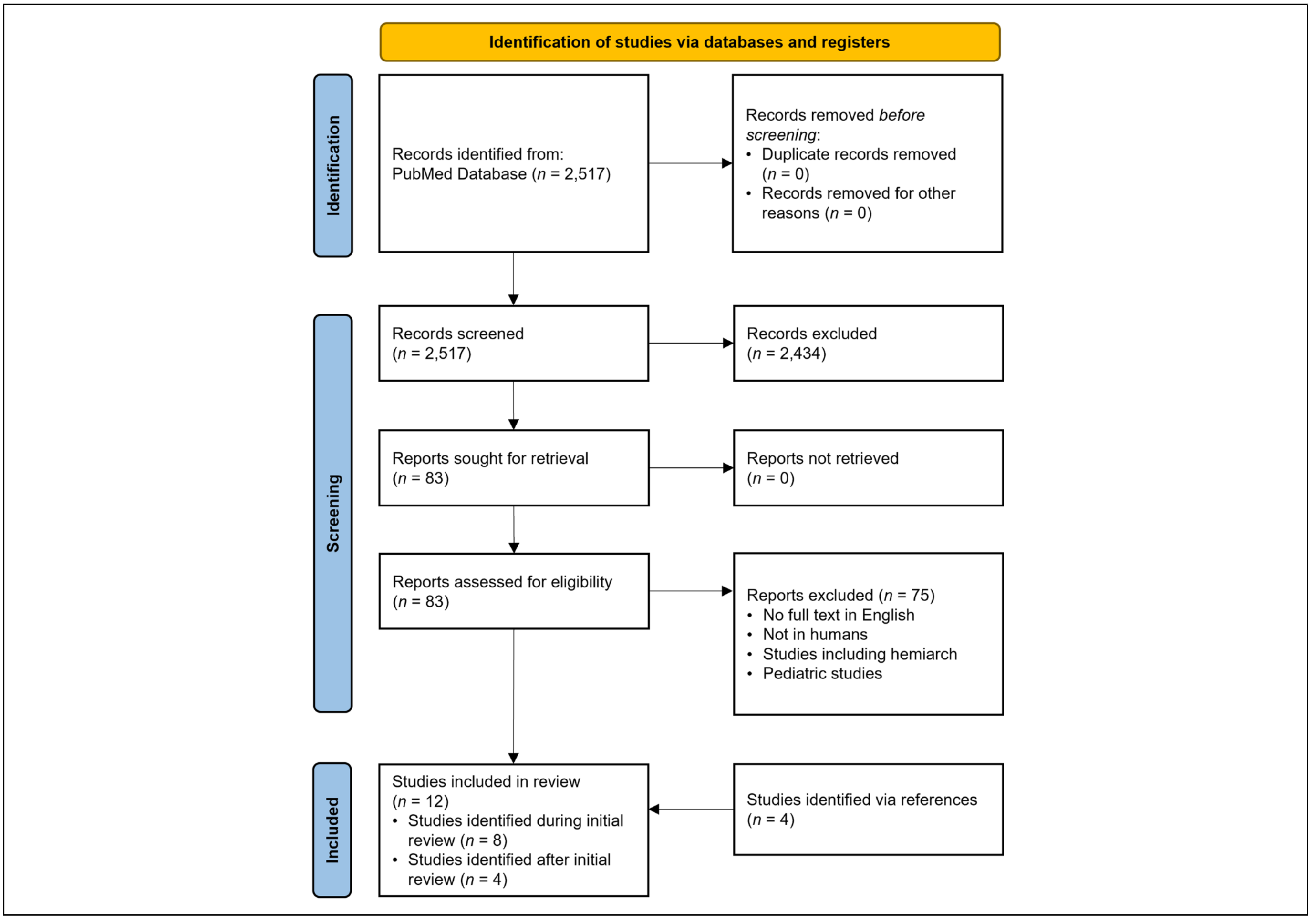

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

undergoing total arch replacement and 64 undergoing hybrid arch repair for aortic arch pathology excluding type A dissections, hybrid repair was associated with a higher rate of PND (12.5% vs 2.9%, $P = 0.004$).[20] Patients in the hybrid arch repair group were older at baseline (68.9 ± 13.4 vs 64.7 ± 14.9 years, $P = 0.041$). After propensity matching, this result was no longer statistically significant, but the higher rate of PND in hybrid patients was still evident (14.5% vs 2.1%, $P = 0.070$).

Acute Kidney Injury

Among 12 studies included in this review, 7 studies (Table 4) provided direct comparisons of the rate of postoperative AKI between patients undergoing conventional open versus hybrid open-endovascular surgery. Out of 7 studies, 5 found no difference in the rate of AKI following surgery between the different approaches. In one of these studies,[18] matching also revealed no significant difference in the rate of postoperative AKI. The 2 studies that found a significant difference in the rate of AKI both found higher rates of AKI among patients undergoing conventional open repair.[24,25]

Length of Stay

When reviewing LOS, 9 of the 12 studies (Table 5) evaluated LOS among patients undergoing conventional open approach compared to those undergoing hybrid approach.[17–20,22,24–27] We have divided these studies into those evaluating hospital LOS and intensive care unit (ICU) LOS (Table 5). Hospital LOS was shorter in patients undergoing hybrid arch replacement compared to open in most studies,[18–20,24,25] while few studies found no difference,[22,26] and no studies found hybrid arch replacement to be associated with longer hospital LOS.

Results were similar for ICU LOS between the 2 groups, although 1 study found the hybrid approach to be associated with longer ICU LOS compared to open (8.65 ± 12.00 vs 4.51 ± 4.37 days, $P = 0.011$).[22] In this single-institutional study of 182 patients undergoing hybrid or open surgery, hospital LOS for the cohort did not vary (38 ± 29 vs 33 ± 20 days, $P = 0.15$), and differences in ICU stay persisted despite propensity matching. However,

Table 2. Overview of Studies and Postoperative Outcome Measures.

		Sample size		Referenced postoperative outcome measure(s)						GRADE certainty rating
Author	Study type	OR	HR	LOS	PND	AKI	Reintervention	Short-term mortality	Long-term survival	
Murphy et al. (2009)	Retrospective cohort	12	18	Yes	No	Yes	No	Yes	No	Moderate
Milewski et al. (2010)	Retrospective cohort	1,196	64	Yes	Yes	No	No	Yes	Yes	High
Nakamura et al. (2013)	Retrospective cohort	74	51	No	No	No	No	No	Yes	High
Iba et al. (2014)	Retrospective cohort; risk-adjusted analysis	143	50	Yes	Yes	Yes	Yes	Yes	Yes	High
Tokuda et al. (2016)	Retrospective cohort; risk-adjusted analysis	124	58	Yes	Yes	No	No	Yes	Yes	High
Kang et al. (2016)	Retrospective cohort	20	35	No	Yes	Yes	Yes	Yes	Yes	High
Benrashid et al. (2016)	Retrospective cohort	47	101	Yes	Yes	Yes	Yes	Yes	Yes	High
Souza et al. (2017)	Retrospective cohort	12	13	Yes	No	Yes	No	Yes	No	Moderate
Gokalp et al. (2018)	Retrospective cohort	15	11	Yes	No	Yes	Yes	Yes	Yes	Moderate
Joo et al. (2019)	Retrospective cohort; risk-adjusted analysis	174	64	Yes	Yes	No	Yes	Yes	Yes	High
Shi and Wang (2020)	Retrospective cohort	212	97	Yes	No	Yes	Yes	No	Yes	High
Mizuno et al. (2022)	Retrospective cohort	75	56	No	Yes	No	Yes	Yes	Yes	High

Abbreviations: AKI, acute kidney injury; GRADE, Grading of Recommendations, Assessment, Development and Evaluations; HR, hybrid repair of aortic arch; LOS, length of stay; OR, open repair of aortic arch; PND, permanent neurologic dysfunction.

Table 3. Permanent Neurologic Dysfunction.

Study	Sample size	Open	Hybrid	*P* value
Mizuno et al. (2022)	Open: $n = 75$ Hybrid: $n = 56$	1.3%	0%	0.386
Joo et al. (2019)	Open: $n = 174$ Hybrid: $n = 64$	2.9%	12.5%	0.004
Benrashid et al. (2016)	Open: $n = 47$ Hybrid: $n = 101$	2.1%	3.0%	0.99
Tokuda et al. (2016)	Open: $n = 124$ Hybrid: n = 58	12%	17%	0.36
Kang et al. (2016)	Open: $n = 20$ Hybrid: $n = 35$	15.0%	5.7%	0.342
Iba et al. (2014)	Open: $n = 143$ Hybrid: $n = 50$	2%	6%	0.76
Milewski et al. (2010)	Open: $n = 45$ Hybrid: $n = 27$	9%	13%	1.00

matching excluded 34% of the hybrid group who were so high risk that no matching patients in the open group existed.

Short-Term Mortality

When assessing short-term mortality, 10 of the 12 studies (Table 6) evaluated operative mortality, in-hospital mortality, or 30-day mortality. All studies found no difference in short-term mortality,[17–23,25–27] and these findings persisted in studies that performed matching.[18,20,22] Short-term mortality across all studies ranged from 0% to 30% in the open operation cohort and 0% to 23% in the hybrid operation cohort. Studies reporting mortality rates at the upper limit of the open arch range were those that had the smallest open cohort sample sizes,[17,19,23,25–27] while those with larger sample sizes had short-term mortality rates approaching 0%.[18,20–22]

Table 4. Acute Kidney Injury.

Study	Sample size	Open	Hybrid	*P* value
Shi and Wang (2020)	Open: $n = 212$ Hybrid: $n = 97$	23.8%[a] 10.2%[b]	5.2%[a] 2.6%[b]	0.003[a] 0.243[b]
Gökalp et al. (2018)	Open: $n = 15$ Hybrid: $n = 11$	20%	0%	0.238
Souza et al. (2017)	Open: $n = 12$ Hybrid: $n = 13$	0%	7.7%	1.00
Benrashid et al. (2016)	Open: $n = 47$ Hybrid: $n = 101$	12.8%	5.9%	0.20
Kang et al. (2016)	Open: $n = 20$ Hybrid: $n = 35$	10.0%	5.7%	0.616
Iba et al. (2014)	Open: $n = 143$ Hybrid: $n = 50$	1.0%	0%	0.40
Murphy et al. (2009)	Open: $n = 12$ Hybrid: $n = 18$	41.7%	0%	0.002

[a]Age ≥60 years.
[b]Age <60 years.

Midterm and Long-Term Survival

Out of 12 studies (Table 7), 9 measured midterm and long-term survival percentages, recording anywhere from 1-year to 10-year survival rates. Midterm survival at 1, 2, and 3 years was evaluated in 8 studies. Out of 4 studies comparing 1-year survival, none found a difference between open and hybrid operations. At 2 years, 1 out of 2 studies found a difference with patients 60 years or older undergoing hybrid operation having a higher survival rate than those 60 years or older undergoing open operation (95.1% vs 65.2%, $P = 0.037$).[24] This study was among 309 patients with comparable baseline comorbidities between groups. No patients under 60 years died in this cohort. Survival at 3 years was similar in most studies, although 2 reported differences in survival. Mizuno et al. evaluated 131 patients and found that despite a higher proportion of patients with chronic obstructive pulmonary disease (COPD), which has been cited as a risk factor for decreased long-term survival following thoracic aortic surgery,[28] survival at 3 years was higher in patients undergoing the hybrid approach (83.1% vs 74.7%, $P = 0.001$).[21] In contrast, Nakamura et al. evaluated 3-year survival in a similarly sized cohort and found that survival was lower in patients undergoing the hybrid approach (74.8% vs 95.1%, $P = 0.035$).[16] Interestingly, most patients in both cohorts were over 70 years old, and age did not differ between groups in either cohort. Another study did not report survival percentages,[17] and is thus not included in Table 7. However, Milewski et al. reported follow-up time between groups using Kaplan–Meier statistics.[17] They evaluated 45 patients undergoing open and 27 patients undergoing hybrid arch repair for atherosclerosis-related and dissection-related aneurysms. Patients in the hybrid group had a higher comorbidity burden in that they were older and had higher rates of COPD, yet there was no difference in follow-up survival between groups with a mean follow-up time of 22.7 ± 3.4 months in the open total arch cohort and 13.3 ± 2.6 months in the hybrid arch cohort ($P = 0.32$).

Long-term survival at 5 and 10 years differed in most studies reporting these outcomes. In those reporting differences,[16,20] survival was higher in patients undergoing open repair at both time points. Joo et al. evaluated clinical outcomes among patients undergoing open ($n = 174$) versus hybrid ($n = 64$) repair, excluding type III hybrid procedure, for management of aortic arch diseases, excluding type A dissection.[20] Patients undergoing open repair had higher estimated survival at 5 and 10 years (87% ± 5.5% vs 69.5% ± 7.4%; 81.9% ± 4.8% vs 40.8% ± 11.1%, respectively; $P = 0.003$). When risk adjusted by matching, these survival differences persisted, although 25% of the hybrid group was excluded upon matching. In another study, Nakamura et al. evaluated predictors of long-term mortality among patients undergoing aortic arch surgery for the management of atherosclerotic aortic arch aneurysm—74 patients underwent conventional open repair and 51 patients underwent type III hybrid repair.[16] Survival at 5 and 10 years was higher in patients undergoing conventional open surgery (88.7% vs 71.7%; 82.8% vs 71.7%, respectively; $P = 0.035$). Independent risk factors associated with long-term mortality included PND, chronic renal failure, and age. Importantly, although survival was lower in the hybrid group, the hybrid approach itself was not an independent risk factor for late death, and there was no significant difference in aorta-related death between open and hybrid groups.

Postoperative Reintervention

Postoperative reintervention rates were compared between patients who underwent total arch replacement and those who underwent hybrid arch repair in 7 of the 12 studies that were reviewed (Table 8). Postoperative reintervention was defined as any occurrence of surgical or endovascular intervention that was conducted for the purpose of treating complications of the aorta following the initial total arch or hybrid arch

Table 5. Difference in Hospital and ICU LOS.

Study	Sample size	Open	Hybrid	*P* value
Hospital LOS, days				
Shi and Wang (2020)	Open: *n* = 212 Hybrid: *n* = 97	28.6 ± 5.0[a] 19.5 ± 2.8[b]	22.3 ± 2.0[a] 18.6 ± 1.8[b]	<0.001[a] 0.061[b]
Joo et al. (2019)	Open: *n* = 174 Hybrid: *n* = 64	16.7 ± 12.4	11.9 ± 8.6	<0.01
Souza et al. (2017)	Open: *n* = 12 Hybrid: *n* = 13	18 (3–42)	8 (5–70)	0.862
Tokuda et al. (2016)	Open: *n* = 124 Hybrid: *n* = 58	33 ± 20	38 ± 29	0.15
Benrashid et al. (2016)	Open: *n* = 47 Hybrid: *n* = 101	6 (5–9)	5 (4–8)	0.04
Iba et al. (2014)	Open: *n* = 143 Hybrid: *n* = 50	32.9 ± 35.7	25.9 ± 29.5	0.001
Milewski et al. (2010)	Open: *n* = 45 Hybrid: *n* = 27	17.5 ± 16.2	20.1 ± 15.9	—
Murphy et al. (2009)	Open: *n* = 12 Hybrid: *n* = 18	20.8 ± 10.8	11.6 ± 6.2	0.012
ICU LOS, days				
Shi and Wang (2020)	Open: *n* = 212 Hybrid: *n* = 97	5.2 ± 2.0[a] 2.7 ± 0.9[b]	4.5 ± 1.2[a] 2.4 ± 0.6[b]	0.018[a] 0.053[b]
Joo et al. (2019)	Open: *n* = 174 Hybrid: *n* = 64	5.3 ± 6.7	3.2 ± 5.7	0.02
Gökalp et al. (2018)	Open: *n* = 15 Hybrid: *n* = 11	5.9 ± 4.7	3.8 ± 1.5	0.447
Souza et al. (2017)	Open: *n* = 12 Hybrid: *n* = 13	2 (0–25)	3 (0–16)	0.805
Tokuda et al. (2016)	Open: *n* = 124 Hybrid: *n* = 58	4.51 ± 4.37	8.65 ± 12.00	0.011
Iba et al. (2014)	Open: *n* = 143 Hybrid: *n* = 50	4.7 ± 9.0	1.6 ± 2.2	<0.001
Murphy et al. (2009)	Open: *n* = 12 Hybrid: *n* = 18	16.4 ± 12.9	5.2 ± 4.8	0.005

Abbreviations: ICU, intensive care unit; LOS, length of stay.
Data presented as mean ± SD or median (range).
[a]Age ≥ 60 years.
[b]Age < 60 years.

repair. Endoleak was the most common indication for reintervention, affecting as high as 57% of patients in whom reintervention was required.[19] More specifically, the highest rates of postoperative reintervention were associated with type I endoleak; however, it is noteworthy to mention that reintervention was not necessarily indicated for all patients in whom endoleak occurred.[23] Postoperative rates of reintervention at 1 year were explicitly investigated in 2 studies.[18,19] The study conducted by Iba et al. retrospectively evaluated 193 total patients—143 of whom underwent total arch replacement and 50 of whom underwent hybrid repair.[18] Benrashid et al. evaluated 148 total patients, 47 and 101 of whom underwent open and hybrid repair, respectively.[19] Both studies attributed significantly higher rates of reintervention to the hybrid patient cohorts relative to the open cohorts (3.0% vs 0.7%, $P < 0.001$; 18.0% vs 4.0%, $P = 0.010$).

Similar outcomes attributing significantly greater incidence of postoperative reintervention among the hybrid patient cohorts were evident in 2 studies that investigated reintervention rates at 2 years, 3 studies that investigated reintervention rates at 3 years, and 1 study that investigated reintervention rates at 5 years (Table 8). The study conducted by Shi and Wang further stratified the comparison of 2-year reintervention rates between the open and hybrid cohorts by age.[24] Interestingly, a higher rate of reintervention was attributed among the hybrid cohort of patients younger than 60 years old, as compared to those older than 60 years (7.7% vs 5.2%, $P < 0.05$). Still, reintervention remained significantly more common among the hybrid patient cohorts (5.2% vs 0%; 7.7% vs 0%; $P < 0.05$). Among 7 studies that compared postoperative reintervention rates between hybrid and total arch replacement cohorts, the Mizuno et al. study was the only one that attributed higher reintervention rates to the open arch repair cohort (16.3% vs 0%).[21] However, the authors did indicate that statistical analysis of this finding was not feasible—citing that Cox regression analysis was not suitable due to limitations in their data.

Table 6. Short-Term Mortality.

Study	Sample sizes	Open	Hybrid	*P* value
Operative mortality				
Tokuda et al. (2016)	Open: $n = 124$ Hybrid: $n = 58$	0%	3.4%	0.10
Murphy et al. (2009)	Open: $n = 12$ Hybrid: $n = 18$	16.7%	5.6%	0.34
In-hospital mortality				
Milewski et al. (2010)	Open: $n = 45$ Hybrid: $n = 27$	16%	11%	0.739
Iba et al. (2014)	Open: $n = 143$ Hybrid: $n = 50$	3%	2%	0.76
Souza et al. (2017)	Open: $n = 12$ Hybrid: $n = 13$	17%	23%	0.248
Mizuno et al. (2022)	Open: $n = 75$ Hybrid: $n = 56$	1.3%	0%	0.386
Benrashid et al. (2015)	Open: $n = 47$ Hybrid: $n = 101$	10.6%	13.9%	0.79
Joo et al. (2018)	Open: $n = 174$ Hybrid: $n = 64$	4.6%	6.3%	0.739
30-day mortality				
Kang et al. (2016)	Open: $n = 20$ Hybrid: $n = 35$	30%	11.4%	0.144
Gökalp et al. (2018)	Open: $n = 15$ Hybrid: $n = 11$	20%	0%	0.238

Discussion

Aortic arch pathology including aneurysms and dissections is associated with high morbidity and mortality.[29,30] Conventional total aortic arch replacement has been considered the gold standard for managing aortic arch pathology, yet hybrid surgical-endovascular interventions have been more recently defined. While current practice often reserves hybrid intervention for patients who are high risk for open surgical repair, there is uncertainty regarding the optimal approach for improving short-term and long-term outcomes for all patients. In our review of pertinent literature comparing open and hybrid repair, we found that most of the literature supported the findings of similar rates of PND, AKI, and short-term mortality between approaches and higher postoperative reintervention rates following hybrid repair. Reported outcomes of studies included in this review often conflicted regarding midterm and long-term survival and hospital and ICU LOS following open and hybrid repair.

Other studies have evaluated these outcomes in similar settings with different inclusion criteria. In a meta-analysis of 189 matched pairs among 5 studies, Zhan et al. concluded that the rate of permanent stroke was higher among patients undergoing hybrid repair (14.3% vs 2.1%, odds ratio = 0.18, 95% CI: 0.07 to 0.46, $P < 0.001$).[31] However, their analysis included a study by Hiraoka et al. in which the chimney technique was included in the hybrid arch repair cohort, although this is not a sternotomy-based hybrid approach.[32] Three larger meta-analyses that were unmatched each found no difference in PND between those undergoing open versus hybrid arch repair.[7–9] The majority of literature supports our finding of similar PND rates between open and hybrid repair. In accordance with our findings regarding AKI, 3 meta-analyses also found no difference in the rate of AKI between these 2 approaches.[7,9,31] Four meta-analyses have compared short-term mortality among patients undergoing open or hybrid repair, and none found a difference in short-term mortality between procedures.[7–9,31] In the largest of these studies, Chakos et al. included 9 retrospective studies of a total of 2,023 patients and found short-term mortality rates of 10.4% (95% CI: 6.7 to 15.8) in conventional total arch replacement and 7.9% (95% CI: 5.2 to 11.9) in hybrid repair ($P = 0.10$),[7] similar to short-term mortality rates of studies in our review. Comparative literature on reintervention rates between open and hybrid repair agreed with our finding of higher reintervention rates among patients undergoing hybrid repair.[20,33–35]

Reported outcomes of midterm and long-term survival and LOS were frequently inconsistent among studies in our review. Existing literature outside of the studies included in our review also differ. One study found lower midterm 2-year survival among patients undergoing the hybrid approach,[31] while another study found no difference in midterm 2-year survival.[9] Regarding long-term survival, 1 meta-analysis found higher long-term survival among patients undergoing the hybrid approach,[7] while another meta-analysis found no difference in late mortality between these cohorts.[8] In a meta-analysis evaluating LOS, Zhan et al. found no significant difference in hospital or ICU LOS in patients undergoing the open versus hybrid approach.[31] Among our studies, Shi and Wang conducted a subgroup analysis by age among an institutional cohort of 309 patients in which differences in LOS were only

Table 7. Midterm and Long-Term Survival Rates.

Study	Sample sizes	Open	Hybrid	*P* value
1-year survival				
Kang et al. (2020)	Open: $n = 20$ Hybrid: $n = 35$	79.7%	87.3%	0.319
Gökalp et al. (2018)	Open: $n = 15$ Hybrid: $n = 11$	73.3%	100%	0.113
Tokuda et al. (2016)	Open: $n = 124$ Hybrid: $n = 58$	96%	88%	0.066
Benrashid et al. (2015)	Open: $n = 47$ Hybrid: $n = 101$	82.6%	70.6%	0.39
2-year survival				
Shi and Wang (2020)	Open: $n = 212$ Hybrid: $n = 97$	65.2%[a]	95.1%[a]	0.037[a]
Tokuda et al. (2016)	Open: $n = 124$ Hybrid: $n = 58$	93%	80%	0.066
3-year survival				
Kang et al. (2016)	Open: $n = 20$ Hybrid: $n = 35$	72.4%	83.8%	0.319
Iba et al. (2014)	Open: $n = 143$ Hybrid: $n = 50$	87%	81%	0.13
Mizuno et al. (2022)	Open: $n = 75$ Hybrid: $n = 56$	74.7%	83.1%	0.001
Benrashid et al. (2015)	Open: $n = 47$ Hybrid: $n = 101$	79.8%	58.4%	0.39
Nakamura et al. (2014)	Open: $n = 74$ Hybrid: $n = 51$	95.1%	74.8%	0.035
5-year survival				
Benrashid et al. (2015)	Open: $n = 47$ Hybrid: $n = 101$	70%	46.6%	0.39
Joo et al. (2018)	Open: $n = 174$ Hybrid: $n = 64$	87% ± 5.5%	69.5% ± 7.4%	0.003
Nakamura et al. (2014)	Open: $n = 74$ Hybrid: $n = 51$	88.7%	71.7%	0.035
10-year survival				
Joo et al. (2018)	Open: $n = 174$ Hybrid: $n = 64$	81.9% ± 4.8%	40.8% ± 11.1%	0.003
Nakamura et al. (2014)	Open: $n = 74$ Hybrid: $n = 51$	82.8%	71.7%	0.035

Data presented as percentage or mean ± SD.
[a]Age ≥60 years; no significant difference in patients age <60 years.

significant in patients older than 60 years—these patients had longer LOS following open approach,[24] suggesting that age may influence LOS. Similar to what we found upon our review, literature does not seem to provide a clear answer as to how midterm and long-term survival and LOS compare between patients undergoing open and hybrid aortic arch surgery. It is unclear whether differences exist and whether age may play a role in explaining any differences.

Our study has limitations. All studies included in our systematic review were retrospective in nature, thus introducing the possibility of selection bias. Patients undergoing hybrid arch repair may not have been deemed candidates for conventional open repair. Although most studies included in our review had comparable baseline characteristics between groups, there were studies that did not, and there may have been other unmeasured variables influencing outcomes. In addition, there are likely institutional differences between study sites regarding the indications for open versus hybrid arch repair. Some centers may not have the technological capabilities for hybrid arch repair—centers performing these repairs may be those that are high-volume centers, limiting the generalizability of our findings. By including only comparator studies, we aimed to limit the effect of these limitations.

Conclusions

Our review of the literature highlights outcomes for which existing data provide consistent results and outcomes for which more data are needed to clarify differences. The data show that among patients undergoing open versus hybrid arch repair for aortic arch pathology, short-term mortality rates are low and comparable, rates of PND and AKI are similar, and patients undergoing hybrid

Table 8. Postoperative Reintervention Rates.

Study	Sample sizes	Open	Hybrid	*P* value
1-year postoperative reintervention				
Iba et al. (2014)	Open: $n = 143$ Hybrid: $n = 50$	0.70%	3.0%	<0.001
Benrashid et al. (2015)	Open: $n = 47$ Hybrid: $n = 101$	4.0%	18.0%	0.010
2-year postoperative reintervention				
Iba et al. (2014)	Open: $n = 143$ Hybrid: $n = 50$	0.70%	14.0%	<0.001
Shi and Wang (2020)	Open: $n = 212$ Hybrid: $n = 97$	0%[a] 0%[b]	5.2%[a] 7.7%[b]	<0.05[a] <0.05[b]
3-year postoperative reintervention				
Iba et al. (2014)	Open: $n = 143$ Hybrid: $n = 50$	0.70%	20.0%	0.001
Kang et al. (2015)	Open: $n = 20$ Hybrid: $n = 35$	0%	25.7%	0.020
Benrashid et al. (2015)	Open: $n = 47$ Hybrid: $n = 101$	4.3%	20.8%	0.01
5-year postoperative reintervention				
Gökalp et al. (2018)	Open: $n = 15$ Hybrid: $n = 11$	13.3%	18.2%	0.738
Joo et al. (2018)	Open: $n = 174$ Hybrid: $n = 64$	3.4%	55.4%	0.01
Mizuno et al. (2022)	Open: $n = 75$ Hybrid: $n = 56$	16.3%	0%	—

[a]Age ≥60 years.
[b]Age <60 years.

arch repair are more likely to require reintervention. However, it is unclear how midterm and long-term survival of each approach compare. In addition, LOS may or may not differ between groups but does not seem to affect short-term outcomes. Future prospective studies should address longer-term survival, in addition to delineating which patients are best suited to receive one or the other of these complementary surgical therapies.

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