Systematic review of clinical outcomes in hybrid procedures for aortic arch dissections and other arch diseases

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Objective: Available data on clinical outcomes of hybrid aortic arch repair are limited, especially for patients with aortic dissection. The objective of this review was to provide pooled analysis of periprocedural mortality and neurologic outcomes in hybrid procedures involving the aortic arch for dissection and other aortic diseases.

Methods: Studies involving hybrid aortic arch procedures (2002-2011) were systematically searched and reviewed. End points were periprocedural mortality, stroke, and spinal cord ischemia.

Results: A total of 50 studies including 1886 patients were included. Perioperative mortality ranged from 1.6% to 25.0% with a pooled event ratio of 10.8% (95% confidence intervals [CI], 9.3-12.5). Perioperative stroke, regardless of severity, ranged from 0.8% to 25.0% (pooled ratio 6.9%; 95% CI, 5.7%-8.4), and spinal cord ischemia, including permanent and transitory events, ranged from 1.0% to 25.0% (pooled ratio, 6.8%; 95% CI, 5.6-8.2). Neurologic but no mortality risk was affected by timing and center volume with decreased rates in more recent and higher volume studies. In dissected aorta, perioperative mortality rate was 9.8% (95% CI, 7.7-12.4), stroke 4.3% (95% CI, 3.0-6.3), and spinal cord ischemia 5.8% (95% CI, 4.2-7.9). Perioperative mortality was higher in diseases that extended to the ascending aorta (15.1% vs 7.6%; odds ratio, 2.8; 95% CI, 1.17-6.7; $P = .021$), whereas there were no significant differences in the neurologic risks of stroke or spinal cord ischemia.

Conclusions: Hybrid repair of the aortic arch carries not negligible risks of perioperative mortality and neurologic morbidity. Risk of neurologic complications has decreased with timing and center volume and may be limited in dissection repairs. However, contemporary information on aortic hybrid arch procedures is mainly provided by small case series or retrospective studies with wide range of results. (*J Thorac Cardiovasc Surg* 2012;144:1286-1300)

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Repair of aortic arch diseases remains a surgical challenge. Despite significant advances in operative care, conventional treatment is still associated with significant incidence of perioperative mortality and neurologic complications. Furthermore, many patients are denied surgical intervention owing to their significant comorbidities.

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Recent advances in thoracic stent grafts have enhanced the management of thoracic aorta disorders. Nevertheless, when the disease extends into the aortic arch, conventional endovascular techniques are challenged.

Endovascular exclusion of the aortic arch combined with an open surgical component, effectively named “hybrid” aortic arch repair, has been recently introduced as an effective alternative to decrease morbidity and mortality in selected patients.^{1,2} However, the available data on clinical outcomes are limited, particularly for patients with dissection. In addition, several different approaches to hybrid arch repair have been described.

The aim of this study was to perform a systematic review of the literature on hybrid operative strategies for aortic arch repair with a pooled analysis of periprocedural clinical outcomes (mortality and neurologic complications) particularly when applied for aortic dissection.

METHODS

Search Strategy

A literature search was undertaken to identify all published studies in the past 10 years reporting on hybrid treatment of aortic arch diseases. Candidate studies in English were sought through a computerized search of the Ovid and MEDLINE (National Library of Medicine, Bethesda, Md) databases for the period of January 2002 to November 2011. Key words entered in this search were “hybrid” or “debranching,” with “aortic arch,” “endovascular,” and “dissection.” Additionally, manual evaluation of the reference lists of the retrieved articles and reviews on this area subject was undertaken.

Abbreviations and Acronyms

95% CI = 95% confidence interval
OR = odds ratio

Study Selection

Studies were considered for inclusion on the basis of these criteria:

- Reporting on combined open surgical and endovascular repair of aortic arch
- Including at least 5 patients treated with this method
- Reporting on clinical outcome

In some articles, patients treated with hybrid procedures were not the total but a subpopulation and no detailed information was given for this subgroup. Data were included if there was a separate description of these patients or if relevant data could be sufficiently retrieved from the article.

Studies containing duplicate data were excluded and the ones with the most recent or the best-documented material from the same authors were used for analysis.

An extensive effort was made to individualize outcomes of patients with aortic dissection. However, many articles combined outcomes for arch aneurysm and dissection and did not report results separately for the dissection cohort. Furthermore, acute, subacute, and chronic dissections, as well as type A and B dissections, were usually combined. Data on dissected aorta were separately analyzed only when clear information was provided for this subgroup.

Definitions

Inasmuch as the variety of hybrid techniques is strictly related to the availability of landing zones and disease extension, 3 subgroups of hybrid repairs were separately analyzed: “arch debranching,” “frozen elephant trunk,” and “stented elephant trunk with endovascular repair of thoracoabdominal aorta.”¹

Aortic arch zones were classified according to Mitchell/Ishimaru: zone 0 is proximal to the innominate artery, zone 1 involves the origin of the left common carotid artery, zone 2 includes the left subclavian artery, zone 3 extends beyond the origin of the left subclavian artery to the beginning of descending thoracic aorta, and zone 4 involves the descending thoracic aorta.³

Statistical Analysis

Data retrieved for each study were entered in a purposed designed dataset, pooled, and analyzed according to published guidelines for synthesis of information from the existing literature (Moose). Study quality was rated according to formal assessment check list.⁴ Meta-analysis was conducted using a specific statistical package (Comprehensive Meta-analysis Package, version 2; Biostat, Englewood, NJ). Primary outcome measures were perioperative (30-day or in-hospital) incidence of neurologic complications (stroke and spinal cord ischemia) and mortality. Event rates, ranges, and corresponding 95% confidence intervals (95% CI) were used to summarize data pooled from all eligible published studies.

A separate analysis of the outcome measures was performed in 3 subgroups by type of hybrid repair (debranching, frozen elephant trunk, stented elephant trunk) and in the subgroup of repairs for dissections when results were clearly given in this type of aortic disease. To evaluate whether results were affected by time experience or volume center, we repeated analyses with data breakdown by publication year (studies before 2007 and since 2007) and by center volume (studies with ≥ 20 and < 20 volume).

Secondary analyses were performed in studies by comparing zone 0 versus zone 1.

The differences in proportions of complication rates by zone were analyzed using the χ^2 and Fisher exact tests. The estimates of outcome rates, the corresponding odds ratios (OR), and the differences between event rates were given with the 95% CI.

RESULTS

Search Results

The literature search (see Figure 1) identified 153 potential publications. Seventy-four were considered relevant for the purposes of this review. Sixteen were duplicate publications without details on outcome and were excluded. Six were excluded because they were reviews of other studies, and 2 were excluded because they did not provide detailed results, leaving a total of 50 studies available for the analysis including 1886 patients (complete list of included and excluded studies shown as E-References online only).

Main characteristics of the included studies are shown in Tables 1 to 4.^{2,5-E53} Most were retrospective studies, and there was no level 1 evidence. In most studies, different types of aortic disease and hybrid repair were combined. Furthermore, most series provided outcomes for emergency and elective repair without providing separate outcomes. Finally, some studies were mainly focused on high-risk patients (unfit for open surgery), whereas high-risk and average risk patients were combined in other studies and the issue was not always clarified to detect separate information.

Twenty-seven studies including 642 patients focused on arch debranching.^{2,13-15,20-E42}

Seventeen studies and 1103 patients were available for frozen elephant trunk technique.^{5-12,16-19,E43-E47} Nine studies and 141 patients were available for stented elephant trunk.^{15,E34,E35,E48-E53}

When information on different subgroup techniques (debranching, frozen elephant trunk, or stented elephant trunk) was provided by the same study, data were separately extracted and analyzed for each specific subgroup. In 3 studies, information was available for both debranching and stented elephant trunk techniques.^{15,E34,E35} In another study, different outcomes were provided in different population settings receiving frozen elephant trunk and these were separately analyzed.¹²

Data from 17 studies were available for analysis of patients with acute/chronic type A and B aortic dissection.^{2,5-20}

Details by landing zone were available from 19 studies.^{2,13,14,E21-E28,E30,E31,E33,E34,E36,E37,E41,E53}

Outcomes

Primary outcome measures in the individual studies and pooled data are shown in Figures 2, 3, and 4.

FIGURE 1. Search strategy.

Mortality (Figure 2). Perioperative mortality ranged from 1.6% to 25.0% with a pooled event ratio of 10.8% (95% CI, 9.3-12.5). In the group of 27 studies focused on debranching, mortality ranged from 2.0% to 23.7% with a pooled event ratio of 11.9% (95% CI, 9.4-15.1)^{2,13-15,20-E42} (Figure 2, A).

In the 17 studies reporting on frozen elephant trunk, perioperative mortality ranged from 1.7% to 18.2% with a pooled event ratio of 9.8% (95% CI, 8.0-11.9)^{5-12,16-19,E43-E47} (Figure 2, B).

In the 9 studies reporting on stented elephant trunk, perioperative mortality ranged from 1.6% to 25.0%

with a pooled event ratio of 13.2% (95% CI, 7.8-21.4)^{15,E34,E35,E48-E53} (Figure 2, C).

Neurologic outcomes (Figures 3 and 4). Perioperative stroke, regardless of severity, ranged from 0.8% to 25.0% with a pooled event ratio of 6.9% (95% CI, 5.7-8.4). Stroke rates ranged from 0.8% to 18.8% in the debranching group (7.3%; 95% CI, 5.3-10), from 1.0% to 16.0% in the frozen elephant trunk group (6.2%; 95% CI, 4.8-8.0), and from 1.6% to 25.0% in the stented elephant trunk group (10.9%; 95% CI, 5.8-19.7) (Figure 3, A-C).

TABLE 1. Dissection

First author	Year	Dissection (N)	Total (N)	A	B	Acute	Thirty days or in hospital		
							Death	Stroke	Spinal ischemia
Baraki ⁵	2007	21	39	15	6	7	3	?	0
Chavan ⁶	2005	15	22	11	4	1	1	?	?
Chen ⁷	2010	28	28	28	0	27	4	3	3
Di Eusanio ⁸	2011	49	49	39	10	0	5	0	6
Fleck ⁹	2002	8	8	8	0	?	1	1	0
Gorlitzer ¹⁰	2007	5	7	4	1	3	0	1?	0
Ingrund ²	2010	9	12	3	6	9	1	0	0
Jakob 1 ¹¹	2008	22	22	22	0	22	2	2	0
Jakob 2 ¹²	2011	102	102	102	0	0	13	3	8
Jakob 3 ¹²	2011	88	88	88	0	88	16	5	5
Lu ¹³	2011	18	22	0	18	5	2	1	0
Ma ¹⁴	2011	24	24	?	?	?	0	0	0
Obitsu ¹⁵	2011	9	17	9	0	0	0	0	0
Shimamura 1 ¹⁶	2008	57	126	41	16	31	2	?	4
Shimamura 2 ¹⁷	2009	33	69	13	20	12	?	1	?
Sun ¹⁸	2011	291	291	291	0	148	9	7	7
Uchida ¹⁹	2006	35	35	35	0	35	2	0	0
Wang ²⁰	2008	14	20	0	14	?	1	1	0

TABLE 2. Debranching (group I)

First author	High risk	Emer.	R/P	Year	Years	Total	Debranching	M/F	Age	Dissection	Stage 1/2	Partial or Total	Zones 0, 1, 2
Bergeron ^{E21}	Yes, 48%	Yes, 15%	P	2006	2001-2005	29	29	23/6	NR	13	0/29	16/11	15, 10, 4
Canaud ^{E22}	Yes, 44	Yes, 27%	R	2010	1998-2008	44	10	NR	NR	NR	NR	4/6	6, 4, 24
Carrel ^{E23}	Yes, 6	?	R	2005	2001-2003	6	6	NR	NR	0	NR	1/5	5, 1, 0
Chan ^{E24}	Yes, 16	Yes, 7?	R	2008	2005-2007	16	16	13/3	65	6	16/0	9/5	5, 8, 3
Chen ^{E25}	No	Yes	R	2008	2005-2008	6	6	NR	NR	1	6/0	0/6	6, 0, 0
Chiesa ^{E26}	No	No?	R	2010	1999-2009	116	51	43/43	NR	21	NR	27/24	24, 27, 65
Ferrero ^{E27}	Yes, 40%	Yes	R	2011	2005-2010	27	27	22/5	71.6	4	NR	16/11	11, 4, 12
Geisbüsch ^{E28}	Yes, 47%	Yes, 34%	R	2011	1997-2009	47	47	33/14	64	15	50%?	32/15	10, 25, 12
Gelpi ^{E29}	Yes, 15	No	R	2010	2004-2009	15	15	12/3	70	2	0/15	NR	NR
Gottardi ^{E30}	Yes	No?	R	2008	1996-2007	73	60	34/15	NR	9	36/24	60/0	0, 36, 24
Weigang ^{E31}	Yes, 26	No	R	2009	NR	26	26	20/6	NR	6	1 st. prefer.	0/26	26, 0, 0
Ham ^{E32}	Yes	Yes	R	2011	2005-2011	NR	16	NR	NR	NR	NR	NR	NR
Holt ^{E33}	No	Yes	R	2010	2001-2009	78	39	NR	NR	NR	NR	16/23	9, 17, 13
Hughes 1 ^{E34}	No	Yes	R	2009	2005-2008	21	21	NR	NR	NR	21/0	0/21	12, 9, 0
Ingrund ²	No	Yes, 12	R	2010	2007-2009	12	12	6/6	54	9	NR	8/4	4, 8, 0
Lee ^{E35}	Yes, 86%	Yes, 5.4%	R	2011	2005-2009	37	37	23/14	63	13	0/37	NR	NR
Lu ¹³	No	Yes, 22%	R	2011	2001-2009	22	18	19/3	49	18	3/15	NR	1, 16, 11
Ma ¹⁴	No	?	R	2011	2005-2010	24	24	16/8	42	24	NR	NR	3, 10, 11
Murashita ^{E36}	Yes	No	R	2011	2007-2010	27	27	22/5	76	NR	NR	23/4	4, 19, 4
Obitsu ¹⁵	No	No	R	2011	1995-2008	25	25	NR	NR	0	22/3	20/5	NR
Saleh ^{E37}	Yes, 16	No	R	2007	2005-2007	16	16	12/4	67	0	0/16	0/16	16, 0, 0
Schumacher ^{E38}	Yes, 25	Yes, 32%	R	2006	1998-2006	25	25	20/5	65	2	9/16	16/9	9, 16, 0
Sueda ^{E39}	Yes	No	R	2003	NR	7	7	NR	NR	0	NR	5/2	NR
Szeto ^{E40}	Yes, 8	Yes, 2.5%	R	2007	2005-	8	8	7/1	67	1	8/0	0/8	NR
Vallejo ^{E41}	Yes	Yes	R	2011	2002-2011	38	38	27/11	65.4	20	24/14	11/27	20, 12, 8
Wang ²⁰	Yes, 20	Yes	R	2008	2002-2007	34	20	NR	NR	14	15/5	NR	4, 11, 5
Zhou ^{E42}	Yes, 31	No	R	2006	2004-2005	31	16	NR	NR	0	8/8	NR	11, 5, 0

Emer, Emergencies; R, retrospective; P, prospective; NR, not registered.

Perioperative spinal cord ischemia including permanent and transitory events ranged from 1.0% to 25.0% with a pooled event ratio of 6.8% (95% CI, 5.6-8.2). Rates

ranged from 1.0% to 14.3% in the debranching group (4.3%; 95% CI, 2.8-6.4), from 1.3% to 25.0% in the frozen elephant trunk group (7.9%; 95% CI, 6.3-9.9), and from

TABLE 3. Characteristics in frozen elephant trunk (group II)

First author	Year	Study years	Total (N)	FELT (N)	Age	M/F	R/P	High risk	Emergency	Dissection
Baraki ⁵	2007	2001-2006	39	39	62 y	M 24/F 15	R	No	No	21
Chavan ⁶	2005	?	22	22	64 y	M 13/F 9	P	No	No	15
Chen ⁷	2010	2004-2009	28	28	51.2 y	M 22/F 6	R	No	Yes, n 27	28
Fleck ⁹	2002	2001-2002	8	8	55 y	M 5/F 3	R	Emerg ?	Yes	8
Flores ^{E43}	2006	1996-2004	25	25	73 y	M 19/F 6	R	No	?	5
Di Eusanio ⁸	2011	2007-2010	49	49	59 y	M 43/F 6	R	No	No	49
Gorlitzer ¹⁰	2007	2005-2006	7	7	62 y	M 5/F 2	R	No	Yes	5
Jakob 1 ¹¹	2008	2001-2007	22	22	57 y	M 17/F 5	R	No	Yes	22
Jakob 2 ¹²	2011	2005-2010	102	102	57 y	M 82/F 20	P register	No	No	102
Jakob 3 ¹²	2011	2005-2010	88	88	59 y	M 68/F 20	P register	No	Yes, n 88	88
Jakob 4 ¹²	2011	2005-2010	84	84	66 y	M 54/F 20	P register	No	No	84
Miyairi ^{E44}	2002	1996-2000	19	19	69 y	M 15/F 4	R	No	No	2
Mizuno ^{E45}	2003	1996-2000	8	8	75 y	M 6/F 2	R	No	No	0
Sakurai ^{E46}	2006	1997-2001	23	23	70 y	M 21/F 2	R	Yes	No	1
Shimamura 1 ¹⁶	2008	1994-2004	126	126	67.8 y	M 86/F 40	R	No	Yes, n 37	57
Shimamura 2 ¹⁷	2009	2004-2007	69	69	66.2 y	M 55/F 14	R	No	Yes, n 13	33
Sun ¹⁸	2011	2003-2008	291	291	45 y	M 238/F 53	R	No	Yes, n 148	291
Uchida 1 ^{E47}	2010	1997-2008	58	58	73.9 y	M 52/F 6	R	Yes	?	0
Uchida 2 ¹⁹	2006	1997-2002	35	35	67.8 y	M 13/F 22	R	No	Yes, n 35	35

FELT, Frozen elephant trunk; R, retrospective; P, prospective; Emerg, emergency.

TABLE 4. Characteristics in stented elephant trunk (group III)

First author	Year	Study years	Total (N)	ET (N)	Age	M/F	R/P	High risk	Dissection	Emerg	Zone 0, 1, 2
Carroccio ^{E48}	2005	6 y	12	12	69	M 7/F 5	R	Yes, n 12	0	Yes 16%	
Greenberg ^{E49}	2005	2000-2004	22	22	73	M 11/F 11	R	Yes	4	Yes 4.5%	
Hughes ^{E34}	2009	2005-2008	7	7	?	?	R	No	?	Yes	0 = 3, 1 = ?, 2 = 4
Kawaharada ^{E50}	2009	2001-2007	31	31	70	M 24/F 7	R	No	4	No	
Kieffer ^{E51}	2005	1995-2003	16	16	73	M 14/F 2	R	No	0	No	0 = 10, 1 = 6, 2 = 0
Jim ^{E52}	2011	2005-2009	10	10	67,5	M 3/F 7	R	Yes, n 10	3	No	
Lee ^{E35}	2011	2005-2009	58	21	68	M 13/F 8	R	Yes, 86%	4	No	
Obitsu ¹⁵	2011	1995-2008	17	17	?	?	R	No	9	No	
Tse ^{E53}	2004	1999-2003	5	5	?	?	R	No	?	Yes	0 = 0, 1 = 3, 2 = 2

R, Retrospective; P, prospective; ET, elephant trunk; Emerg, emergency.

1.6% to 14.3% in the stented elephant trunk group (7.2%; 95% CI, 3.5-14.5) (Figure 4, A-C).

Dissections (Figure 5, A-C). For 828 patients operated on for aortic dissection (including types A and B, chronic, and acute), data on outcomes were available.^{2,5-20}

Characteristics of patients with dissections are shown in Table 1. In patients with aortic dissection, perioperative mortality from hybrid repair ranged from 0.0% to 14.3% with a pooled event ratio of 9.8% (95% CI, 7.7-12.4). Regarding periprocedural neurologic complications, stroke ranged from 0.0% to 12.5% with a pooled event ratio of

Perioperative mortality in debranching

A

FIGURE 2. Perioperative mortality in hybrid arch repair. A, Debranching technique. B, Frozen elephant trunk technique. C, Stented elephant trunk technique. CI, Confidence interval; ET, elephant trunk.

Perioperative mortality in frozen elephant trunk

B

Perioperative mortality in stented elephant trunk

C

FIGURE 2. (continued).

4.3% (95% CI, 3.0-6.3) and spinal cord ischemia ranged from 0.0% to 12.2% with a pooled event ratio of 5.8% (95% CI, 4.2-7.9).

Analyses by publication year. When breakdown of study by publication year (2007) was applied, pooled results showed no decreased mortality rates and a tendency for

Perioperative stroke in debranching

A

FIGURE 3. Perioperative stroke in hybrid arch repair. A, Debranching technique. B, Frozen elephant trunk technique. C, Stented elephant trunk technique. CI, Confidence interval; ET, elephant trunk.

lower neurologic complication in most recent series, but the numbers in each subgroup were smaller. In the 16 studies published before 2007, pooled mortality ratio was 11.4% (95% CI, 7.9-16.2), stroke 9.9% (95% CI, 6.4-15.1), and spinal cord ischemia 12.7% (95% CI, 8.7-18.4); in studies published since 2007, pooled ratios were 10.7% (95% CI, 8.1-12.5) for mortality, 6.4% (95% CI 5.2-7.9) for stroke, and 5.6% (95% CI 4.5-7.0) for spinal cord ischemia. Specifically for dissection cases, pooled mortality, stroke, and spinal ischemia rates were 7.2% (95% CI, 2.7-17.7), 5.8% (95% CI, 1.1-24.9), and 2.8% (95% CI, 4.0-17.2) in old studies and 10.0% (95% CI, 7.8-12.8), 4.2% (95% CI, 2.9-6.2), and 5.9% (95% CI, 4.3-8.1), respectively, in recent studies.

For debranching subgroups, pooled mortality, stroke, and spinal cord ischemia were 12.7%, 6.5%, and 5.1% in old studies and 11.8%, 7.4%, and 4.2% in recent

studies; for the frozen elephant trunk group, pooled mortality, stroke, and spinal cord ischemia were 8.5%, 8.8%, and 16.4% in older studies and 10%, 5.9%, and 6.3% in recent studies; for the stented subgroup, pooled mortality, stroke, and spinal cord ischemia were 15.8%, 18.8%, and 10.5% in older studies and 11.0%, 5.6%, and 4.4% in recent studies.

Analyses by volume. To assess whether higher volumes affected the results, we analyzed studies with low volume (<20) and those with larger volume (≥ 20) separately. Higher volume seemed to decrease the neurologic complication, especially stroke, but no mortality rates. Pooled ratios of mortality, stroke, and spinal cord ischemia were 11.4% (95% CI, 7.9-16.3), 11.2% (95% CI, 7.4-16.6), and 8.9% (95% CI, 5.6-13.8) in the 22 studies at low volume and 10.7% (95% CI, 9.1-12.5), 6.1% (95% CI, 5.0-7.6), and 6.4% (95% CI, 5.2-7.9), respectively, in

Perioperative stroke in frozen elephant trunk

B

Perioperative stroke in stented elephant trunk

C

FIGURE 3. (continued).

the remaining studies at higher volume. Specifically, in the dissection subgroup, pooled mortality stroke and spinal cord ischemia were 9.1% (95% CI, 4.4-17.9), 7.0% (95% CI, 2.7-17.3), and 4.6% (95% CI, 1.5-13.4) in low volume studies and 9.9% (95% CI, 7.7-12.7), 4.0%

(95% CI, 2.6-5.9), and 5.9% (95% CI, 4.3-8.1) in higher volume studies.

For the debranching subgroup, pooled mortality, stroke, and spinal cord ischemia were 10.2%, 9.6%, and 5.6% in low volume studies and 12.5%, 6.5%, and 3.8% in

Perioperative spinal cord ischemia in debranching

A

FIGURE 4. Perioperative spinal cord ischemia in hybrid arch repair. A, Debranching technique. B, Frozen elephant trunk technique. C, Stented elephant trunk technique. *CI*, Confidence interval; *ET*, elephant trunk.

higher volume studies; for the frozen elephant trunk group, pooled mortality, stroke, and spinal cord ischemia were 10.7%, 10.2%, and 18.2% in low volume studies and 9.8%, 6.1%, and 7.3% in higher volume centers; for the stented subgroup, pooled mortality, stroke, and spinal cord ischemia were 14.7%, 15.5%, and 6.2% in low volume studies and 11.3%, 5.4%, and 8.1% in higher volume centers.

When both the cutoff values (publication year and volume) were applied, similar results were achieved inasmuch as most old studies were at low volume.

Details for subgroup analyses by year and volume are provided in [Appendixes E1 and E2](#).

Zones (Figure 6, A-C). A secondary analysis was performed according to landing zone 0 versus 1 for hybrid arch procedures. For the present analysis, zones 2 or more were excluded. Data were available from 19 studies including 187 patients with landing zones 0 and 202 with landing zone 1.^{2,13,14,E21-E28,E30,E31,E33,E34,E36,E37,E41,E53}

Pooled perioperative mortality was 15.1% (95% CI, 10.3-21.5) for landing zone 0 and 7.6% (95% CI, 4.3-3.0) for landing zone 1, resulting in a significant higher risk for zone 0 (OR, 2.8; 95% CI, 1.17-6.7; $P = .021$; [Figure 6, A](#)).

Pooled perioperative stroke was 7.1% (95% CI, 4.1-12.2) for zone 0 and 10.8% (95% CI, 6.4-17.7) for zone 1, resulting in a nonsignificant difference between zones (OR, 0.45; 95% CI, 0.13-1.54; $P = .20$; [Figure 6, B](#)).

Pooled spinal cord ischemia was 6.5% (95% CI, 3.5-11.8) in zone 0 and 5.2% (95% CI, 2.7-9.8) in zone 1, resulting in a nonsignificant difference between zones (OR, 1.43; 95% CI, 0.32-6.47; $P = .63$; ([Figure 6, C](#)).

DISCUSSION

Although in the recent years hybrid repair appears to be an appealing procedure for the treatment of aortic arch diseases in selected patients, the technique has not been validated as a treatment option and this literature search did

Perioperative spinal cord ischemia in frozen elephant trunk

B

Perioperative spinal cord ischemia in stented elephant trunk

C

FIGURE 4. (continued).

not identify prospective randomized or large nonrandomized studies comparing hybrid arch procedures with other conventional or innovative treatment strategies for aortic arch repair.

This review specifically focused on outcomes of patients receiving hybrid arch repair for aortic dissection. As reported by pooled analysis of 17 studies^{2,5-20} hybrid arch procedures in dissected aorta can be performed with

mortality risks (ranging from 0.0% to 14.3% with a pooled event ratio of 9.8%) similar to other hybrid arch repairs but with relatively low periprocedural neurologic risks (pooled stroke incidence, 4.3%; pooled spinal cord ischemia incidence, 5.8%). High volume centers and more recent experiences may have influenced decreased stroke rates. These data may be even more relevant because they included high-risk patients and

Perioperative mortality in dissection

FIGURE 5. Perioperative results in hybrid arch repair for aortic dissection. A, Perioperative mortality. B, Perioperative stroke. C, Perioperative spinal cord ischemia. *CI*, Confidence interval.

emergency cases. Unfortunately, there were no detailed outcomes for type A/B dissection or chronic/acute cases, neither risk nor timing stratification to provide more detailed information.

Our analysis showed that the overall hybrid arch procedures were associated with about 10% periprocedural mortality and about 7% periprocedural risk of stroke or spinal cord ischemia. Mortality was not affected by increased volume center and time of experience, whereas neurologic complications were positively affected: in studies with fewer than 20 cases, pooled stroke rates of 11.2% and spinal cord ischemia rates of 8.9% were found, whereas in studies with larger case loads, the pooled rates were 6.1% for stroke and 6.4% for spinal cord ischemia. Similarly, pooled stroke and spinal cord ischemia rates were 9.9% and 12.7% in older studies while 6.4% and 5.6%, respectively, in studies published in 2007 or after. Furthermore, we measured all the spinal cord ischemia occurring in the periprocedural period (30 days or in-hospital) and included permanent and temporary events, thereby leading to potential overestimation of risks.

However, different techniques for different disease extension and patient settings have been used in hybrid arch repair, and the clinical outcomes have not always been separately reported, making it difficult to compare or pool the results across studies. To make results more comparable, we separately analyzed hybrid arch procedures (regardless of the aortic disease) consisting in aortic arch “debranching,” “frozen elephant trunk,” and “stented elephant trunk” using the classification suggested by Eagleton and Greenberg¹ and Szeto and Bavaria.^{E78} However, large heterogeneity still remained.

Our data on outcomes of hybrid arch repairs are in similar ranges of series published during the past 10 years for open arch repairs (references online only).^{E54-E60} Although better results have been published in selected experiences,^{E59,E60} open surgery for the aortic arch remains a very challenging procedure in many common centers.

From this review, the pooled stroke incidence during hybrid arch repair was not negligible but affected by volume and experience: in the debranching group the rates were 9.6% in low volume and 6.5% in high

Perioperative stroke in dissection **B****Perioperative spinal cord ischemia in dissection** **C**

FIGURE 5. (continued).

Perioperative mortality by zone

FIGURE 6. Perioperative results in hybrid repairs by landing zone (zone 0 vs zone 1) A, Perioperative mortality. B, Perioperative stroke. C, Perioperative spinal cord ischemia. *CI*, Confidence interval.

volume centers. In the frozen group, pooled stroke rates were 10.2% and 8.8% in low volume and older studies, whereas rates were 6.1% and 5.9% in higher volume and recent studies. Similarly, for stented elephant trunk, stroke rates of 15.5% and 18.8% were detected in low volume and old studies, and rates of 5.4% and 5.6% in higher volume and recent studies.

Similarly to other reviews that analyzed total versus partial debranching stroke risk,^{E76,E79} we stratified the results according to landing zones: our review confirmed 2.8 higher mortality risks for total debranching (landing zone 0) but did not show significant differences in the neurologic risks of stroke or spinal cord ischemia. Analyses by zone could not be stratified by year and volume because of the small numbers.

This review has several limitations. Although it is one of the largest reviews published to date regarding hybrid arch repair, the pooled results are weakened because of large heterogeneity in techniques and lack of standardization in reporting patients' specific data and end points. Even though data were separately extracted and analyzed by 3 different operative techniques, we were unable to perform detailed analyses on patients and technique risk stratification. Furthermore, we specifically focused the review on periprocedural clinical outcome and did not assess technical feasibility and long-term

results. However, feasibility data were indeed more inconsistently published across studies and pooled analysis would have provided limited information. Finally, some small sample size studies were included whereas a larger number of patients is needed to better identify statistically significant differences. However, breakdown of data by volume center was performed to exclude the smaller series from calculations.

In conclusion, hybrid repair of aortic arch disease presents a persistent high risk of perioperative mortality, comparable with open repair. However, rates of neurologic complications seem to have decreased with timing and center volume and may be low in dissection cases: 4.3% periprocedural stroke, 5.8% spinal cord ischemia. Hybrid arch repair involving the ascending aorta (zone 0) presents almost 3 times higher mortality than repair involving zone 1, although the incidence of neurologic complications may be similar.

Nevertheless, no reliable long-term data exist to ascertain the durability of the hybrid arch procedure, and contemporary conclusions are mainly provided from relatively small case series or retrospective studies. Further research is required to strengthen outcomes of this treatment, and ideally technologic improvements may be made in the next years to help to further improve the outcomes of aortic arch repair.

Perioperative stroke by zone

B

Perioperative spinal cord ischemia by zone

C

FIGURE 6. (continued).

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