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ORIGINAL ARTICLE

Distal Arch Aneurysm Repair Using Left Subclavian Artery Transposition With Stented Elephant Trunk in the Hybrid Repair Era

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Background Hybrid aortic arch repair is an invasive approach to the surgical management of distal aortic arch aneurysm. The complications associated with hybrid aortic arch repair, such as stroke and endoleaks, are not uncommon and late reintervention is frequent. We retrospectively reviewed our experience of distal aortic arch aneurysm repair using the stented elephant trunk procedure with left subclavian artery (LSCA)-left common carotid artery (LCCA) transposition in the hybrid repair era.

Methods Between May 2009 and September 2016, 19 patients with distal aortic arch aneurysm underwent LSCA-LCCA transposition with stented elephant trunk implantation under hypothermic cardiopulmonary bypass with selective antegrade cerebral perfusion. All patients were males with a median age of 51 ± 14 (range 20–69) years.

Results There were no in-hospital deaths. Continuous renal replacement therapy was not required in patients with preoperative renal dysfunction after surgery. No neurologic deficits were observed in any patients prior to hospital discharge. One patient underwent concomitant thoracic endovascular aortic repair after this technique. One case required reoperation due to bleeding. One patient required debridement due to poor wound healing. During a mean follow-up of 33 ± 21 months, one patient died.

Conclusions Satisfactory results were obtained in suitable patients undergoing surgery for distal aortic arch aneurysm using LSCA-LCCA transposition with stented elephant trunk implantation in the hybrid repair era. The straightforward nature of the surgical approach, with avoidance of the complications related to hybrid aortic arch repair and reduction of late re-intervention favours this technique for treating distal aortic arch aneurysm.

Keywords Distal aortic arch aneurysm • Stented elephant trunk technique • Left subclavian artery-Left common carotid artery transposition • Hybrid repair

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Introduction

Distal aortic arch aneurysm refers to an aneurysm involving at least the left subclavian artery (LSCA) origin, but not extending beyond the origin of the left carotid artery (LCCA) [1]. Using conventional open surgery, distal aortic arch aneurysm poses a challenge because of the location and the size of the aneurysmal body, the protection of the heart and brain, and the choice of cardiopulmonary bypass (CPB) technique. Thoracic endovascular aortic repair (TEVAR) with concomitant aortic arch vessel revascularisation (namely, hybrid procedure) was a novel approach for this disease. Because of its acute angulated morphology, prevention of the supra-aortic branches, and an inadequate proximal sealing zone, hybrid aortic arch repair for distal aortic arch aneurysm is a very complex procedure. Postoperative complications, such as stroke [2], endoleak [3], and retrograde aortic dissection [4] are very common and the need for late reintervention is high [5]. Management of distal aortic arch aneurysm remains controversial. In this study, we reviewed our results of surgical treatment of distal aortic arch aneurysm using the stented elephant trunk procedure with LSCA-LCCA transposition in the hybrid repair era.

Methods

Patients

From May 2009 and September 2016, 19 patients with distal aortic arch aneurysm (Figure 1) underwent surgical treatment using LSCA-LCCA transposition with the stented elephant trunk procedure under hypothermic CPB with selective antegrade cerebral perfusion (SACP) at Beijing Aortic Disease Center, Beijing Anzhen Hospital. Aneurysm type included true aneurysm in 12 patients, false aneurysm in six patients, and penetrating ulcer in one patient. This technique was approved by the institutional review board of Capital Medical University.

The mean age of our patient cohort was 51 ± 14 (range 20–69) years; all patients were male. Hypertension was noted in 12 patients, diabetes mellitus in one patient, and old cerebral infarction in one patient. Five subjects had coronary artery disease and only two patients required intervention. Previous percutaneous coronary intervention, ligation of the patent ductus arteriosus, Bentall procedure, and endovascular aortic repair (EVAR) were noted (one case each). Innominate artery aneurysm was observed in one patient and dilatation of the ascending aorta in another. Preoperative complications were common (Table 1). Aortic aneurysms involving the distal aortic arch and thoracic descending aorta were identified prior to surgery by computed tomography (CT).

Surgical Technique

Patients were placed on the operating table in the supine position. During the induction of general anaesthesia, measurement of radial and femoral arterial blood pressure was performed. The right axillary artery (RAxA) was exposed for the arterial cannulation for CPB and SACP via a 6–8 cm skin incision at the right subclavicular region. After median sternotomy, the heart, ascending aorta, transverse arch, and aortic arch vessels were exposed. After systemic heparinisation, total CPB was started by arterial cannulation of the RAxA and venous dual-stage atriocaval cannulation of the right atrium. Myocardial protection was achieved with intermittent antegrade perfusion of cold-blood cardioplegic solution.

If a cardiac or proximal aortic procedure was required, those procedures were generally performed during the cooling phrase. When the nasopharyngeal temperature reached 25 °C, the brachiocephalic arteries were cross-clamped and

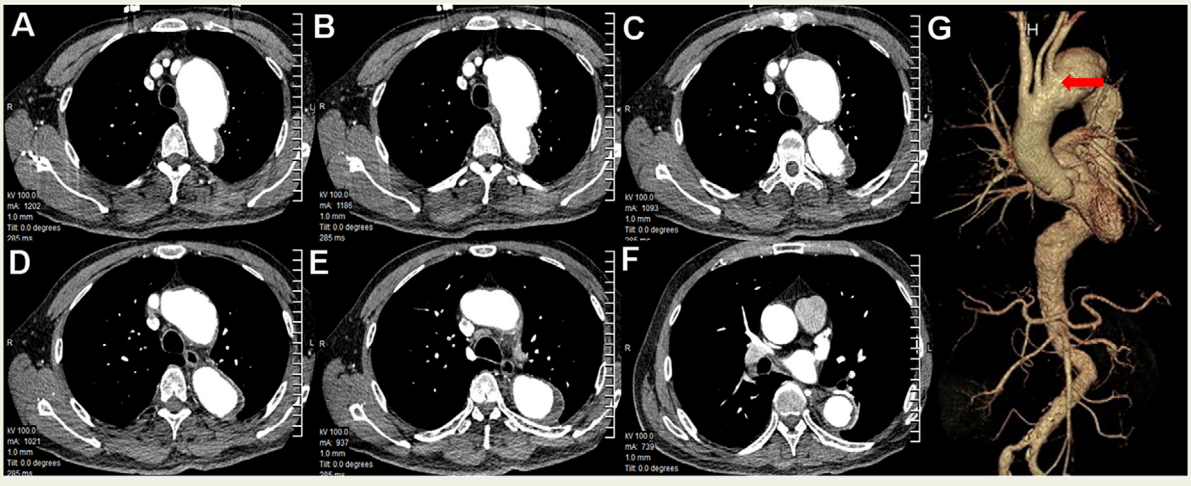

Figure 1 Preoperative CT images of a patient with distal aortic arch aneurysm (A, B, C, D, E and G). As demonstrated by three-dimensional CT reconstruction, the distal aortic arch was involved and expanded (G). The LSCA was originating from the aneurysmal body as showed by the red arrow (G).
Abbreviations: CT, computed tomographic; LSCA, left subclavian artery

Table 1 Clinical profiles of patients with distal aortic arch aneurysm using a stented elephant trunk procedure.

No.	Sex	Age	Symptoms and findings	Concomitant aortic lesions	Concomitant procedure	Outcomes	Follow-Up results
1	M	68	Hypertension/CAD/old Cerebra infarction	Penetrating ulcer of proximal DTA			Death
2	M	56	Hypertension/CAD/ Previous PCI		CABG		Alive
3	M	47	Hypertension/CAD	Pseudoaneurysm of proximal DTA			Alive
4	M	65	CAD/Previous EVAR				Alive
5	M	62	Hypertension		Planned TEVAR		Alive
6	M	69	Hypertension				Alive
7	M	20	Hypertension/TEVAR failure				Alive
8	M	65	Hypertension/CAD	Pseudoaneurysm of proximal DTA	CABG		Alive
9	M	63	Hypertension				Alive
10	M	49	Previous PDA ligation				Alive
11	F	39		Pseudoaneurysm of proximal DTA			Alive
12	M	58					Alive
13	M	41	Hypertension/ascending aortic dilation		Plasty of the AA		Alive
14	M	43	Previous AAR		Bentall/AA-femoral artery bypass	Sternal debridement	Alive
15	M	41	Innominate arterial aneurysm		AA-RCCA bypass/ AA-RSCA bypass		Alive
16	M	63	Hypertension	Pseudoaneurysm of proximal DTA			Alive
17	M	27	Hypertension	Pseudoaneurysm of proximal DTA		Bleeding	Alive
18	M	53	Diabetes	Pseudoaneurysm of proximal DTA			Alive
19	M	56	Hypertension	Penetrating ulcer of proximal DTA			Alive

Abbreviations: AA, ascending aorta; AAR, ascending aortic replacement; Bentall, Bentall procedure; CABG, coronary artery bypass grafting; CAD, coronary artery disease; DTA, descending thoracic aorta; PCI, percutaneous coronary intervention; PDA, patent ductus arteriosus; RCCA, right common carotid artery; RSCA, right subclavian artery; TEVAR, thoracic endovascular aortic repair.

circulatory arrest was commenced. In our centre, measurement of blood pressure in the left radial artery and/or backbleeding through the LCCA were adopted to assess whether intraoperative cerebral circulation in the left hemisphere was adequate [6]. The brain was perfused through the RAxA using unilateral SACP at approximately 5–10 mL kg^{-1} min^{-1} if the left radial artery pressure was 15–20 mmHg or greater.

The anterior wall between the LCCA origin and the LSCA origin was incised longitudinally. After the surgical stent-graft was implanted into the distal aorta in a bound, compressed state, the stented elephant trunk incorporating the distal aorta was firmly fixed to the proximal normal aortic wall using the suture line. After the anastomosis was completed, air was eliminated and rewarming was started. After the LSCA was transected circumferentially 0.5–1.0 cm distal to its origin, the proximal LSCA stump was closed using the suture line. Then, the distal segment of the LSCA was anastomosed to the LCCA in an end-to-side manner.

Results

Surgical Data

Mean CPB duration, aortic cross-clamp time, and SACP time were 144 ± 26 (range, 90–201), 65 ± 28 (range, 26–140), and 26 ± 10 (range, 11–54) minutes, respectively. Concomitant coronary artery bypass grafting as performed in two patients, plasty of the ascending aorta in one patient, and TEVAR in one patient.

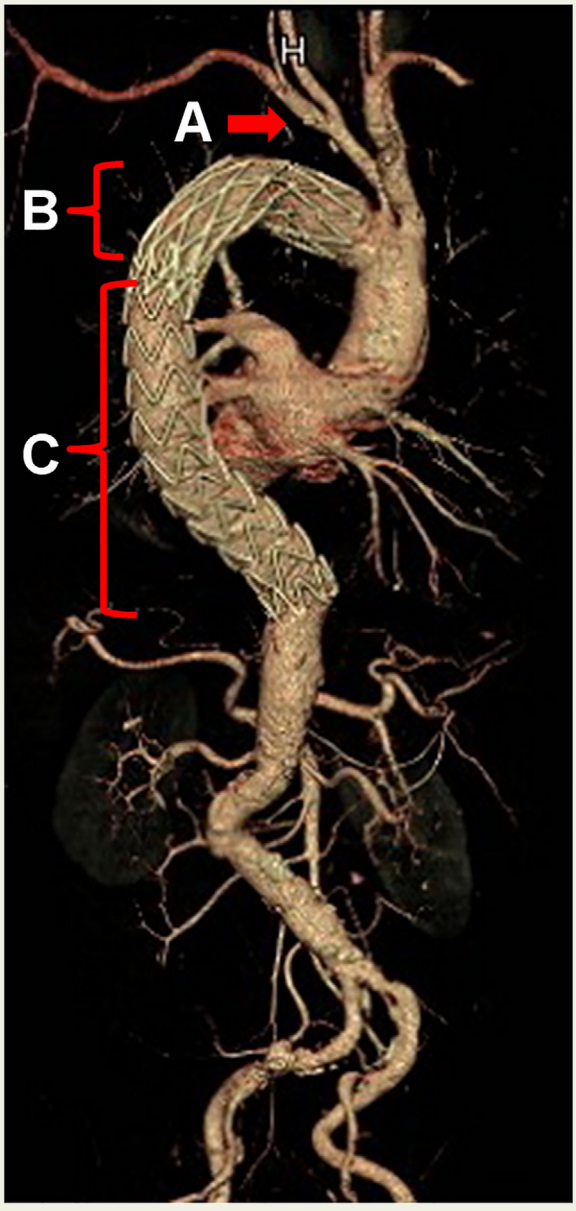

Figure 2 Three-dimensional CT reconstruction of a distal aortic arch aneurysm using the stented elephant trunk procedure with LSCA-LCCA transposition following endoluminal exclusion of the distal descending aorta with the stent-graft serving as the new proximal landing zone 14 months postoperatively. The satisfactory patency of the anastomotic site between the LSCA and the LCCA are demonstrated by the red arrow (A); the aneurysmal body was excluded by the surgical graft (B) and the interventional stent-graft (C).
Abbreviations: CT, computed tomography; LSCA, left subclavian artery; LCCA, left common carotid artery

Morbidity and Mortality

There were no in-hospital deaths. The median ventilator support time was 26 ± 16 (range 12–83) hours. The median ICU stay was 45 ± 14 (range 19–105) hours. Reoperation was required in one case due to bleeding, and sternal debridement in one due to poor wound healing. In accordance with a predetermined plan, TEVAR with the stent-graft serving as the new proximal landing zone was successfully performed in one patient. No cerebral complications were observed in this group. All patients recovered and were discharged from the hospital. A low rate of morbidity and morbidity was obtained in this group.

Follow-Up Period

All cases were followed up for a mean of 33 ± 21 (range 8–94) months; there was one late death from an unknown cause. Spinal cord injury and visceral organ ischaemia were not observed during the follow-up period. Patients resumed their normal activities and began antihypertensive therapy after hospital discharge. Anastomotic patency between the LSCA and LCCA was confirmed on postoperative computed tomography (CT). The aneurysmal sac was excluded in all patients with distal aortic arch aneurysm (Figure 2).

Discussion

Since TEVAR was first introduced to treat diseases of the thoracic descending aorta [7], it has been widely applied to treat a range of aortic disease [8,9]. Its application is limited in descending aortic disease with an adequate landing zone due to the morphology of the angulated aortic arch and protection of the supra-aortic branches. To expand its clinical application to aortic disease, the supra-aortic branches are debranched to increase the proximal landing zone following TEVAR via the femoral artery (hybrid technique) [8–10].

However, the hybrid technique did not eliminate the complications associated with TEVAR. Due to the presence of mural thrombi and atherosclerotic plaques, the manipulation of the endograft in the transverse arch can lead to stroke. The hybrid procedure is associated with a significant stroke incidence of 9.7% to 14.3% during TEVAR [2,5,11] and is associated with a high mortality rate [2]. Endoleak is another troublesome problem during hybrid aortic repair and a high endoleak prevalence of 19% to 24.5% occurred [11,12]. The overall rate of aortic re-intervention is 36% at 5 years [5]. In addition, antegrade type A dissection should not be ignored while using the hybrid technique [4].

TEVAR using the chimney or fenestrated technique is an option for distal aortic arch aneurysm. However, unsatisfactory perioperative outcomes and follow-up results are obtained using this technique, with a rate of re-intervention as high as 30.3% [13]. TEVAR with a branched graft is another choice in patients with distal aortic arch aneurysm. The early results were promising in a multicentre trial [14]. However, the late re-intervention rate was as high at 18% compared with open surgery [15]. Although short-term benefits are gained, patients selected for TEVAR have worse long-term survival rates than patients selected for open repair after risk-adjusted and propensity-matched comparisons [16]. During hybrid aortic arch repair for aortic aneurysm, similar outcomes were also obtained in a meta-analysis: hybrid arch

repair resulted in more re-interventions, even though it is a less invasive approach and requires fewer days in the hospital [17]. These results suggest that TEVAR should be undertaken in higher-risk or elderly patients.

Open surgery continues to be the gold standard for surgical treatment of aortic disease involving the aortic arch and descending aorta. Even in older patients, open surgery for aortic arch lesions obtained satisfactory surgical results [18,19]. In a cohort of 157 patients older than 75 years who underwent conventional total arch replacement, the in-hospital mortality rate was 7.6% (12 of 157). Similar surgical outcomes were also obtained in another centre: Hata et al. [19] reported that 24 octogenarians with distal aortic arch aneurysms underwent distal limited open stenting without in-hospital mortality, brain damage, and renal or respiratory failure.

Using conventional open surgery, surgical manipulation of the distal aortic arch aneurysm remains troublesome due to extensive and aggressive surgical trauma via a clamshell incision or a combined sternotomy and thoracotomy, difficult manipulation when adopting a left thoracotomy, and complications associated with soft prosthetic grafting when utilising a conventional elephant trunk. Especially regarding conventional elephant trunk, several issues should be considered: difficulty in achieving haemostasis, inconvenience for completing the distal anastomosis, kinking and flapping of the prosthetic graft [20], and rupture of aortic aneurysm during the interval between the first and second stages of the procedure [21].

Focussing on protection of the heart and brain, convenient surgical manipulation, prevention of complications associated with TEVAR or hybrid technique, avoidance of managing stent-graft failure and the advantage of the stented elephant trunk procedure, LSCA-LCCA transposition with stented elephant trunk implantation was performed in our cohort of patients with distal aortic arch aneurysm via a median sternotomy: (i) an aortic arch aneurysm located distal to the LCCA origin; (ii) anatomic contraindications to TEVAR; (iii) concomitant proximal aortic arch lesions; or (iv) concomitant cardiac disease. After the LSCA was transposed to the LCCA, the aneurysmal body distal to the LCCA origin was completely excluded after the stented elephant trunk was implanted into the distal aorta. Furthermore, it is much easier to protect the brain using SACP through a median sternotomy. The effectiveness of this technique was illustrated by our postoperative outcomes in which no injury to the cerebrum occurred. Our stented elephant trunk, which consists of a woven Dacron graft, ensures a desirable long-term result.

Compared to hybrid aortic arch repair, surgical trauma was relatively aggressive using the stented elephant trunk procedure. However, the complications associated with hybrid aortic arch repair were prevented after the surgical stent-graft incorporating the distal aorta was firmly attached to the proximal normal aortic wall using the suture line. In addition, patients tended to be younger in this group (mean age 53 $\pm$ 6 years) and would survive longer after successful surgery. During the follow-up period, no aortic events occurred and no reoperation was required. Due to the excellent outcomes obtained using this technique, we think that the stented elephant trunk procedure is justified for a select group of patients in the hybrid repair era.

In conclusion, satisfactory midterm surgical results were obtained for distal aortic arch aneurysm using the stented elephant trunk procedure with LSCA-LCCA transposition in this era of hybrid repair. Low mortality and morbidity rates, a lower prevalence of late aortic events, and a low reoperation rate favour this technique in suitable patients with distal aortic arch aneurysm.

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Conflict of Interest

Authors have nothing to disclose with regards to commercial support.

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