Original Article

Clinical outcomes of the type II hybrid procedure for the repair of extensive aortic arch pathology

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Background: Type II hybrid arch repair (HAR) has been used for the repair of extensive aortic arch pathology. The aim of this study was to retrospectively analyze single-stage hybrid treatment involving replacement of the ascending aorta, arch debranching, and zone 0 stent graft deployment.

Methods: We retrospectively analyzed clinical data from 41 patients with acute and chronic aortic disease who underwent a type II hybrid arch procedure at Beijing Anzhen Hospital and Beijing Chaoyang Hospital from January 2020 to August 2022. The femoral arteries and right axillary arteries were used as cannulation sites to decrease the risk of malperfusion. During surgery, the nasopharyngeal temperature was lowered to 30 ℃. Demographic, perioperative, and late results data were retrieved and analyzed.

Results: The mean age of the patients was 54.9±11.1 years, and 31 patients (75.6%) were men. In all cases, zone 0 stent graft deployment was successful, with no in-hospital mortality. The median follow-up time was 10.5 [interquartile range (IQR), 4.8–17.6] months, and the survival rate was 94.9% during follow-up. Complications included cerebral infarction (3 patients, 7.3%) and renal failure requiring dialysis (3 patients, 7.3%). There were no occurrences of paraplegia, and no stent-related complications occurred during the follow-up period.

Conclusions: The single-stage hybrid arch procedure achieved satisfactory early results and represents a less invasive approach for treating complex diffuse aortic disease that affects the arch. This strategy is an important technical advance in the treatment of high-risk patients with extensive aortic arch pathology.

Keywords: Debranching; hybrid arch repair (HAR); thoracic endovascular aortic repair (TEVAR); aortic arch pathology

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Introduction

Advances in intensive care management and surgery have improved the outcomes of total aortic arch repair (TAR) (1). However, owing to the nature and extent of surgery, this approach is associated with significant morbidity and a 4–20% 30-day mortality (2), with individual high-volume aortic centers consistently reporting mortality rates higher than 10% (3). Meanwhile, the rate of permanent neurological deficit is 4–12% (4).

Type II hybrid arch repair (HAR) combines non-circulation arrest endovascular total arch exclusion and open ascending aortic replacement with arch vessel debranching (5). Type II HAR has been used for many types of aortic disease, including aortic arch disease and descending and ascending aorta pathologies, particularly for patients previously denied surgery due to comorbidities (6).

Previous studies reported that type II HAR can decrease the rates of morbidity and mortality (7,8). Theoretically, this procedure minimizes bleeding during arch replacement due to better anatomical excess in zone 0. In addition, type II HAR reduces the risk of stroke, as the procedure ensures continuous blood flow to the brain during the operation, negates the need of additional cannulation for assisted cerebral perfusion. However, previous study has shown that the incidence of early mortality after type II HAR is equal to that of conventional arch repair (7). In this paper, we report our institutional experience with type II HAR for patients with extensive aortic arch pathology. We present this article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-586/rc).

Highlight box

Key findings

- Extensive aortic arch pathology repair using type II hybrid arch procedure leads to favorable early outcomes in patients with acute and chronic aortic disease.

What is known and what is new?

- To minimize the morbidity and mortality associated with total aortic arch repair, type II hybrid arch repair (HAR) have been developed to perform arch replacement by using endovascular technology.
- On the basis of our experience with type II HAR, we suggest that rerouting the neck vessels on the proximal ascending aorta and creating a proximal landing zone enables better control of the distal lesion, thereby preventing or effectively managing occurrence of dissected aneurysm in the descending aorta via a low-risk procedure.

What is the implication, and what should change now?

- Type II HAR is a less invasive approach for treating complex diffuse aortic disease affecting the arch, providing satisfactory early results, and representing a significant technical advancement for high-risk patients with extensive arch pathology.

Methods

Patient selection

This investigation was a two-center, retrospective, observational cohort study, and the Ethics Committee of Beijing Anzhen Hospital approved the use of clinical data (Institutional Review Board File No. 2014019). Beijing Chaoyang Hospital was informed and agreed the study. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Written informed consent was obtained from all patients enrolled in the study.

From January 2020 to August 2022, in Beijing Anzhen Hospital and Beijing Chaoyang Hospital, we enrolled consecutive patients who underwent the type II HAR procedure involving replacement of the ascending aorta, complete debranching, and thoracic endovascular aortic repair (TEVAR; in zone 0) (*Figure 1*). The surgical indications used for the type II HAR were the following: (I) type A aortic dissection (TAAD) involving the aortic arch or the descending aorta regardless of the location of the intimal tear; (II) type A aortic intramural hematoma (TAIMH) extending beyond the distal arch and ascending aorta diameter by ≥50 mm or a hematoma thickness ≥10 mm; and (III) thoracic aortic aneurysm (TAA) concomitant with type B aortic dissection (TBAD), type B aortic intramural hematoma (TBIMH), or penetrating aortic ulcer (PAU) with an ascending aortic diameter ≥42 mm or atheroma grades 3 or 4 in the ascending aorta (9). The exclusion criteria are as follows: (I) genetic diseases such as Marfan's syndrome, autoimmune diseases such as arteritis and Behcet's disease; (II) total aortic arch replacement or stented elephant trunk surgery combined with thoracic aortic stent implantation (type III hybrid aortic surgery) (*Figure 2*).

All criteria utilized in surgical planning were considered as relative factors rather than absolute indications or contraindications for either open surgery or hybrid assistive technology. In our center, the choice of procedure was based on the patient's preoperative status, frailty, the extent of the aortic pathology treated, and the risk of hypothermic

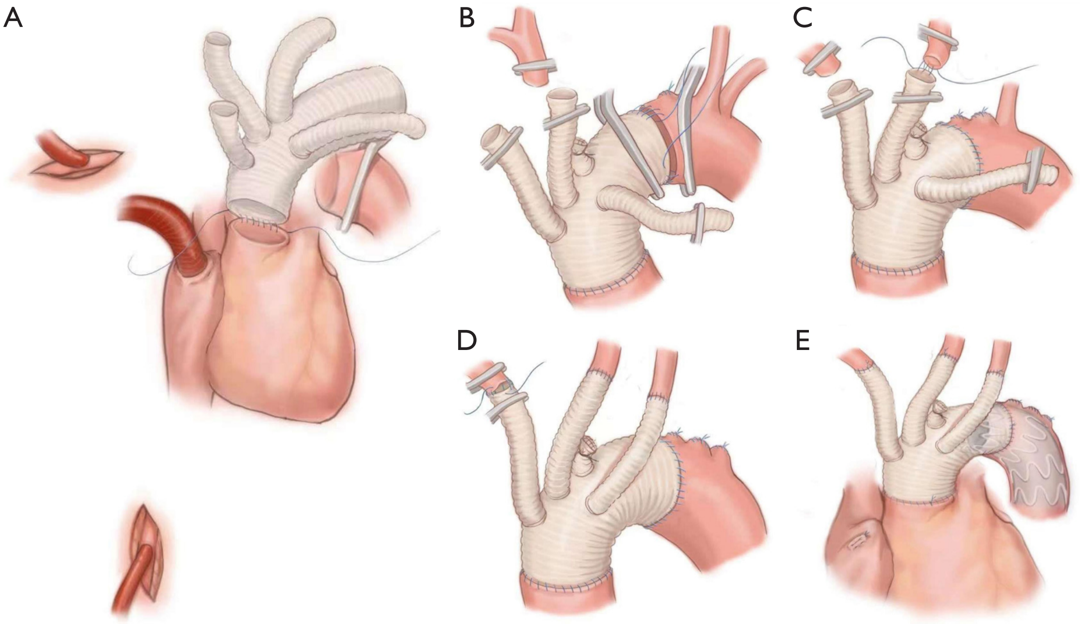

Figure 1 Type II hybrid procedures. (A) The right axillary and femoral arteries are both used as cannulation sites, and a two-stage cannula is inserted into the right atrium for venous drainage. A four-branched prosthesis graft is anastomosed to the sinotubular junction to replace the ascending aorta. (B) The arch is transected between the innominate artery and the left common carotid artery. The distal end of the four-branched graft is sutured end-to-end to the aortic arch. (C) The branches of the artificial vessel are sequentially anastomosed with the left common carotid artery, left subclavian artery, and innominate artery. (D) The left subclavian is sutured to the perfusion branch of the four-branched graft, and the two branches near the aortic root are sutured to the left common carotid and innominate arteries, respectively. (E) The endograft is passed in retrograde fashion through the incision of the original femoral cannulation. Its proximal end is anchored to the prosthetic graft to complete the arch repair.

circulatory arrest, which was assessed by the surgeons. Finally, 41 patients who were deemed unfit for open surgical replacement of the aortic arch were included for analysis and divided into three groups: (I) TAAD group; (II) TAIMH group; and (III) TAA with TBAD/TBIMH/PAU group.

Data collection

Collected variables were categorized as follows: (I) preoperative (age, sex, body mass index, euroSCORE, hypertension, chronic obstructive pulmonary disease, diabetes, coronary heart disease, cerebrovascular disease, peripheral arterial disease, smoking, history of cardiac surgery, history of TEVAR, history of percutaneous coronary intervention, malperfusion (cardiac, renal, lower limb, cerebral, and visceral), left ventricular ejection fraction, ascending aorta diameter, aortic regurgitation, and pericardial effusion); (II) intraoperative (operation time, cardiopulmonary bypass time, aortic cross clamp time, lowest nasopharyngeal and rectal temperature, concomitant procedures, red blood cell infusion, and plasma infusion); and (III) postoperative outcomes (intensive care unit time, ventilator time, postoperative hospital stay, in-hospital death, stroke, paraplegia, dialysis, arrhythmia, pulmonary infection, respiratory failure, incision complication, secondary thoracotomy, septicemia, reintubation, and tracheotomy).

Surgical management

Figure 1 shows the surgical procedure. The nasopharyngeal temperature was lowered to 30 ℃ for all patients. Both the right axillary and femoral arteries were utilized as cannulation sites in this procedure to reduce the likelihood of malperfusion during the operation. A two-stage cannula was inserted into the right atrium for venous drainage. Cardiopulmonary bypass was then initiated, and the

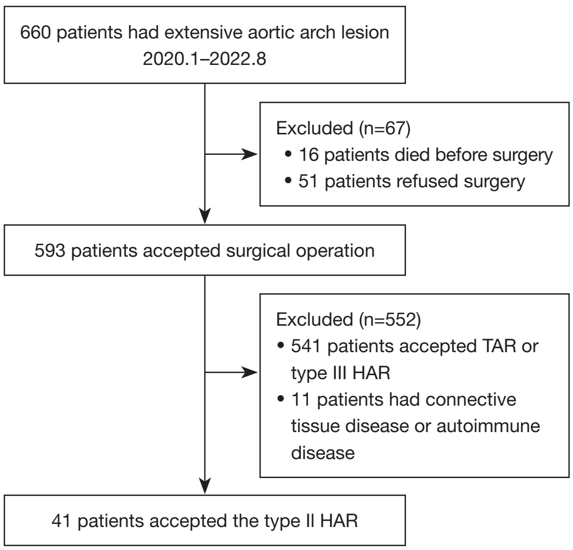

Figure 2 The flow chart of this study. TAR, total arch replacement; HAR, hybrid aortic repair.

nasopharyngeal temperature was maintained at 30 ℃. During the cooling period, the ascending aorta was cross-clamped. The aneurysm or dissection was opened longitudinally, and the valve leaflets and coronary ostia were examined. The heart was arrested using cold blood cardioplegia, followed by the anastomosis of a four-branched prosthesis graft to the sinotubular junction for the purpose of ascending aorta replacement. One clamp was placed on the innominate artery, while the aortic clamp was repositioned proximally to the left carotid artery. In order to establish a sufficient proximal landing zone, the arch was divided between the innominate artery and the left common carotid artery. The distal end of the four-branched graft was then connected end-to-end to the aortic arch. Following the expulsion of air in the ascending aorta, the arch clamp was released to restore coronary perfusion. The branches of the prosthesis were subsequently connected in sequence to the left common carotid artery, left subclavian artery, and innominate artery through anastomosis. The left subclavian was sutured to the perfusion branch of the four-branched graft, and the two branches near the aortic root were sutured to the left common carotid and innominate arteries, respectively. The purpose of this was to allow for sufficient landing zone, prevent arch vessel kinking (10) (*Figure 1*). Following successful weaning from cardiopulmonary bypass, protamine administration was initiated. Prior to commencing the TEVAR procedure, meticulous hemostasis was achieved to mitigate the potential for hemodynamic instability. The endograft was introduced in a retrograde manner through the original femoral cannulation site, with its proximal end securely affixed to the prosthetic graft for arch repair completion. A deliberate oversizing of the stent graft by 10–20% in the proximal landing zone was undertaken to ensure proper positioning of the distal end within the descending aorta. In select cases, an additional stent graft was incorporated. When treating patients with TAAD, we often deployed two stents and placed the end of the distal stent approximately at the level of the eighth thoracic vertebra to enable sufficient aortic remodeling (false lumen elimination) of the dissecting aorta and decrease the reoperation rate.

Definitions

The primary end point of this study was postoperative mortality. Aortic dissection is defined as an intimal tear propagating the blood flow into the media, resulting in the separation of the aortic wall layers by an intimal flap. The propagation of this process forms a true and a false lumen, with or without communicating re-entries (11). In accordance with contemporary guidelines, aortic intramural hematoma is characterized by a localized hemorrhage within the aortic wall of >5 mm and may occur with or without intimal disruption (11). PAU was considered to be an ulceration of aortic atherosclerotic plaque penetrating through the internal elastic lamina into the media. Malperfusion of organs was defined as vessel occlusion as determined by computed tomography angiography scans combined with abnormal laboratory values or symptoms or signs attributable to disturbed blood flow to end organ systems; malperfusion was divided into five categories depending on the ischemic organ: cardiac, renal, lower limb, cerebral, and visceral malperfusion. Postoperative stroke was defined as a new brain injury proven by radiographic evidence after the procedure. Postoperative arrhythmia was considered to be postoperative atrial fibrillation, ventricular fibrillation, and all the other forms of arrhythmia. Incision complication was defined as incision infection, poor incision healing, incision bleeding, and sternal dehiscence.

Follow-up

Follow-up data were collected through outpatient appointments or telephone communication. Imaging monitoring was conducted using computed tomography angiography prior to discharge, at 3, 6, and 12 months following the surgery, and subsequently on an annual basis.

Statistical analysis

Continuous variables were presented as either the mean ± standard deviation or the median with interquartile range (IQR), depending on their distribution. Statistical comparisons between continuous variables were conducted using the unpaired Student *t*-test or Mann-Whitney test as deemed suitable. Additionally, one-way analysis of variance (ANOVA) and the Kruskal-Wallis test were utilized for normally distributed continuous variables and skewed continuous variables, respectively. Categorical variables were represented as numerical values or percentages and were assessed using either the Pearson chi-squared test or Fisher exact test as deemed appropriate. Survival rates were determined utilizing the Kaplan-Meier analytical approach, with distinctions between the three groups evaluated through the log-rank test. Statistical significance was defined as a two-tailed P value of less than 0.05. All statistical analyses were conducted using the R software package (The R Foundation of Statistical Computing, Vienna, Austria).

Results

Preoperative characteristics

We included 41 patients in our analysis: 24 (58.5%) patients with TAAD, 7 (17.1%) with TAIMH, and 10 (24.4%) with TAA and TBAD/TBIMH/PAU. *Table 1* shows the preoperative baseline characteristics. The mean age of this cohort was 54.9±11.1 years, and there were 31 men (75.6%). Of the patients with TAAD with an acute course, 75.0% (n=18) underwent emergency procedures, which was a higher proportion than that of the TAIMH and TAA with TBAD/TBIMH/PAU groups (42.9% and 70.0%, respectively). A history of hypertension was reported for 82.9% of patients. Only 1 (2.4%) patient had previous cardiac surgery, and 2 (4.9%) had undergone TEVAR. The mean ejection fraction of the total group was 61.8%±5.8% (ranged from 45% to 75%), and the mean ascending aorta diameter was 42.6±4.9 mm (ranged from 33 to 55 mm). Despite there being no statistical differences in the echocardiographic characteristics among the three groups, the ascending aorta diameter of the TAA with TBAD/TBIMH/PAU group was larger than that of TAAD and TAIMH groups (43.3±3.9 *vs.* 42.9±5.4 and 40.4±4.4 mm, respectively). Additionally, patients with TAIMH were more likely to have cardiac malperfusion (28.6%) and renal malperfusion (42.9%), whereas patients with TBAD/TBIMH/PAU were more likely to have lower limb malperfusion, although these differences were not statistically significant.

Surgery data

All 41 patients underwent type II HAR procedure. *Table 2* lists the details of the operations. The overall median operation time was 7.0 (IQR, 7.0–8.0) hours, and the median operation times for the TAAD, TAIMH, and TAA with TBAD/TBIMH/PAU groups were 8.0 (IQR, 7.0–8.0), 7.0 (IQR, 7.0–8.0), and 7.0 (IQR, 5.4–7.8) hours, respectively. Six patients (14.6%) underwent aortic valvuloplasty, and 7 patients (17.1%) underwent coronary artery bypass grafting. The TAA with TBAD/TBIMH/PAU group had a shorter operation time compared with the other groups, albeit without a significant statistical difference. The overall mean cardiopulmonary bypass time and aortic cross-clamp time were 168.6±33.7 min (ranged from 118 to 241 min) and 67.2±20.3 min (ranged from 40 to 150 min), respectively (179.9±32.7 and 74.6±20.2 min in the TAAD group, 175.1±30.4 and 67.4±13.9 min in the TAIMH group, and 136.9±14.4 and 49.5±12.9 min in TAA with TBAD/TBIMH/PAU group). The TAA with TBAD/TBIMH/PAU group had a shorter cardiopulmonary bypass time and aortic cross-clamp time compared with the others.

Additionally, the median amount of infusion of red blood cells and plasma was 2.0 (IQR, 0.0–4.0) U and 400.0 (IQR, 0.0–400.0) mL, respectively. The TAA with TBAD/TBIMH/PAU group had the least amount of red blood cell (median, 0.0 U; IQR, 0.0–2.0 U) and plasma infusion (median, 200.0 mL; IQR, 0.0–400.0 mL) of the three groups, although this was not significantly different. In addition, the mean lowest nasopharyngeal temperature and rectal temperature during operation was 29.8±1.3 ℃ (ranged from 26.8 to 32.0 ℃) and 30.6±1.2 ℃ (ranged from 28.3 to 32.7 ℃), respectively.

Postoperative outcomes

The postoperative data are summarized in *Table 3*. During the hospital stay, no patient died. The median intensive care unit time in the overall population was 85.3 (IQR, 38.2–118.8) hours. The median ventilator time and postoperative hospital length of stay were 19.0 (IQR, 15.0–83.5) hours and 9.0 (IQR, 7.0–16.0) days in the overall population, respectively. Strokes occurred in 3 (7.3%) patients, contributing to one death. Three (7.3%) patients

Table 1 Characteristics of patients before operation

Characteristics	Total	TAAD	TAIMH	TAA with TBAD/TBIMH/PAU
Number	41	24	7	10
Age (years)	54.9±11.1	55.1±11.0	49.0±11.1	58.4±10.6
Male	31 (75.6)	17 (70.8)	5 (71.4)	9 (90.0)
BMI (kg/m^2)	26.9±3.4	26.1±3.3	28.3±2.9	27.8±3.7
Time from onset				
Hyperacute (<24 h)	9 (22.0)	7 (29.2)	0 (0.0)	2 (20.0)
Acute (2–7 days)	7 (17.1)	4 (16.7)	1 (14.3)	2 (20.0)
Sub-acute (8–30 days)	21 (51.2)	11 (45.8)	6 (85.7)	4 (40.0)
Chronic (>30 days)	4 (9.8)	2 (8.3)	0 (0.0)	2 (20.0)
EuroSCORE	6.5±2.3	7.5±1.6	4.4±2.1	6.5±2.3
Hypertension	34 (82.9)	21 (87.5)	5 (71.4)	8 (80.0)
Diabetes	3 (7.3)	1 (4.2)	0 (0.0)	2 (20.0)
COPD	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Coronary heart disease	1 (2.4)	1 (4.2)	0 (0.0)	0 (0.0)
Cerebrovascular disease	5 (12.2)	2 (8.3)	0 (0.0)	3 (30.0)
Peripheral arterial disease	1 (2.4)	0 (0.0)	0 (0.0)	1 (10.0)
Smoking	18 (43.9)	9 (37.5)	4 (57.1)	5 (50.0)
History of cardiac surgery	1 (2.4)	0 (0.0)	1 (14.3)	0 (0.0)
History of TEVAR	2 (4.9)	2 (8.3)	0 (0.0)	0 (0.0)
History of PCI	2 (4.9)	1 (4.2)	0 (0.0)	1 (10.0)
Cardiac malperfusion	6 (14.6)	3 (12.5)	2 (28.6)	1 (10.0)
Renal malperfusion	9 (22.0)	5 (20.8)	3 (42.9)	1 (10.0)
Lower limb malperfusion	5 (12.2)	2 (8.3)	1 (14.3)	2 (20.0)
Cerebral malperfusion	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Visceral malperfusion	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
LVEF (%)	61.8±5.8	61.9±5.6	60.9±7.5	62.1±5.7
Ascending aorta diameter (mm)	42.6±4.9	42.9±5.4	40.4±4.4	43.3±3.9
Aortic regurgitation				
Mild	19 (46.3)	11 (45.8)	4 (57.1)	4 (40.0)
Moderate	2 (4.9)	2 (8.3)	0 (0.0)	0 (0.0)
Pericardial effusion	7 (17.1)	5 (20.8)	2 (28.6)	0 (0.0)

Data are presented as n (%) or mean ± standard deviation. TAAD, type A aortic dissection; TAIMH, type A aortic intramural hematoma; TAA with TBAD/TBIMH/PAU, thoracic aortic aneurysm concomitant with type B aortic dissection, type B aortic intramural hematoma, or penetrating aortic ulcer; BMI, body mass index; COPD, chronic obstructive pulmonary disease; TEVAR, thoracic endovascular aortic repair; PCI, percutaneous coronary intervention; LVEF, left ventricular ejection fraction.

Table 2 Characteristics of patients during operation

Characteristics	Total	TAAD	TAIMH	TAA with TBAD/TBIMH/PAU
Number	41	24	7	10
Operation time (hours)	7.0 (7.0–8.0)	8.0 (7.0–8.0)	7.0 (7.0–8.0)	7.0 (5.4–7.8)
Cardiopulmonary bypass time (min)	168.6±33.7	179.9±32.7	175.1±30.4	136.9±14.4
Aortic cross-clamp time (min)	67.2±20.3	74.6±20.2	67.4±13.9	49.5±12.9
With aortic root replacement	1 (2.4)	1 (4.2)	0 (0.0)	0 (0.0)
With AVP	6 (14.6)	5 (20.8)	1 (14.3)	0 (0.0)
With CABG	7 (17.1)	6 (25.0)	1 (14.3)	0 (0.0)
Lowest nasopharyngeal temperature (℃)	29.8±1.3	29.9±1.4	29.5±1.2	29.7±1.0
Lowest rectal temperature (℃)	30.6±1.2	30.4±1.2	30.4±1.2	30.9±1.1
RBC infusion (U)	2.0 (0.0–4.0)	2.0 (0.0–4.0)	2.0 (0.0–4.0)	0.0 (0.0–2.0)
Plasma infusion (mL)	400.0 (0.0–400.0)	400.0 (200.0–450.0)	400.0 (0.0–400.0)	200.0 (0.0–400.0)

Data are presented as n (%), mean ± standard deviation, or median (IQR). TAAD, type A aortic dissection; TAIMH, type A aortic intramural hematoma; TAA with TBAD/TBIMH/PAU, thoracic aortic aneurysm concomitant with type B aortic dissection, type B aortic intramural hematoma, or penetrating aortic ulcer; AVP, aortic valvuloplasty; CABG, coronary artery bypass grafting; RBC, red blood cell; IQR, interquartile range.

Table 3 Characteristics of patients after operation

Characteristics	Total	TAAD	TAIMH	TAA with TBAD/TBIMH/PAU
Number	41	24	7	10
ICU time (hours)	85.3 (38.2–118.8)	88.6 (40.2–160.3)	92.9 (41.0–105.7)	39.1 (23.5–99.7)
Ventilator time (hours)	19.0 (15.0–83.5)	27.8 (15.1–101.6)	18.0 (15.2–27.2)	18.0 (14.5–34.0)
Palinesthesia time (hours)	5.0 (3.0–8.0)	5.2 (3.0–12.2)	4.0 (3.5–4.0)	6.0 (2.1–6.9)
Postoperative length of hospital stay (days)	9.0 (7.0–16.0)	11.5 (7.0–21.8)	8.0 (7.0–9.5)	8.5 (6.5–10.8)
In-hospital death	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Cerebral infarction	3 (7.3)	2 (8.3)	0 (0.0)	1 (10.0)
Paraplegia	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Dialysis	3 (7.3)	2 (8.3)	0 (0.0)	1 (10.0)
Arrhythmia	9 (22.0)	6 (25.0)	1 (14.3)	2 (20.0)
Pulmonary infection	11 (26.8)	8 (33.3)	1 (14.3)	2 (20.0)
Respiratory failure	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Incision complication	1 (2.4)	1 (4.2)	0 (0.0)	0 (0.0)
Secondary thoracotomy	1 (2.4)	1 (4.2)	0 (0.0)	0 (0.0)
Septicemia	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Reintubation	3 (7.3)	1 (4.2)	1 (14.3)	1 (10.0)
Tracheotomy	1 (2.4)	0 (0.0)	0 (0.0)	1 (10.0)

Data are presented as n (%) or median (IQR). TAAD, type A aortic dissection; TAIMH, type A aortic intramural hematoma; TAA with TBAD/TBIMH/PAU, thoracic aortic aneurysm concomitant with type B aortic dissection, type B aortic intramural hematoma, or penetrating aortic ulcer; ICU, intensive care unit; IQR, interquartile range.

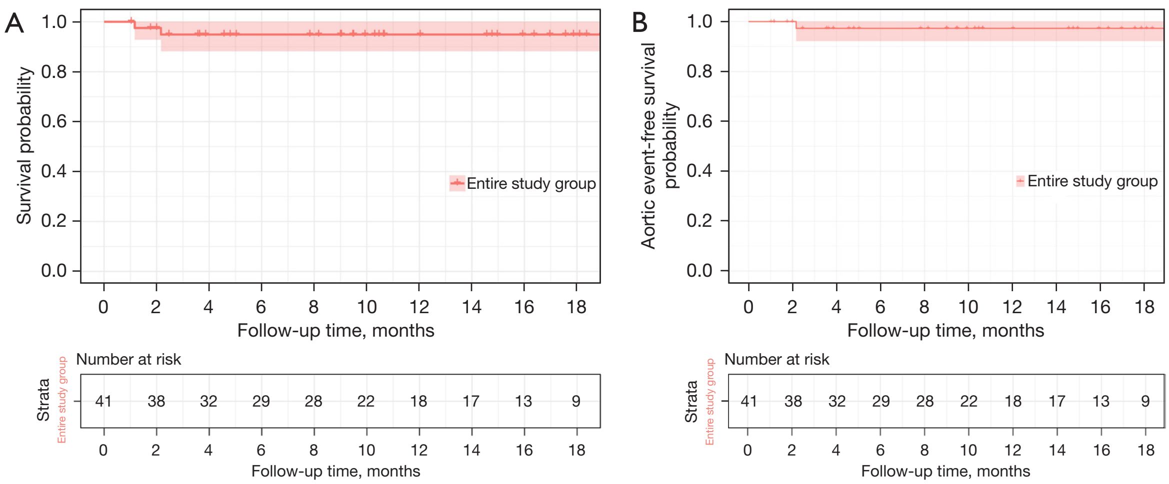

Figure 3 Cumulative Kaplan-Meier curve (A) and aortic event-free curve (B) of the entire study group undergoing the type II hybrid procedure. The log-rank P value is shown. The 95% CI is shown in red shading. CI, confidence interval.

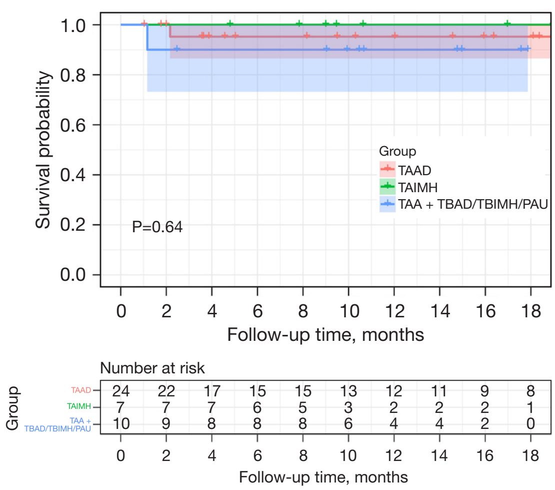

Figure 4 Cumulative Kaplan-Meier curve of each group undergoing the type II hybrid procedure. The log-rank P value is shown. The 95% CIs are shown in red, green, and blue shading. TAAD, type A aortic dissection; TAIMH, type A aortic intramural hematoma; TAA + TBAD/TBIMH/PAU, thoracic aortic aneurysm concomitant with type B aortic dissection, type B aortic intramural hematoma, or penetrating aortic ulcer; CI, confidence interval.

experienced renal failure requiring dialysis after operation, and 1 (2.4%) patient had secondary thoracotomy. None of the patients in our study had paraplegia, respiratory failure, or septicemia.

Follow-up was 100% complete at a median of 10.5 (IQR, 4.8–17.6) months. Two patients died during the follow-up period. The first death occurred in the TAA with TBAD/TBIMH/PAU group 35 days after surgery and was due to stroke. The second death occurred in the TAAD group 65 days after surgery due to distal rupture of residual dissection in the descending aorta. Kaplan-Meier curves were used to determine the cumulative survival and aortic event of the entire study cohort (*Figure 3*) and the cumulative survival of each group (*Figure 4*). The survival rate for the whole cohort was 94.9% [95% confidence interval (CI): 88.2–100.0%], and the survival rates in the TAAD group, TAIMH group, and TAA with TBAD/TBIMH/PAU group were 95.6% (95% CI: 87.4–100.0%), 100.0% (95% CI: 100.0–100.0%) and 90.0% (95% CI: 73.2–100.0%), respectively.

Discussion

The principal finding of this study was that all operations were completed successfully, and for patients with extensive aortic arch pathology, type II HAR was associated with 0% hospital mortality and paraplegia. Only 2 patients (4.9%) died during the follow-up period. We also observed a favorable endoleak rate (0%) and excellent freedom from reintervention (100%) during follow up.

The TAR procedure is performed to treat thoracic aorta diseases, including pseudoaneurysm that involves the arch, penetrating atherosclerotic ulcer, aneurysm, and dissection (Figure S1). TAR can be used to restore an open aortic arch through the elephant trunk approach or one-stage open repair via clamshell incision (12). Notably, the invasive open surgical repair of extensive aortic arch disease requires hypothermic circulatory arrest. Consequently, use of TAR may lead to significant mortality and morbidity (13). Long periods of circulatory arrest cause elevated inflammatory responses and a high risk of visceral ischemia and stroke (14). Additionally, hypothermia may increase the occurrence of coagulopathy and bleeding due to distal anastomosis (1). Circulatory arrest may negatively affect cognitive function, even when used for short periods. Moreover, because of their medical comorbidities, a number of patients do not qualify for this treatment, and surgery is denied despite the availability of advanced cerebral-protective perfusion strategies.

TAR used in TAAD is limited by its complexity. Indeed, according to the International Registry of Acute Aortic Dissection, TAR is performed for only 12% of patients (15). A large retrospective study (n=3,265) of open TAR cases showed a 10% rate of in-hospital mortality at specialized centers and a permanent neurological deficit rate of >6.7% (16). Thus, alternative strategies with lower morbidity and mortality are urgently needed (17). Treatment of patients with extensive aortic disease is technically challenging and in need of further innovation (18).

The progression of endovascular technology and expertise, along with the acquisition of advanced catheter-based proficiencies in cardiothoracic and cardiovascular surgery, have resulted in a rise in the utilization of hybrid aortic arch procedures. These procedures are now feasible for high-risk patients with multiple comorbidities. Type II HAR has emerged as an effective alternative to conventional surgical repair in the treatment of various aortic arch diseases (13,19). While TAR remains the conventional treatment approach, hybrid aortic arch reconstruction offers a less invasive alternative for older adult patients and those with multiple comorbidities or high-risk anatomical characteristics, such as a history of cardiac surgery (20).

However, it is not clear whether the hybrid technique is superior to conventional open repair of aortic arch lesions. Previous study indicated that the outcomes of the hybrid strategy are similar to those of traditional arch replacement (21). Cazavet and colleagues (21) reported that the mortality rates of the two approaches were 20% and 19% for the hybrid technique and conventional open repair, respectively. Iba *et al.* (22) demonstrated the superiority of the hybrid procedure in facilitating early postoperative recovery, while Hiraoka *et al.* (23) observed a heightened risk of stroke in patients undergoing the hybrid approach. Jakob and colleagues (24) applied the hybrid technique for the treatment of DeBakey type I dissection and noted significantly improved early outcomes, including a lower mortality rate of 9% compared to 22% with the conventional method. The limited sample size of our cohort precludes us from making a conclusive determination; however, our observed mortality rate of 4.9% aligns closely with findings from prior study (25). Although mounting evidence suggests that the hybrid approach may be effective in treating aortic arch disease, no randomized studies have been conducted to compare hybrid arch procedures with conventional open surgical approaches (26).

In our center, we advocate TAR and implantation of a frozen elephant trunk (FET) in addition to proximal repair in type A dissection. FET simplifies the second-phase operation of the thoraco-abdominal aorta after arch repair in TAAD. However, in China, <10% of patients undergo reoperative surgery on the thoracoabdominal aorta after TAAD (27). The mortality rate for reoperative surgery on the proximal descending aorta is 8% in specialized aortic surgery centers (28). Our contention is that in practical clinical scenarios, particularly for patients exhibiting residual false lumen progression to complex thoracoabdominal aneurysms, palliative medical management emerges as a commonly utilized option, particularly among elderly individuals. Compared with TAR + FET, HAR has better distal plasticity and can rapidly thrombose the distal dissection or quickly eliminate distal hematoma (12). Thrombosis occurring within the false lumen may serve to obviate potential secondary tear locations in the aortic arch and descending aorta, thereby mitigating secondary enlargement and diminishing the necessity for reoperation stemming from distal dilation (29). Thus, in a single procedure, type II HAR surgery can resolve all lesions in most patients.

The main difference between the hybrid and FET techniques is the timing of device replacement. In FET, the placement of end grafts during circulatory arrest may lead to hemodynamic instability prior to achieving complete hemostasis following FET deployment. In contrast, the hybrid approach involves placing end grafts after the patient has been successfully weaned from cardiopulmonary bypass and complete hemostasis has been attained. It is imperative to ensure hemodynamic stability before proceeding with TEVAR. Differences in hemodynamic stability can explain differences between the FET and hybrid methods in the incidence of spinal cord injury and organ malperfusion.

Moreover, deploying a stent graft into an acutely dissected aorta involves a high risk of aortic disruption, peripheral embolization, malperfusion, and paraplegia (30). We also assert that in acute dissections that intraoperatively address issues of the descending aorta via FET, not knowing whether resection of the intimal tear will effectively exclude the false lumen may lead to the treatment of patients who might not benefit from the deployment of a stent graft in the descending aorta. The incidence of FET-associated spinal cord injuries and stroke are 3–22% and 3–16%, respectively (31), which may limit the use of this procedure. Moreover, the incidence of endoleak associated with FET is 2–18% (31), and the need for endovascular intervention may reach 22% (32).

For patients with malperfusion syndromes, pseudocoarctation of the true lumen, or a dynamic flap, we consider the type II HAR approach for the treatment of aortic dissection with the creation of a proximal landing zone via ascending aortic replacement. This approach is followed by concomitant retrograde stent grafting of the descending thoracic aorta to establish or stabilize true lumen flow. We believe that insertion of the stent graft into the arch and the descending aorta rebalances the blood flow between the true lumen and the patent false lumen in the distal descending aorta and abdominal aorta. The expansion of the true lumen and pressure reduction in the false lumen of the abdominal aorta may achieve better organ and lower limb perfusion as well as aortic remodeling in the abdominal aorta.

All procedures in this study were performed by two experienced surgeons at a high-volume center. The surgeons were proficient in TAR + FET. Therefore, the dissociation of the branch vessels of the aortic arch did not make the operation more difficult. Moreover, this approach appears to be more reproducible even when performed by surgeons without training in aortic arch repair.

Limitations

Our study shows that this procedure can be used to treat acute and chronic cases of diffuse thoracic aortic pathology involving the arch. Nevertheless, these feasibility rates should be interpreted with caution because the underlying data were from two centers with considerable endovascular experience, which limits the generalization of these results. Our study was also limited by failure to include a control group that was composed of patients who underwent conventional arch replacement. The retrospective design of the study was another limitation.

Conclusions

Our study revealed satisfactory early results for type II HAR. On the basis of our experience with type II HAR, we suggest that rerouting the neck vessels on the proximal ascending aorta and creating a proximal landing zone enables better control associated distal pathology. Nevertheless, there is need to routinely monitor patient progress following HAR to improve outcomes.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-586/rc

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-586/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The Ethics Committee of Beijing Anzhen Hospital approved the use of clinical data (Institutional

Review Board File No. 2014019). Beijing Chaoyang Hospital was informed and agreed the study. Written informed consent was obtained from all patients enrolled in the study.

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