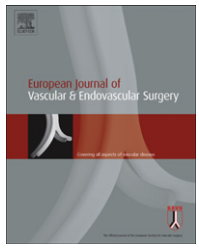
Eur J Vasc Endovasc Surg (2010) **39**, 683–690



REVIEW

Hybrid Treatment of Complex Aortic Arch Disease with Supra-aortic Debranching and Endovascular Stent Graft Repair

G.A. Antoniou [a], K. El Sakka [a], M. Hamady [b], J.H.N. Wolfe [a,*]

[a] *Regional Vascular Unit, St Mary's Hospital, Praed Street, Imperial College Healthcare NHS Trust, London W2 1NY, UK*
[b] *Department of Interventional Radiology, St Mary's Hospital, Praed Street, Imperial College Healthcare NHS Trust, London W2 1NY, UK*

Submitted 27 October 2009; accepted 3 February 2010
Available online 15 March 2010

KEYWORDS
Aortic arch;
Stent graft;
Hybrid procedure;
Aneurysm;
Endovascular treatment

Abstract *Background:* Aortic arch disease has conventionally been the domain of open surgical repair. Hybrid open and endovascular repair has evolved as an alternative, less invasive, treatment option with promising results. A systematic literature review and analysis of the reported outcomes was undertaken.
Methods: An Internet-based literature search using MEDLINE was performed to identify all studies reporting on hybrid aortic arch repair with supra-aortic branch revascularisation and subsequent stent graft deployment. Debranching should involve at least one carotid artery, so that patients merely requiring a carotid-subclavian bypass were not included. Only reports of five patients or more were included in the analysis. Outcome measures were technical success, perioperative, 30-day and late morbidity and mortality.
Results: Eighteen studies fulfilled our search criteria, and data from 195 patients were entered for the analysis. No comparative studies of hybrid aortic arch repair with other conventional or innovative treatment modalities were identified. Complete arch repair was performed in 122 patients (63%). The overall technical success rate was 86% (167/195). The most common reason for technical failure was endoleak (9%, 17/195). Overall perioperative morbidity and mortality rates were 21% (41/195) and 9% (18/195), respectively. The most common perioperative complication was stroke (7%, 14/195). Four aneurysm-related deaths were reported during follow-up (2%). No long-term data on hybrid aortic arch repair were identified.

* Corresponding author.
E-mail address: jwolfe@uk-consultants.co.uk (J.H.N. Wolfe).

doi:10.1016/j.ejvs.2010.02.002

Conclusions: Hybrid repair of complex aortic arch disease is an alternative treatment option with acceptable short-term results. Stroke remains a frequent complication and mortality rates are significant. Further research with large comparative studies and longer follow-up is required.

Conventional treatment of aortic arch disease consists of open surgical repair using cardiopulmonary bypass and deep hypothermic circulatory arrest. However, this major aortic reconstructive surgery is associated with significant morbidity and mortality, and these figures show little improvement despite considerable advances in operative techniques and perioperative management.[1–5] The need for less invasive strategies with less physiological insult and operative trauma has resulted in the evolvement of innovative endovascular techniques. This potentially broadens the application to higher-risk patients.

The introduction of endovascular stent graft technology has reached an evolutionary threshold for the treatment of complex aortic diseases. The aortic arch presents specific challenges to endovascular repair, which mainly arise from the involvement of the supra-aortic branches and the tight inner curve. Fenestrated and branched stent graft techniques have been reported; however, they are still at an experimental stage.[6–9] Hybrid repair, which constitutes a combination of open supra-aortic branch revascularisation and endovascular aortic repair, has increasingly evolved as an alternative option for selected patients, and promising results have been reported.[10–14] The aim of the present study was to perform a review of the operative strategies and a pooled analysis of the reported outcomes along with an evaluation and critical overview of this innovative method.

Methods

Search strategy

Searching was undertaken to identify all published studies reporting on hybrid open surgical and endovascular treatment of complex aortic arch disease. A public domain database (MEDLINE) was searched using a web-based search engine (PubMed) for articles published between January 1995 and July 2009. The keywords used were 'aortic arch' and 'endovascular', 'hybrid' or 'debranching'. Additionally, related articles suggested by the PubMed search engine and reviews on this area (hybrid treatment of aortic disease) were further searched for any additional relevant articles. A second-level search including manual evaluation of the reference lists of the retrieved articles was also undertaken in order to broaden our search. The literature search was confined to publications in the English language. The whole search strategy, including the literature search, study selection and data extraction, was performed independently by two authors.

Study selection

Studies considered for inclusion in the data synthesis and analysis fulfilled the following predefined criteria: (1) they reported on the combined open surgical and endovascular repair of aortic arch disease; (2) open repair preceded endovascular stent graft repair of the arch pathology and consisted of various types of supra-aortic debranching bypasses, which involved debranching of at least one carotid artery; (3) they included a case series of at least five patients treated with this method; and (4) they reported on the outcome as expressed by the technical success, morbidity and mortality figures. In heterogeneous groups, the outcome figures of the selected subgroup of patients having undergone the aforementioned treatment were to be clearly stated. Furthermore, studies reporting on hybrid aortic arch treatment using cardiac arrest and extracorporeal circulation were excluded from the analysis.

Data extraction, synthesis and analysis

Data abstracted from individual studies were: year of publication; number of patients treated; baseline demographic characteristics of the study population; type of aortic arch pathology; number of emergency procedures; landing zone for endograft placement; synchronous or metachronous open and endovascular procedures; type of aortic arch debranching; type of intra-operative neuromonitoring; technical success rate; perioperative, early and late mortality and morbidity; perioperative stroke rate; spinal cord ischaemia rate; and length of hospital stay as well as length of follow-up. Data retrieved from each paper were entered into a purpose-designed database using SPSS® 15 for Windows® (SPSS Inc, Chicago, IL, USA). Primary outcome measures were technical success and 30-day morbidity and mortality rates, whereas secondary outcome measures were short-term morbidity and mortality. Simple descriptive statistics were used to perform the pooled analysis and calculate the overall outcome measures. The 'reporting standards for endovascular aortic aneurysm repair' were used to define technical success and standardise reporting of deaths and complications.[15]

Results

Literature search results

The systematic review of the literature identified 79 original studies reporting on hybrid approaches for aortic arch repair, using revascularisation of the supra-aortic branches prior to endovascular stent graft repair. Of these, 37 were case reports and were, therefore, excluded from this study. Sixteen papers were considered ineligible because they contained mixed study groups and the outcome measures of the hybrid aortic arch repair group were not clearly stated. Furthermore, six articles were excluded because of the limited numbers of patients, and another two papers were

not entered in the analysis because they reported on hybrid arch repair using cardiopulmonary bypass. Eighteen studies fulfilled our defined inclusion criteria.[16–33] Of these, four were duplicate publications from the same centre and author team.[16–19] Only the most recent of these reports were used in the analysis.[16,17] Additionally, after a careful scrutiny of the selected literature, five studies were not included because they were thought to contain duplicate cases.[20–24] Finally, 11 studies remained for analysis.[16,17,25–33] The search strategy is depicted in Figure 1. All of these studies are retrospective or prospective case series.

Study characteristics and procedures

The selected articles report on 195 patients with complex aortic arch disease treated with hybrid supra-aortic extra-anatomic bypass or transposition and endovascular stent graft implantation. The baseline characteristics of these studies are presented in Table 1. Demographic characteristics and risk factors of the study populations are not demonstrated by all authors, even though the majority of them indicated the use of hybrid treatment when co-morbid risk factors precluded patients from conventional open surgical repair. Aortic arch pathology consisted of aneurysm in 112 cases, dissection in 29 cases, aortic ulcers in nine cases, pseudoaneurysm, atherosclerosis and hypoplastic aortic arch 1 case each, whereas it was not specified in 42 cases. The elective, urgent or emergency nature of the hybrid aortic arch repair is not stated by all authors. However, some studies report an emergency combined opened and endovascular procedure for aortic rupture in a significant proportion of their patients. Furthermore, there is controversy with regard to the simultaneous or metachronous surgical/endovascular procedures, with some authors performing the hybrid repair at a single stage and others preferring a two-stage repair.

The first part of the hybrid procedures consists of debranching of the supra-aortic vessels, in order to achieve an adequate proximal landing zone for successful stent graft placement and sealing. The supra-aortic branch revascularisation procedures can be broadly divided in two types, depending on whether the arch pathology encompasses all or some of the supra-aortic vessels: the complete and the partial arch repair, respectively. The total arch repair or rerouting is performed when the arch pathology extends to zone 0, and consists of revascularisation of the innominate, left carotid and, in some cases, the left subclavian artery by anastomosing a bifurcated or trifurcated graft to the anterior aspect of the ascending aorta. Partial arch repair or hemi-arch transposition is performed when the arch pathology involves the left carotid artery (zone 1), and may be subdivided into three types: the right carotid to left carotid bypass (with or without subsequent left carotid to left subclavian bypass), the autologous double transposition and the right carotid to left subclavian bypass with left carotid artery insertion. Complete arch repair was performed in 122 out of the 195 patients (63%), whereas partial arch repair was performed in 70 (36%). Revascularisation of the left subclavian artery was selectively performed in some cases (Table 1).

Outcome

The primary and secondary outcome measures of the individual studies are presented in Table 2. Technical success was defined as aortic debranching combined with successful endograft deployment with secure proximal and distal fixation, according to the reporting standards for endovascular aneurysm repair. The primary technical success rate ranged between 69% and 100% among the studies, with an overall mean of 86% (167/195). The most common reason for technical failure was type I or type III endoleak, which occurred in 17 cases (9%). Other causes of technical failure and their frequency are presented in Table 3. Conversion to

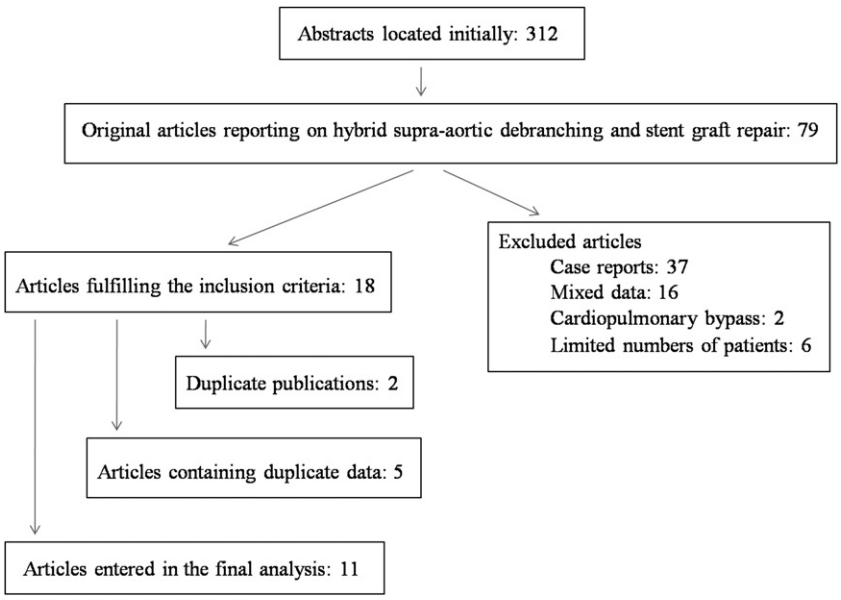


Figure 1 Search strategy.

Table 1 Study characteristics and types of procedures.

Author/year	No cases	M/F	Mean age	EL/UR/EM	Dissection/ aneurysm/ pseudoaneurysm/ ulcer/other	1—2 stage procedure	Landing zone 0/1/2	Type of debranching
Weigang et al. (2009)[25]	26	NR	NR	NR	6/15/0/5/0	1 stage preferred	26/0/0	Complete arch repair — 26
Chan et al. (2008)[26]	16	13/3	65	9/2/5	2/14/0/0/0	1 stage	5/8/3	Complete arch repair — 5, partial arch repair (C—C bypass) — 8 and (C—S bypass) — 3
Hughes et al. (2008)[27]	7	NR	NR	NR	2/5/0/0/0	1 stage	7/0/0	Complete arch repair — 7
Chen et al. (2008)[28]	6	NR	NR	2 ruptured	1/4/1/0/0	1 stage	6/0/0	Complete arch repair — 6
Melissano et al. (2007)[29]	26	22/4	NA	25/1/0	NA	1 stage	14/12/0	Complete arch repair — 14, partial arch repair (C—C bypass with 2 LSA revascularizations) — 12
Czerny et al. (2007)[30]	27	20/7	72	NR	5/18/0/4/0	2 stage	10/17/0	Complete arch repair — 10, partial arch repair (double transposition) — 17
Bergeron et al. (2006)[16]	25	21/4	72	NR	11/14/0/0/0	2 stage	15/10/0	Complete arch repair — 15, partial arch repair (C—C bypass) — 10
Saleh et al. (2006)[17]	15	9/6	74	3 symptomatic (pain)	0/15/0	2 stage	15/0/0	Complete arch repair — 15
Schumacher et al. (2006)[31]	25	20/5	65	8 contained rupture	2/23/0/0/0	2 stage in 16 patients (next day)	9/16/0	Complete arch repair — 9, partial arch repair (RCA—LSA bypass snd LCA insertion) — 16
Kieffer et al. (2005)[32]	16	14/2	73	NR	NR	NR	10/6/0	Complete arch repair — 10,[a] partial arch repair (RCCA to LSA bypass and reinsertion of the LCCA) — 6
Carrel et al. (2004)[33]	6	NR	NR	NR	0/4/0/0/2	NR	5/1/0	Complete arch repair — 5, partial arch repair (C—C bypass) — 1 (all LSA revascularization: either transposition or separate graft)

M, male; F, female; EL, elective; UR, urgent, EM, emergent; C, carotid; S, subclavian; RCA, right carotid artery; LSA, left subclavian artery; and NR, not reported.

[a] 1 extra-anatomic bypass from the iliac artery.

open surgical repair at the original operation or on a subsequent occasion is reported to have been performed in five cases (3%). The perioperative mortality rate ranged between 0% and 25%, with an overall mean of 9% (18/195). The most common causes of operative death were cardiac adverse events (3%), followed by stent graft-related complications, which occurred in five patients (3%) and were caused by ventricle, aortic or iliac rupture (Table 4). The perioperative morbidity rate, when strokes were exempted, ranged between 0% and 50%, with an overall mean of 14% (27/195). Stroke occurred in 14 patients (7%), which contributed to 34% of all complications. In most cases, it was reported to be a minor temporary event, whereas three stroke-related deaths occurred. Spinal cord ischaemia occurred in one patient only (0.5%), which resolved with cerebrospinal fluid drainage (Table 2). Other causes of perioperative morbidity are listed in Table 4.

No long-term data are provided by the studies. Short-term morbidity and mortality figures were reported in all but one study,[25] and the mean follow-up periods of the studies included in the analysis are presented in Table 2. Short-term mortality ranged between 0% and 19%, with an overall mean of 7% (11/169). Four aneurysm-related deaths were reported (two secondary to aneurysm rupture and two to aorto-oesophageal fistulae), whereas the other causes of death were cardiac events in two cases, pulmonary complications in three cases and sudden death of unknown aetiology in another case. Short-term morbidity figures ranged between 0% and 19%, with an overall mean of 8% (13/169). Most of these complications were associated with

Table 2 Outcome after hybrid aortic arch procedures.

Author/year	Technical success	Perioperative mortality	Perioperative morbidity[a]	Stroke rate	Spinal cord ischaemia	Short-term mortality	Late morbidity	Mean follow-up (m)
Weigang et al. (2009)[25]	26/26 (100%)	4/26 (15%)	5/26 (19%)	1/26 (4%)	0/26 (0%)	NR	NR	NR
Chan et al. (2008)[26]	13/16 (81%)	0/16 (0%)	8/16 (50%)	3/16 (19%)	0/16 (0%)	0/16 (0%)	3/16 (19%)	14
Hughes et al. (2008)[27]	7/7 (100%)	0/7 (0%)	1/7 (14%)	0/7 (0%)	0/7 (0%)	0/7 (0%)	1/7 (14%)	NR
Chen et al. (2008)[28]	6/6 (100%)	0/6 (0%)	0/6 (0%)	0/6 (0%)	0/6 (0%)	0/6 (0%)	0/6 (0%)	9
Melissano et al. (2007)[29]	21/26 (81%)	2/26 (8%)	1/26 (4%)	2/26 (8%)	0/26 (0%)	2/26 (8%)	2/26 (8%)	NR
Czerny et al. (2007)[30]	23/27 (85%)	1/27 (4%)	1/27 (4%)	0/27 (0%)	0/27 (0%)	3/27 (11%)	1/27 (4%)	15
Bergeron et al. (2006)[16]	19/25 (76%)	2/25 (8%)	0/25 (0%)	3/25 (12%)	1/25 (4%)	1/25 (4%)	2/25 (8%)	15
Saleh et al. (2006)[17]	15/15 (100%)	0/15 (0%)	4/15 (27%)	0/15 (0%)	0/15 (0%)	1/15 (7%)	1/15 (7%)	18
Schumacher et al. (2006)[31]	21/25 (84%)	5/25 (20%)	6/25 (24%)	1/25 (4%)	0/25 (0%)	1/25 (4%)	0/25 (0%)	21
Kieffer et al. (2005)[32]	11/16 (69%)	4/16 (25%)	1/16 (6%)	4/16 (25%)	0/16 (0%)	3/16 (19%)	3/16 (19%)	23
Carrel et al. (2004)[33]	5/6 (83%)	0/6 (0%)	0/6 (0%)	0/6 (0%)	0/6 (0%)	0/6 (0%)	0/6 (0%)	Between 8 and 18 m
Total	167/195 (86%)	18/195 (9%)	27/195 (14%)	14/195 (7%)	1/195 (0.5%)	11/169 (7%)	13/169 (8%)	

m, Months; and NR, not reported.
[a] Stroke exempted.

an endoleak (4/169, 2%), which was managed conservatively in two cases of type II endoleak, with coil embolisation in one case of left subclavian artery-related type II endoleak, and with an extension endograft in one case of type I endoleak.

Discussion

Although hybrid repair appears to be an appealing concept for the treatment of aortic arch disease in selected patients, it has not yet been validated as a treatment option. Search of the pertinent literature found that, since the first description of revascularisation of the left carotid and subclavian artery from the ascending aorta prior to stent grafting,[34] only case reports and small case series have been published. No comparative randomised or non-randomised studies of combined open debranching and endovascular procedures with other conventional or innovative treatment strategies for aortic arch repair have been identified. Furthermore, the longest mean follow-up period reported was 23 months, and no long-term data supporting the durability of this method exist. Therefore, conclusions about the long-term efficacy of this treatment cannot be reached.

Table 3 Reasons of technical failure.

Reasons of technical failure	Frequency
Endoleak (type I or III)[a]	17/195 (9%)
Ventricle/aortic/iliac perforation	4/195 (2%)
Haemorrhage	3/195 (1.5%)
Graft migration and aortic occlusion	1/195 (0.5%)
Aortic dissection	1/195 (0.5%)
Endograft-induced brachiocephalic occlusion	1/195 (0.5%)
Short endoprosthesis	1/195 (0.5%)
Total	28/195 (14%)

[a] One type II endoleak from left subclavian artery treated with coil embolization.

Most authors of the selected papers advocate that hybrid aortic arch repair was reserved for high-risk surgical patients, unsuitable for conventional treatment. Application of this method in urgent or even emergency cases with ruptured aneurysm has also been described.[35] Clear indications and the exact role of hybrid repair in the armamentarium of vascular and cardiovascular interventionalists have not been defined. It may be sensible to resort to hybrid repair in patients who are unfit for open repair when morphological anatomic features are fulfilled, but the evidence for this is currently lacking. Morphological prerequisites include adequate length of normal ascending aorta to accommodate the bypass graft, normal diameter ascending aorta to provide adequate landing zone, sufficient aortic valve function and undiseased iliac arteries. Various techniques have been invented to circumvent some of these anatomic limitations. Antegrade graft deployment approach has been described, allowing stent graft navigation through tight arches and avoiding diseased iliac

Table 4 Perioperative morbidity and mortality.

Causes of perioperative mortality	Frequency	Causes of perioperative morbidity	Frequency
Cardiac adverse events	6/195 (3%)	Stroke	14/195 (7%)
Stent graft-related complications	5/195 (3%)	Cardiac complications	9/195 (5%)
Stroke	3/195 (2%)	Pulmonary complications	8/195 (4%)
Pulmonary complications	2/195 (1%)	Renal failure	2/195 (1%)
Not specified	2/195 (1%)	Left hand ischaemia	1/195 (0.5%)
		Bypass graft infection	1/195 (0.5%)
		Aortic dissection	1/195 (0.5%)
		Other	5/195 (3%)
Total	18/195 (9%)	Total	41/195 (21%)

arteries.[25,36] Furthermore, an external banding technique has been proposed in order to create appropriate proximal landing zone, extending the therapeutic applications of hybrid repair.[28,37]

Sound knowledge of the arch pathology achieved with good-quality computed tomography (CT) angiography is of paramount importance. Classification of the thoracic aortic landing zones determines the type of supra-aortic debranching.[12] Several types of revascularisation include total and partial arch repair. Retrograde extra-anatomic bypass from the iliac to the innominate artery has also been described.[12,38] Landing zone 1 stent grafting after previous carotid–carotid bypass has even been performed under local anaesthesia in a high surgical risk patient.[39] Even though the selected papers are restricted by the relatively short follow-up, extra-anatomic arch reconstruction performed has been reported to have good long-term results.[40] Prophylactic revascularisation of the left subclavian artery was selectively performed. Most authors proposed additional transposition or bypass in those patients having previously undergone coronary artery bypass grafting with patent left internal mammary arteries, when the right vertebral artery was occluded or in a diseased vertabro-basilar system. It is also suggested that the adequacy of the contralateral vertebral flow as well as the intracranial circulation has to be assessed preoperatively with ultrasound (US) and CT imaging. Controversy exists with regard to the synchronous or sequential open and endovascular repair, with some authors suggesting two-stage stent grafting in the endovascular suite where imaging facilities are better, with additional avoidance of long operating times. Others, however, argue that with a single-stage procedure, problems with the supra-aortic grafts following stenting can be rectified or open surgical treatment performed.[26]

Our analysis has shown that hybrid procedures were associated with a relatively high primary failure rate. Most failures were associated with type I or type III endoleak, which, in most cases, was successfully managed with extension grafts. The other causes of primary failure were major technical adverse events that required conversion to open surgery, sometimes resulting in death. The overall perioperative mortality and morbidity rates seem to be similar to those associated with open repair. Open surgical repair of aortic arch aneurysms involving the supra-aortic branches usually requires cardiopulmonary bypass and deep hypothermic circulatory arrest. Aside from significant mortality, these procedures are associated with high frequency of transient or permanent neurological deficits. In an attempt to minimise neurological complications, several strategies have been developed, including antegrade or retrograde cerebral perfusion and 'arch first repairs'. Furthermore, effort has been made to assess different cannulation sites. Numerous published studies reporting results of open aortic arch repair, with or without cerebral protection, exist. The largest (more than 50 patients) recent series were selected for comparison with hybrid aortic arch repair (Table 5).[1–3,41–43] Perioperative mortality in these series ranged between 3% and 20%, whereas the incidence of temporary or permanent neurological deficit ranged between 3% and 17%. Based on recently published large series, the mean perioperative stroke/death rate after open surgical repair was 17.5%, as opposed to a figure of 16.4% found from our analysis.[16] In an article evaluating various operative strategies for the ascending aorta and the aortic arch, mortality and stroke rates between 0% and 16.5% and 2% and 18%, respectively, were reported to be associated with open surgical techniques.[11] However, direct comparisons between conventional open and hybrid repairs are very difficult, as the former involve heterogeneous groups with different operative techniques and methods of intraoperative cerebral perfusion. Additionally, such comparisons between the outcomes of conventional open and hybrid repair should be cautious, because high-risk surgical patients with significant co-morbidities were usually excluded from open repair. Further refinement of stent graft technology and increasing experience with endovascular techniques might reduce both technical failure and stent-graft-related mortality figures.

As the reported outcomes with regard to technical success, morbidity and mortality were conflicting, and in an effort to extract uniform reporting results from the papers selected for analysis, recommended standards for endovascular aortic aneurysm repair were used.[15] Furthermore, no uniform inclusion criteria and indications for hybrid treatment nor risk stratification systems were used by the authors of the selected articles. One cannot objectively compare the series, as the demographic characteristics and the risk factors of the study populations are rarely listed. Another limitation of the present study is that in 42 out of the 195 cases the pathology treated is not known. Furthermore, the elective, urgent or emergency nature of the hybrid procedures is not reported by many authors. Because of the lack of this data, the outcomes of the pooled analysis should be approached with caution.

Table 5 Outcome after open repair of aortic arch disease.

Author	Year	No patients	Mean age	EL/EM	Perioperative mortality	Stroke rate	Comments
Strauch et al.[41]	2005	120	61	NR	13%	8%[a]	HEC + selective cerebral perfusion via axillary artery in 49 patients
Matalanis et al.[3]	2003	62	65	39/23	8%	15%[b]	HEC + antegrade or retrograde cerebral perfusion in 48 patients
Nakai et al.[42]	2002	109	72	94/15	15%	17%[a]	HEC + antegrade or retrograde cerebral perfusion
Kikuchi et al.[43]	2002	60	70	52/8	3%	3%[b]	HEC + selective cerebral perfusion in 56 patients
Jacobs et al.[2]	2001	50	47	50/0	6%	10%[b]	HEC + antegrade cerebral perfusion and moderate hypothermia
Okita et al.[1]	1999	246	67	215/31	20%	11%[a]	Selective cerebral perfusion in 112 patients, partial bypass in 58 patients, HEC + retrograde cerebral perfusion in 76 patients

EL, elective; EM, emergency; HEC, hypothermic extracorporeal circulation; and NR, not reported.
[a] Permanent neurological dysfunction.
[b] Temporary or permanent neurological dysfunction.

Conclusions

Hybrid repair of complex aortic arch disease with revascularisation of the supra-aortic branches prior to stent graft deployment has evolved as an alternative treatment option for selected patients who are high surgical risk for conventional open repair. Acceptable results expressed by primary technical success, mortality and morbidity rates can be achieved, even though stroke remains a significant problem. However, no long-term data exist to ascertain the durability of this method, and contemporary conclusions are based on relatively small case series. Further research with large comparative studies is required to consolidate the outcomes of this treatment and define its role in the management of aortic arch disease.

Ethical approval for research

None.

Conflict of Interest

None.

Funding

None.

References

1 Okita Y, Ando M, Minatoya K, Kitamura S, Takamoto S, Nakajima N. Predictive factors for mortality and cerebral complications in arteriosclerotic aneurysm of the aortic arch. *Ann Thorac Surg* 1999;**67**(1):72—8.

2 Jacobs MJ, de Mol BA, Veldman DJ. Aortic arch and proximal supraaortic arterial repair under continuous antegrade cerebral perfusion and moderate hypothermia. *Cardiovasc Surg* 2001; **9**(4):396—402.

3 Matalanis G, Hata M, Buxton BF. A retrospective comparative study of deep hypothermic circulatory arrest, retrograde, and antegrade cerebral perfusion in aortic arch surgery. *Ann Thorac Cardiovasc Surg* 2003;**9**(3):174—9.

4 Harrington DK, Walker AS, Kaukuntla H, Bracewell RM, Clutton-Brock TH, Faroqui M, et al. Selective antegrade cerebral perfusion attenuates brain metabolic deficit in aortic arch surgery: a prospective randomized trial. *Circulation* 2004; **110**(11 Suppl. 1):II231—II236.

5 Strauch JT, Spielvogel D, Lauten A, Galla JD, Lansman SL, McMurtry K, et al. Technical advances in total aortic arch replacement. *Ann Thorac Surg* 2004;**77**(2):581—9.

6 Kawaguchi S, Yokoi Y, Shimazaki T, Koide K, Matsumoto M, Shigematsu H. Thoracic endovascular aneurysm repair in Japan: experience with fenestrated stent grafts in the treatment of distal arch aneurysms. *J Vasc Surg* 2008;**48**(6 Suppl.):24S—29S.

7 Saito N, Kimura T, Odashiro K, Toma M, Nobuyoshi M, Ueno K, et al. Feasibility of the Inoue single-branched stent-graft implantation for thoracic aortic aneurysm or dissection involving the left subclavian artery: short- to medium-term results in 17 patients. *J Vasc Surg* 2005;**41**(2):206—12.

8 Chuter TA, Schneider DB, Reilly LM, Lobo EP, Messina LM. Modular branched stent graft for endovascular repair of aortic arch aneurysm and dissection. *J Vasc Surg* 2003;**38**(4):859—63.

9 Inoue K, Hosokawa H, Iwase T, Sato M, Yoshida Y, Ueno K, et al. Aortic arch reconstruction by transluminally placed endovascular branched stent graft. *Circulation* 1999;**100**(19 Suppl.):II316—II321.

10 Kpodonu J, Diethrich EB. Hybrid interventions for the treatment of the complex aortic arch. *Perspect Vasc Surg Endovasc Ther* 2007;**19**(2):174—84.

11 Moon MC, Morales JP, Greenberg RK. The aortic arch and ascending aorta: are they within the endovascular realm? *Semin Vasc Surg* 2007;**20**(2):97—107.

12 Criado FJ, Barnatan MF, Rizk Y, Clark NS, Wang CF. Technical strategies to expand stent-graft applicability in the aortic arch

and proximal descending thoracic aorta. *J Endovasc Ther* 2002; **9**(Suppl. 2):II32—II38.
13 Schoder M, Lammer J, Czerny M. Endovascular aortic arch repair: hopes and certainties. *Eur J Vasc Endovasc Surg* 2009; **38**(3):255—61.
14 Brinkman WT, Szeto WY, Bavaria JE. Stent graft treatment for transverse arch and descending thoracic aorta aneurysms. *Curr Opin Cardiol* 2007;**22**(6):510—6.
15 Chaikof EL, Blankensteijn JD, Harris PL, White GH, Zarins CK, Bernhard VM, et al. Ad hoc Committee for Standardized Reporting Practices in Vascular Surgery of The Society for Vascular Surgery/American Association for Vascular Surgery. Reporting standards for endovascular aortic aneurysm repair. *J Vasc Surg* 2002 May;**35**(5):1048—60.
16 Bergeron P, Mangialardi N, Costa P, Coulon P, Douillez V, Serreo E, et al. Great vessel management for endovascular exclusion of aortic arch aneurysms and dissections. *Eur J Vasc Endovasc Surg* 2006;**32**(1):38—45.
17 Saleh HM, Inglese L. Combined surgical and endovascular treatment of aortic arch aneurysms. *J Vasc Surg* 2006;**44**(3):460—6.
18 Bergeron P, Coulon P, De Chaumaray T, Ruiz M, Mariotti F, Gay J, et al. Great vessels transposition and aortic arch exclusion. *J Cardiovasc Surg (Torino)* 2005;**46**(2):141—7.
19 Saleh HM. Hybrid repair of aortic arch aneurysm. *Acta Chir Belg* 2007;**107**(2):173—80.
20 Czerny M, Zimpfer D, Fleck T, Hofmann W, Schoder M, Cejna M, et al. Initial results after combined repair of aortic arch aneurysms by sequential transposition of the supra-aortic branches and consecutive endovascular stent-graft placement. *Ann Thorac Surg* 2004;**78**(4):1256—60.
21 Gottardi R, Funovics M, Eggers N, Hirner A, Dorfmeister M, Holfeld J, et al. Supra-aortic transposition for combined vascular and endovascular repair of aortic arch pathology. *Ann Thorac Surg* 2008;**86**(5):1524—9.
22 Czerny M, Gottardi R, Zimpfer D, Schoder M, Grabenwoger M, Lammer J, et al. Transposition of the supraaortic branches for extended endovascular arch repair. *Eur J Cardiothorac Surg* 2006;**29**(5):709—13.
23 Melissano G, Civilini E, Bertoglio L, Setacci F, Chiesa R. Endovascular treatment of aortic arch aneurysms. *Eur J Vasc Endovasc Surg* 2005;**29**(2):131—8.
24 Schumacher H, Böckler D, Bardenheuer H, Hansmann J, Allenberg JR. Endovascular aortic arch reconstruction with supra-aortic transposition for symptomatic contained rupture and dissection: early experience in 8 high-risk patients. *J Endovasc Ther* 2003;**10**(6):1066—74.
25 Weigang E, Parker J, Czerny M, Peivandi AA, Dorweiler B, Beyersdorf F, et al. Endovascular aortic arch repair after aortic arch de-branching. *Ann Thorac Surg* 2009;**87**(2):603—7.
26 Chan YC, Cheng SW, Ting AC, Ho P. Supra-aortic hybrid endovascular procedures for complex thoracic aortic disease: single center early to midterm results. *J Vasc Surg* 2008; **48**(3):571—9.
27 Hughes GC, Nienaber JJ, Bush EL, Daneshmand MA, McCann RL. Use of custom Dacron branch grafts for ''hybrid'' aortic debranching during endovascular repair of thoracic and thoracoabdominal aortic aneurysms. *J Thorac Cardiovasc Surg* 2008; **136**(1):21—8. e1—e6.
28 Chen IM, Wu FY, Shih CC. Banding technique for endovascular repair of arch aneurysm with unsuitable proximal landing zone. *Circ J* 2008;**72**(12):1981—5.
29 Melissano G, Civilini E, Bertoglio L, Calliari F, Setacci F, Calori G, et al. Results of endografting of the aortic arch in different landing zones. *Eur J Vasc Endovasc Surg* 2007;**33**(5):561—6.
30 Czerny M, Gottardi R, Zimpfer D, Schoder M, Grabenwoger M, Lammer J, et al. Mid-term results of supraaortic transpositions for extended endovascular repair of aortic arch pathologies. *Eur J Cardiothorac Surg* 2007;**31**(4):623—7.
31 Schumacher H, Von Tengg-Kobligk H, Ostovic M, Henninger V, Ockert S, Böckler D, et al. Hybrid aortic procedures for endoluminal arch replacement in thoracic aneurysms and type B dissections. *J Cardiovasc Surg (Torino)* 2006;**47**(5):509—17.
32 Kieffer E, Koskas F, Ph Cluzel, Benhamou A, Chiche L. Endoluminal repair of the aortic arch combined with revascularization of supra-aortic arteries. In: Branchereau A, Jacobs M, editors. *EVC 2004 hybrid vascular procedures*. Malden, MA: Blackwell Publishing; 2005. p. 75—84.
33 Carrel TP, Do DD, Triller J, Schmidli J. A less invasive approach to completely repair the aortic arch. *Ann Thorac Surg* 2005; **80**(4):1475—8.
34 Buth J, Penn O, Tielbeek A, Mersman M. Combined approach to stent-graft treatment of an aortic arch aneurysm. *J Endovasc Surg* 1998;**5**(4):329—32.
35 Drenth DJ, Verhoeven EL, Prins TR, Waterbolk TW, Boonstra PW. Relocation of supra-aortic vessels to facilitate endovascular treatment of a ruptured aortic arch aneurysm. *J Thorac Cardiovasc Surg* 2003;**126**(4):1184—5.
36 Zhou W, Reardon ME, Peden EK, Lin PH, Bush RL, Lumsden AB. Endovascular repair of a proximal aortic arch aneurysm: a novel approach of supra-aortic debranching with antegrade endograft deployment via an anterior thoracotomy approach. *J Vasc Surg* 2006;**43**(5):1045—8.
37 Antona C, Vanelli P, Petullà M, Gelpi G, Danna P, Lemma M, et al. Hybrid technique for total arch repair: aortic neck reshaping for endovascular-graft fixation. *Ann Thorac Surg* 2007;**83**(3):1158—61.
38 Criado FJ, Clark NS, Barnatan MF. Stent graft repair in the aortic arch and descending thoracic aorta: a 4-year experience. *J Vasc Surg* 2002;**36**(6):1121—8.
39 Siniscalchi G, Tozzi P, Ferrari E, Delay D, Ruchat P, von Segesser L. Endovascular repair of aortic arch aneurysm after achievement of local anesthesia. *J Thorac Cardiovasc Surg* 2007;**133**(1):262—3.
40 Byrne J, Darling 3rd RC, Roddy SP, Mehta M, Paty PS, Kreienberg PB, et al. Long term outcome for extra-anatomic arch reconstruction. An analysis of 143 procedures. *Eur J Vasc Endovasc Surg* 2007;**34**(4):444—50.
41 Strauch JT, Böhme Y, Franke UF, Wittwer T, Madershahian N, Wahlers T. Selective cerebral perfusion via right axillary artery direct cannulation for aortic arch surgery. *Thorac Cardiovasc Surg* 2005;**53**(6):334—40.
42 Nakai M, Shimamoto M, Yamazaki F, Fujita S, Aoyama A, Chin T, et al. Long-term results after surgery for aortic arch non-dissection aneurysm. *Kyobu Geka* 2002;**55**(4):280—4.
43 Kikuchi Y, Sakurada T, Hirano T, Suzuki M, Kusajima K. Long-term results of the operation for the aortic arch aneurysm. *Kyobu Geka* 2002;**55**(4):309—13.