Transposition of the left vertebral artery during endovascular stent-graft repair of the aortic arch

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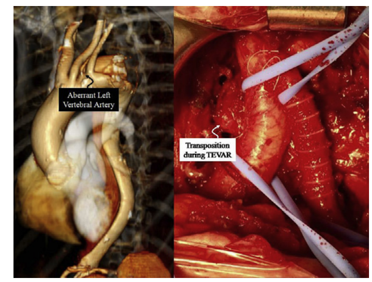
ABSTRACT

Objectives: The aim of this study was to present our experience with the management of isolated left vertebral artery during hybrid aortic arch repairs with thoracic endovascular aortic repair completion.

Methods: This is a single-center, observational, cohort study. Between January 2007 and December 2018, 9 patients (4.5%) of 200 who underwent thoracic endovascular aortic repair were identified with isolated left vertebral artery. The isolated left vertebral artery was the dominant vertebral artery in 4 cases and entered the Circle of Willis to form the basilar artery in all cases. Isolated left vertebral artery transposition was performed in 2 patients during open ascending/arch repair before thoracic endovascular aortic repair completion. In 4 patients, isolated left vertebral artery transposition was performed concomitant with carotid-subclavian bypass during thoracic endovascular aortic repair completion ("zone 2" thoracic endovascular aortic repair). Primary outcomes were early (<30 days) and late survival, freedom from aortic-related mortality, and isolated left vertebral artery patency.

Results: Primary technical success was achieved in all cases. Isolated left vertebral artery–related complication occurred in 1 patient (Horner syndrome). Immediate thrombosis, vagus/recurrent laryngeal nerve palsy, lymphocele, and chylothorax were never observed. Postoperative cerebrovascular accident or spinal cord injury was not observed. Median follow-up was 15 months (range, 3-72). We did not observe aortic-related mortality during the follow-up. Aortic-related intervention was never required. Both isolated left vertebral artery and carotid-subclavian bypass are still patent in all patients with no sign of anastomotic pseudoaneurysm or stenosis.

Conclusions: Although isolated left vertebral artery is not a frequent occurrence, it is not so rare. It may pose additional difficulties during hybrid aortic arch surgical repairs, but isolated left vertebral artery transposition was feasible, safe, and a durable reconstruction. (J Thorac Cardiovasc Surg 2020;159:2189-98)



ILVA transposition with concomitant CSbp.

Central Message

ILVA transposition is safe and durable during open hybrid arch repair or CSbp and descending TEVAR completion.

Perspective

ILVA is not a rare finding in aortic arch surgery. Recognizing its presence is crucial because missing it will lead to potential threatening complications. Thus, although it requires more complex reconstruction, either during open repair or isolate TEVAR, ILVA transposition is feasible and durable and should be recommended in most circumstances.

See Commentaries on pages 2199 and 2200.

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Among supra-aortic trunk (SAT) configurations, isolated left vertebral artery (ILVA) arising directly from the aortic arch has been described as the second most common variant with an incidence of 0.8% to 6.3%.[1-4] An isolated right vertebral artery is a rare occurrence.[4,5]

Scanning this QR code will take you to the article title page to access supplementary information.

Abbreviations and Acronyms

CSbp	= carotid-subclavian bypass
CTA	= computed tomography angiography
ICU	= intensive care unit
ILVA	= isolated left vertebral artery
IQR	= interquartile range
LCCA	= left common carotid artery
LSA	= left subclavian artery
SAT	= supra-aortic trunk
SG	= stent-graft
TEVAR	= thoracic endovascular aortic repair

In recent years, being aware of SAT variants has become crucial, especially when planning interventions involving the aortic arch, either with open or hybrid intervention. First, they could pose significant technical challenges, and second, a missing diagnosis could lead to major neurologic complications.[6-9]

Currently, there are no widely adopted strategies regarding the management of isolated vertebral arteries during aortic arch surgical repairs and thoracic endovascular aortic repair (TEVAR) because of the few data based on description of case reports.[5,6,10-16]

The aim of this study was to present our experience with the management of ILVA during hybrid aortic arch surgical repairs.

MATERIALS AND METHODS

Study Cohort

This is a single-center, observational cohort study. For this study, all patients treated with TEVAR as part of the aortic reconstruction between January 2007 and December 2018 were retrospectively reevaluated. Patients with open aortic non-TEVAR repair (n = 79) or those with an isolate right vertebral artery (n = 1) were excluded from the analysis; thus, only those undergoing an ILVA transposition and TEVAR completion comprised the study cohort (Figure 1). Information about demographics, comorbidities, medical and surgical history, operative details, and postoperative events during the hospital stay and follow-up were all registered. Informed consent for data recording and intervention was signed by each patient. Approval for this specific study was obtained by the local Institutional Review Board, according to the National Policy in the matter of Privacy Act on retrospective analysis of anonymized data. The end of follow-up evaluation for this specific study was March 1, 2019.

Operative Treatment

According to our standardized program, all patients who underwent operative repair (eg, with open, hybrid, or totally endovascular treatment) for thoracic aortic disease underwent preoperative computed tomography angiography (CTA) with postprocessing maximum intensity and multiplanar projections as well as volume-rendering 3-dimensional reconstructions. We evaluated aortic arch involvement, the characteristics

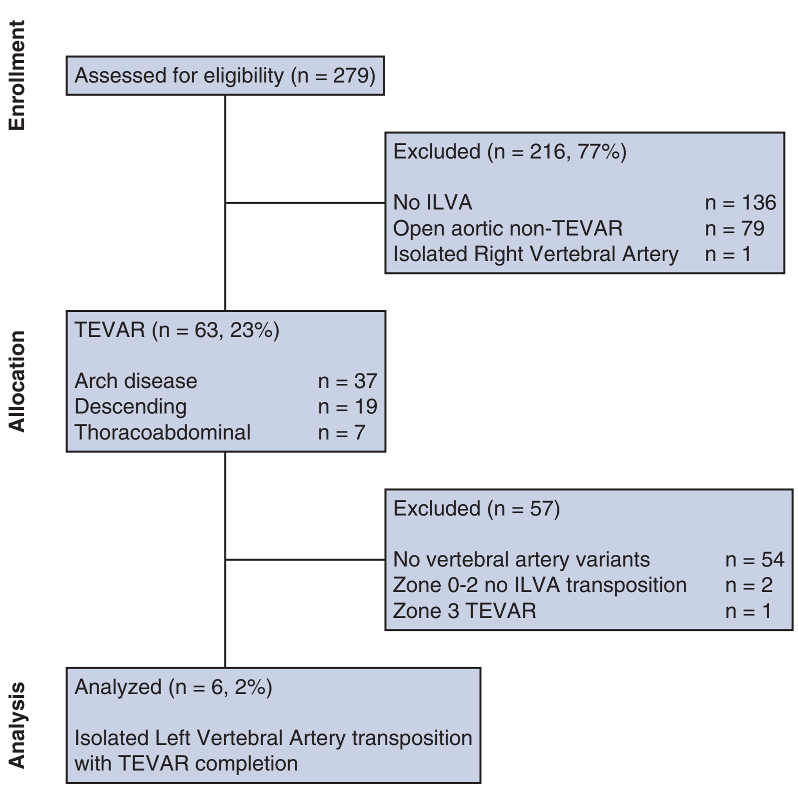

FIGURE 1. Consort diagram of arch/descending/thoracoabdominal aortic repairs (2007-2018; n = 200). *ILVA*, Isolated left vertebral artery; *TEVAR*, thoracic endovascular aortic repair.

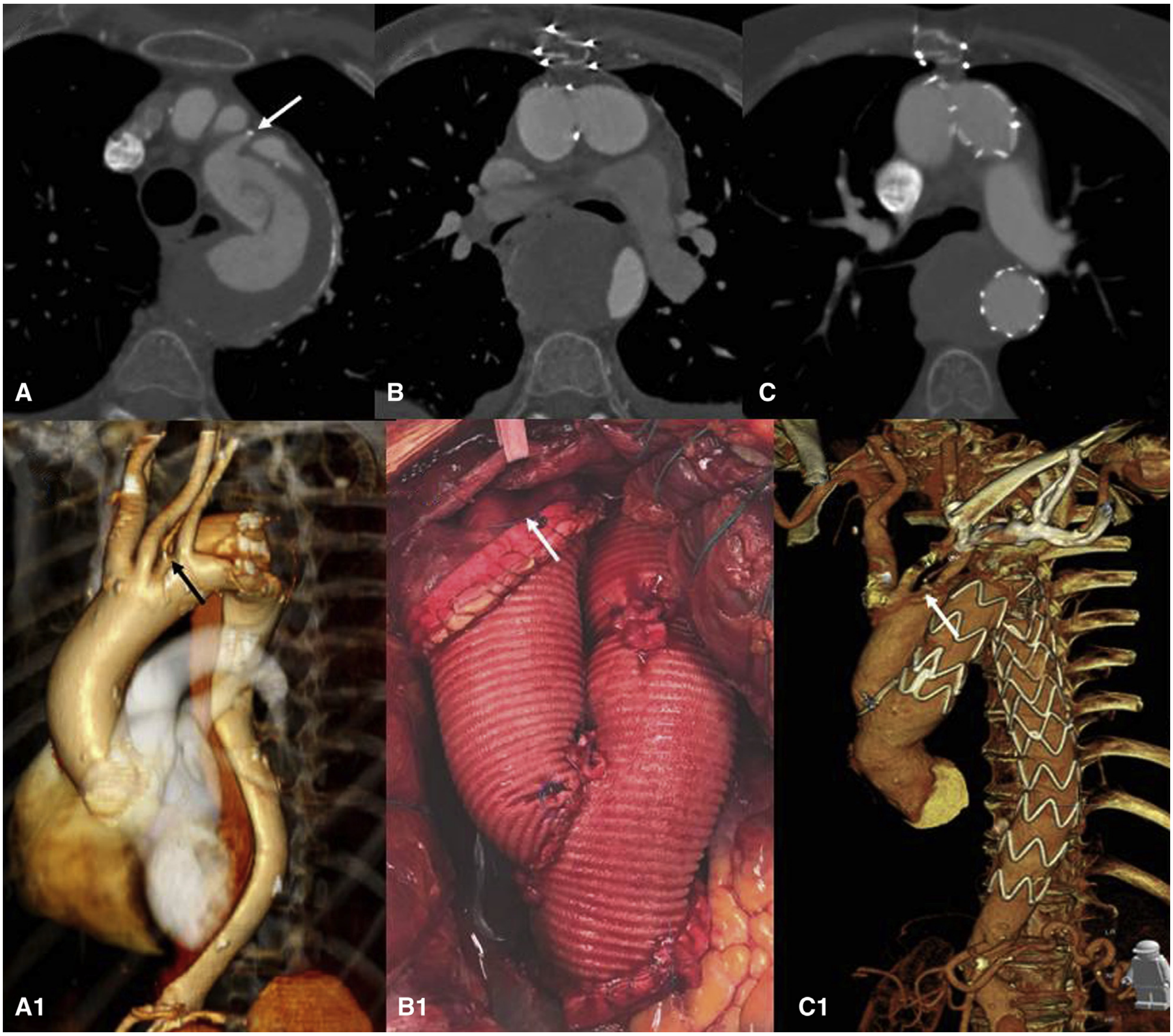

FIGURE 2. Hybrid type II arch repair: (A) CTA with volume rendering reconstruction (B) of a type B acute aortic dissection and aneurysm of the descending thoracic aorta with demonstration of the ILVA; A, *white arrow*; A1, *black arrow*) from the distal arch between the LCCA and the LSA. Hybrid type II arch repair: The origin of the ILVA (B1, *white arrow*) was transposed along with the innominate, LCCA, and LSA using a SAT debranching graft according to the Griepp ''arch first'' technique. Follow-up CTA showed the complete exclusion of the dissection and descending aneurysm (C) as well as the patency of the ILVA (C1, *white arrow*), and the good alignment of the SG at the origin of the debranching graft (C1).

of SAT and brain vessels to exclude concomitant disease or variants, and the integrity of the Willis circle and both the vertebral arteries (Figures 2-4). All interventions were performed in the operating room, equipped to perform open surgical or endovascular procedures. When ILVA transposition was technically feasible during ascending/arch open repair, we used the Griepp ''arch first'' graft technique (Figure 2, *B1*).[17,18] When the exposure of the ILVA was not technically feasible, we preferred to perform a more proximal anastomosis with the debranching of the innominate and left common carotid artery (LCCA) (Figure 3, *B*).[17] In both these cases, TEVAR was performed 2 to 4 weeks later (Figures 2, *C-C1,* and Figure 3, *D*); at that time, patients were scanned again to assess ILVA patency and geometry with angulation of the conventional graft reconstruction, as well as to control eventual modification of the measurements at the distal landing zone. In case of isolate ''zone 2'' TEVAR, we performed a single-stage intervention with carotid-subclavian bypass (CSbp) and transposition of the ILVA to prevent a potential proximal stump blowout. CSbp was always performed first, using a standard supraclavicular surgical access under transcranial-Doppler control and cerebral oxygen saturation monitoring. Then, ILVA was transposed onto the LCCA, proximally to the CSbp, to maintain continuous brain perfusion because of flow inversion within the CSbp (Figure 4, *D* and *E*). The ILVA was always transected as proximal as possible. Special attention was made to avoid losing control of the proximal stump, which was ligated and oversewn. After stent-graft (SG) deployment, the origin of the left subclavian artery (LSA) was closed endovascularly with an endovascular plug. All patients were admitted to the intensive care unit (ICU) postoperatively. Neurologic assessment was performed on an hourly basis by anesthesiologists and surgeons who were part of the intervention team. This was done to detect potential neurologic deficits. For every minimal suspect of neurologic deficit,

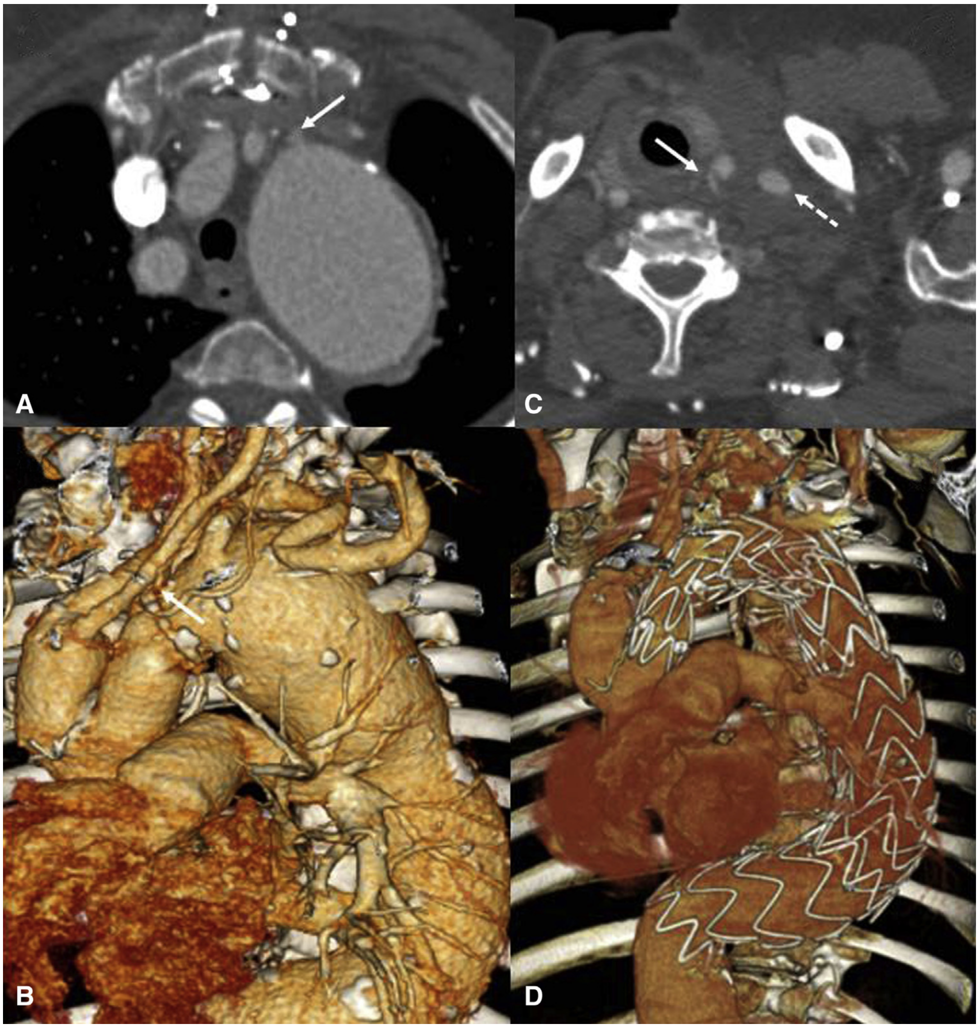

FIGURE 3. Hybrid type II arch repair: CTA (A) showed the origin of the ILVA directly from the arch aneurysm (A, *white arrow*). Postoperative volume rendering 3-dimensional reconstruction (B) showing the proximal anastomosis of the ascending/arch graft performed just proximally to the origin of the ILVA (B, *white arrow*). Follow-up CTA control documenting the patency of the transposed ILVA onto the LCCA (C, *white arrow*) and the prosthetic CSbp (C, *white dotted arrow*). Complete reconstruction of the ascending/arch/descending aorta (D) in a 2-stage approach.

a full neurologic examination was promptly performed by a neurologist. However, cerebrovascular accidents were finally defined on the basis of physical examination, tomographic scan, magnetic resonance imaging, or autopsy. The management of spinal cord ischemia prevention involved different aspects, which agree with the most recent position statement of the European Association for Cardio-Thoracic Surgery vascular domain.[19] Triple-phase CTA follow-up was performed at least after 1 and 12 months, and on an annually basis thereafter (Figures 2, *C1*, 3, *D*, and 4, *F*). Graft materials are reported in the Appendix E1.

Definition and Primary Outcomes

Medical comorbidity grading system, operative outcomes, and follow-up index were defined according to recommended reporting standards and best practice documents of the Society for Vascular Surgery and of the European Association for Cardio-Thoracic Surgery/European Society for Cardio-Vascular Surgery.[19-21] For this particular series, primary technical success was defined as the successful deployment of the SG with the exclusion of the aortic lesion in the absence of surgical conversion to open repair or death at 24 hours or less and patency of the ILVA. TEVAR-related mortality included deaths due to aortic rupture, surgical conversion, or complications of TEVAR unsolved by additional procedures. Primary outcomes were early (<30 days) and late survival, freedom from aortic-related mortality, and ILVA patency during follow-up.

Classifications

Classification of the vertebral artery variable origin was defined according to Lazaridis and colleagues.[4] Aortic arch aneurysms were classified according to Cooley and colleagues[22] based on the extent of the aneurysm and the repair. The type of open hybrid aortic arch repair was classified according to Bavaria and colleagues.[17] Proximal landing zone of the thoracic SG was defined following the arch map classification.[23]

Statistical Analysis

Clinical data were prospectively recorded and tabulated in a Microsoft Excel (Microsoft Corp, Redmond, Wash) database. Statistical analysis was performed with SPSS, release 23.0 for Windows (IBM SPSS Inc, Chicago, Ill). Continuous variables were tested for normal distribution by the

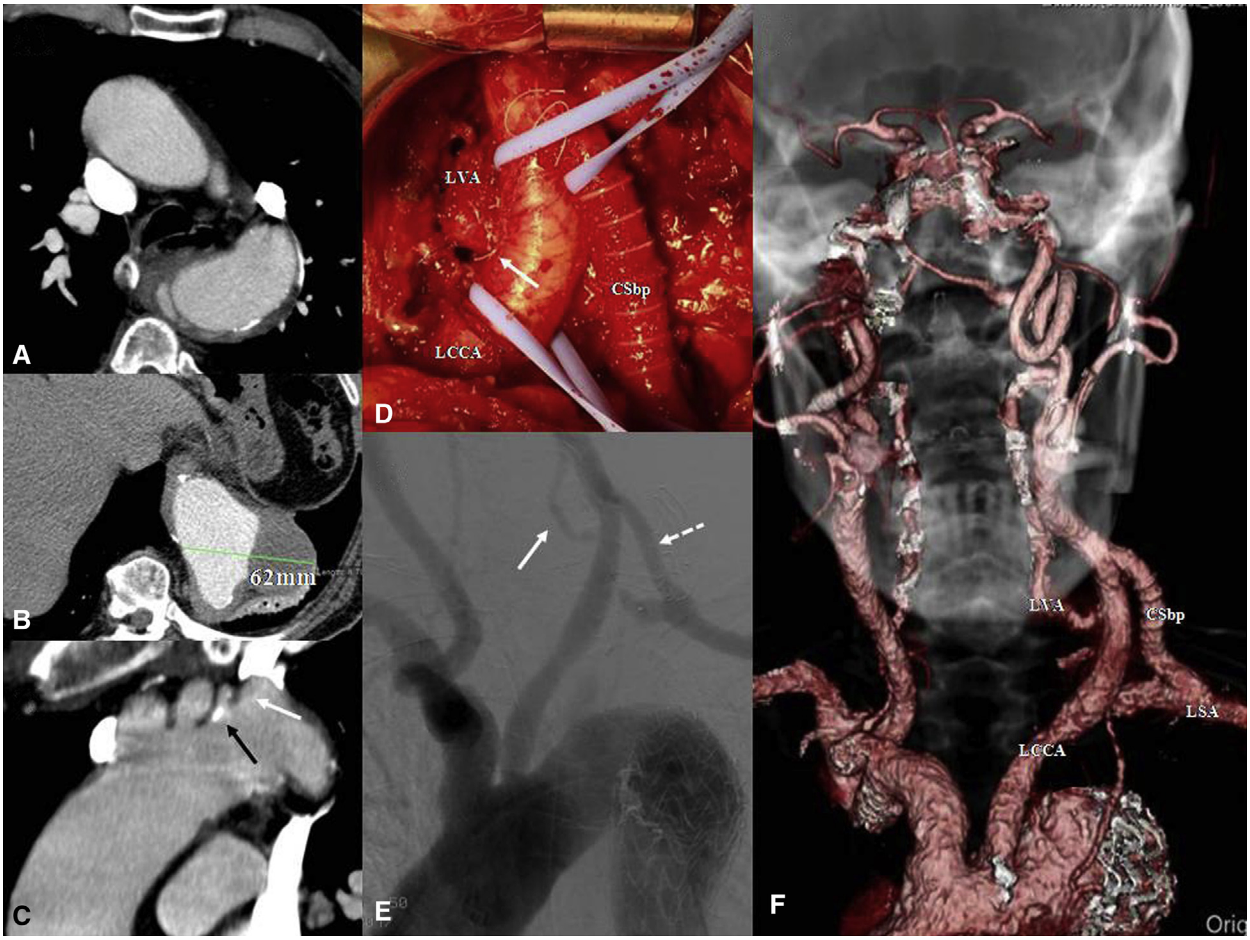

FIGURE 4. "Zone 2" TEVAR: preoperative CTA (A) showed the presence of a complex lesion of the distal arch/descending aorta comprising ulcer-like projections leaking into a descending aneurysm (B). Multiplanar reconstruction documented the presence of an ILVA (C, *black arrow*) just proximal to the LSA origin (C, *white arrow*). Intraoperative view (D) showing the final result of the CSbp and ILVA transposition (*white arrow*): Final completion angiography confirmed the patency of the transposed ILVA (E, *white arrow*) and the CSbp (E, *dotted white arrow*). Follow-up CTA study with the 3-dimensional volume rendering analysis of the cervical reconstruction and the integrity of the Circle of Willis (F). *CSbp*, Carotid-subclavian bypass; *LCCA*, left common carotid artery; *LVA*, left vertebral artery.

Kolmogorov–Smirnov test. Continuous variables were presented with mean ± standard deviation and interquartile range (IQR); otherwise, medians with range were applied. Categoric variables were presented using frequencies and percentages.[20]

RESULTS

Study Cohort

Indication for operative repair and aortic disease extent in the 9 patients with ILVA is reported in Table 1. An anatomic variant of the vertebral arteries was significantly higher in patients with aortic arch pathologies if compared with those confined to the descending/thoracoabdominal aorta (14.2% vs 0.7%; odds ratio, 16.7; $P < .001$). Mean age of patients was 76 ± 3 years (IQR, 73-79), and mean aortic diameter was 62 ± 1.1 mm (IQR, 5.4-6.5). Demographics, comorbidities, and risk factors are shown in Table 2. According to the proposed classification, ILVA presented with the LA2.2 configuration in all cases. In 1 patient, the ILVA was occluded a few millimeters after its origin from the arch along with an asymptomatic occlusion of the left internal carotid artery. Mean ILVA diameter was 3.1 ± 1.0 mm (IQR, 2.2-3.6), and the contralateral vertebral artery mean diameter was 3.5 ± 0.6 mm (IQR, 3.2-4). The ILVA was the dominant vertebral artery in 2 cases and entered the circle of Willis to form the basilar artery in all cases.

Isolated Left Vertebral Artery Interventions

In 3 cases, the ILVA was not transposed: "zone 3" TEVAR (n = 1), chronic occlusion at the origin (n = 1), and isolated transverse open arch graft replacement for a saccular aneurysm of the aortic concavity (n = 1). Therefore, transposition of the ILVA was performed in 6 patients. Elective intervention was performed in 4 cases.

TABLE 1. Classification of the thoracic aortic disease treated with hybrid aortic arch repairs in the presence of isolated left vertebral artery

Type of aortic disease	Study cohort (n = 9)	Open aortic non-TEVAR (n = 79)
Aortic arch		
Degenerative atherosclerotic	4	38
Cooley class[22]		
Type A	2	4
Type B		30
Type C	1	4
Type D	1	
Dissection related	3	
DeBakey class*		
Type I	1	28
Type IIIa	2	
Descending/thoracoabdominal aorta		13
Degenerative atherosclerotic	1	
Estrera†		
Type A		1
Type C		2
Crawford-Safi‡		
Type I		2
Type II		3
Type III		2
Type V		1
Dissection related		2
DeBakey class IIIb		
Intramural hematoma	1	
DeBakey class B		

TEVAR, Thoracic endovascular aortic repair. *Debakey ME, Henly WS, Cooley DA, Morris GC Jr, Crawford ES, Beall AC Jr. Surgical management of dissecting aneurysms of the aorta. *J Thorac Cardiovasc Surg*. 1965;49:130-49. †Estrera AL, Rubenstein FS, Miller CC III, Huynh TT, Letsou GV, Safi HJ. Descending thoracic aortic aneurysm: surgical approach and treatment using the adjuncts cerebrospinal fluid drainage and distal aortic perfusion. *Ann Thor Surg*. 2001;72:481-6. ‡Safi HJ, Estrera AL, Miller CC, Huynh TT, Porat EE, Azizzadeh A, et al. Evolution of risk for neurologic deficit after descending and thoracoabdominal aortic repair. *Ann Thorac Surg*. 2005;80:2173-9.

TABLE 2. Demographic data, comorbidities, and risk factors

Variable (%)	n (%, IQR)
Comorbidities	
Hypertension	6 (100)
Dyslipidemia	5 (83)
COPD	3 (50)
Obesity (BMI >30)	3 (50)
Previous VTx	2 (33)
AAA open repair	
Valve disease	1 (16.7)
Previous stroke	1 (16.7)
Risk factors (%)	
Urgency	2 (33.3)
SVS score (mean ± SD)	8.8 ± 3.1 (6.5-10.8)
$euroSCORE_{log}$ (mean ± SD)	30.6 ± 10.8 (24.3-39.4)
$euroSCORE_{II}$ (mean ± SD)	9 ± 7 (3.9-11.6)

IQR, Interquartile range; *COPD*, chronic obstructive pulmonary disease (Gold stage ≥2); *BMI*, body mass index; *VTx*, vascular treatment; *AAA*, abdominal aortic aneurysm; *SVS*, Society for Vascular Surgery; *SD*, standard deviation; *euroSCORE*, European System for Cardiac Operative Risk Score.

First Stage: Proximal Aortic Repair

Open ascending/arch repair was performed in 5 cases. In 2 cases, the ILVA transposition was performed during the same operation, and 1 case had concomitant coronary artery bypass graft. Distal anastomosis during open ascending/arch repair was always performed between the LCCA and the LSA. Mean cardiopulmonary bypass time was 186 ± 72 minutes (IQR, 165-239), myocardial ischemic time was 103 ± 60 minutes (IQR, 61-155), and systemic arrest time was 51 ± 20 minutes (IQR, 39-50). Mean length of stay in ICU after open ascending/arch repair was 4 ± 2 days (IQR, 4-5), and mean hospitalization was 12 ± 7 days (IQR, 9-14).

Thoracic Endovascular Aortic Repair Procedure

Four patients underwent ILVA transposition during concomitant CSbp and TEVAR completion: 2 after open arch repair and 2 for isolate "zone 2" TEVAR. Mean ILVA occlusion time was 9 ± 2 minutes (IQR, 8.5-9.8). Overall, 6 patients received 2 SGs or more; mean aortic coverage was 32 ± 9 cm (range, 20-40; IQR, 24-39). Median length of stay in ICU after TEVAR was 2 days (range, 0-4), and mean hospitalization was 4 ± 2 days (IQR, 3-5). Type of operative repair, SG implanted, and thoracolumbar level of the SG distal landing zone are reported in Table 3.

Early Outcomes

Primary technical success was achieved in all cases. Complication occurred in 3 cases. Retrograde acute type A dissection occurred in a patient after type I hybrid aortic arch repair (ILVA was not transposed because chronically occluded). Acute lung injury needing prolonged ventilation occurred in a patient with oxygen-dependent chronic respiratory insufficiency who underwent isolate ILVA transposition and TEVAR. Horner's syndrome was observed in 1 patient. Immediate thrombosis, vagus/recurrent laryngeal nerve palsy, lymphocele, and chylothorax were never observed. Postoperative cerebrovascular accident or spinal cord injury was not observed.

Late Outcomes

All patients who survived underwent a regular follow-up program, and none were lost: Median follow-up was 15 months (range, 3-72; follow-up index = 1). Only 1 patient died after 4 months as the result of oxygen-dependent chronic respiratory insufficiency and progressively worsening respiratory condition. The remaining patients are alive and living independently. Both ILVA and CSbp are still patent in all patients with

TABLE 3. Case series summary: Anatomic and technical details

Gender	Age, y	Aortic disease	Extent	Intervention (type)	Urgent	Left CS bypass	ILVA transposition	SG	Distal LZ	Complication	Outcome	Follow-up (mo)
M	80	B-IMH	Descending	TEVAR	No	No	No	Relay	T9	No	Alive	60
F	74	TAA	Arch	SAT debranching	No	Yes	No	Relay	T6	RTAAD	Death (3rd postoperative)	0
F	73	ATBAD	Arch + descending	Open arch graft replacement	Yes	No	Yes	Zenith Alpha	T12	No	Alive	12
M	79	TAA	Descending	TEVAR	Yes	Yes	Yes	C-TAG	L1	Respiratory insufficiency	Death (4 mo)	3
F	72	TAA	Arch + descending	Open arch graft replacement	No	Yes	Yes	Valiant Captivia	T10	No	Alive	3
M	78	CTAAD	Arch + descending	Open arch graft replacement	No	No	Yes	C-TAG ac	T11	No	Alive	3
M	72	CTAAD	Arch + descending	TEVAR	No	Yes	Yes	C-TAG ac	T11	No	Alive	3
F	83	TAA	Arch + descending	Open arch graft replacement	Yes	No	Yes	C-TAG ac	T8	No	Alive	3
M	56	TAA	Arch	Open arch graft replacement	Yes	No	No			No	Alive	3

CS, Carotid-subclavian; *ILVA*, isolated left vertebral artery; *SG*, stent-graft; *LZ*, landing zone; *B-IMH*, type B intramural hematoma; *TEVAR*, thoracic endovascular aortic repair; *TAA*, thoracic aortic aneurysm; *SAT*, supra-aortic trunk; *RTAAD*, retrograde type A acute dissection; *ATBAD*, acute type B aortic dissection; *C-TAG*, conformable thoracic aortic graft; *CTAAD*, chronic type A aortic dissection.

no sign of anastomotic pseudoaneurysm or stenosis. We did not observe aortic-related mortality during the follow-up, aortic-related intervention was never required, and conventional graft/SG infection or endoleaks were never detected.

DISCUSSION

Because SAT variants have a prevalence range of 25.6% to 33.5%, recognizing their presence is extremely important in the treatment of aortic arch/descending thoracic aortic diseases to avoid major complications.[1-4,6-9,12-16] Among SAT variants, ILVA is the second most frequently observed branch variation: The 4.5% prevalence in our TEVAR cohort is in line with the 0.8% to 6.3% rate reported in the literature, according to the different type of cohort evaluated (eg, surgical, autoptic, radiologic).[3,4]

This variant is a demanding situation. Lazaridis and colleagues[4] performed a systematic classification of the vertebral artery variable origin and outlined the presence of different configurations of the vertebral anomalies that may have clinical and surgical implications. In our cohort, ILVA was detected often unilaterally and had a single direct aortic origin between the LCCA and the LSA in all cases, which has been reported to be the most frequent configuration among vertebral artery anomalies.[4] The only unexpected finding in our cohort was that atypical ILVA origin had a right-side predominance in 55% of the cases.[4,8,9] All these characteristics may play an important role when planning aortic arch repair either surgically or with TEVAR.

Whether the ILVA should be reconstructed in all cases is currently a matter of debate: Specific recommendations on ILVA transposition have not been widely adopted.[6,10,11] Ding and colleagues[24] used a selective algorithm for ILVA transposition during TEVAR for type B aortic dissection, mainly dictated by the proximal landing zone of the SG. However, missing ILVA or a simple coverage without transposition may cost major neurologic complications such as posterior stroke or spinal cord ischemia. Our experience is somewhat different because we had to manage ILVA in different aortic arch scenarios. Three additional reasons formed the basis why we preferred to perform ILVA transposition under any circumstances. Transposition during open ascending/arch surgery has been recommended if technically feasible, but indication during TEVAR with hybrid cervical debranching has been left to single-center experiences.[5,11,25] Second, although experience with a large number of cases from the literature is lacking, case reports published to date have reported satisfactory technical and clinical outcomes after ILVA transposition during TEVAR (Table 4).[5,12-16] Last but not least, additional risk factors such as extensive aortic coverage, especially in the presence of a previous abdominal aortic surgery, may be accepted indication for a nondominant ILVA. This latter was the case in a patient had a previous infrarenal aortic aneurysm repair and was admitted with a contained rupture and hypotension, 2 previously described predictors of increased risk of spinal cord injury during TEVAR.[11,26,27] Maintaining a valid technical expertise will be even more important when single-branch thoracic devices will be available on the market for a total endovascular repair during "zone 2" TEVAR.

In aortic surgery, technical aspects are no less important than the surgical decision-making process. Considering hybrid cervical debranching for "zone 2" TEVAR, ILVA

TABLE 4. Hybrid aortic arch TEVAR in patients with aberrant left vertebral artery: Literature summary

Author	Year	Patient (n)	Aortic disease	ILVA configuration	Treatment (type)	ILVA treatment	LSA management	TEVAR	Complication	Stroke	SCI	Follow-up (mo)	Outcome	ALVA status
Gottardi and colleagues[12]	2005	1	DTAA	LA2.2	SAT debranch	Transposition onto LCCA	Overstented	2-stage	No	No	No	3	Alive and well	Patent
Moss and colleagues[13]	2013	1	DTAA	LA2.2	SAT debranch	Transposition onto LCCA	Bypass graft	2-stage	AF	No	No	6	Alive and well	Patent
Massimi and Woo[5]	2017	2	DTAA	LA2.2	Cervical debranch	Transposition onto LCCA	Bypass graft	1-stage	No	No	No	6, 12	Alive and well	Patent
Lee and colleagues[14]	2017	1	DTAA	LA2.2	Cervical debranch	Transposition onto LCCA	Bypass graft	2-stage	No	No	No	Not specifically reported	Alive and well	Patent
Blumberg and colleagues[15]	2017	1	B-IMH	LA2.2	Cervical debranch	Transposition onto LCCA	Bypass graft	2-stage	No	No	No	12	Alive and well	Patent
Takei and colleagues[16]	2018	1	DTAA	LA2.2	SAT debranch	Transposition onto LCCA	Bypass graft	1-stage	No	No	No	Not specifically reported	Not specifically reported	Patent

ILVA, Isolated left vertebral artery; *LSA*, left subclavian artery; *TEVAR*, thoracic endovascular aortic repair; *SCI*, spinal cord ischemia; *ALVA*, apical left ventricular aneurysm; *DTAA*, descending thoracic aortic aneurysm; *SAT*, supra-aortic trunk; *LCCA*, left common carotid artery; *B-IMH*, type B intramural hematoma.

transposition onto the LCCA could be a technically demanding intervention.[5,15] However, in general the LSA is easily manageable by the supra-clavicular approach and the ILVA is readily accessible because of its posterior, parallel course to the LCCA. Moreover, good and durable results have been reported in surgical series dealing with extracranial left vertebral artery reconstructions.[28-31] Although Blumberg and colleagues[15] proposed a different reverse technique, in our experience we used the same technique performed for left hemiarch debranching, with CSbp that was performed first. This sequence allowed us to maintain antegrade perfusion to the ILVA during the CSbp, whereas during carotid crossclamping for ILVA transposition the reversed flow in the CSbp continued to perfuse the brain thus minimizing the risk of ischemic injury. Considering transposition during open hybrid arch repairs, others have described several types of separate transposition of the ILVA.[31] In our experience, we opted to use the Griepp ‘‘arch first’’ technique for 2 reasons. First, in our 2 cases, SAT anatomy helped us because all vessels were close together. Second, it required a single anastomosis, thus reducing the operating time while avoiding making such a delicate anastomosis of a small-caliber vessel in a high-pressure aortic area. Last, this type of graft configuration still secured us a technical ease TEVAR deployment within a safe prosthetic landing zone.[17]

A 2-stage approach was used preferentially for type II hybrid arch repair. With our policy, this allowed to stabilize

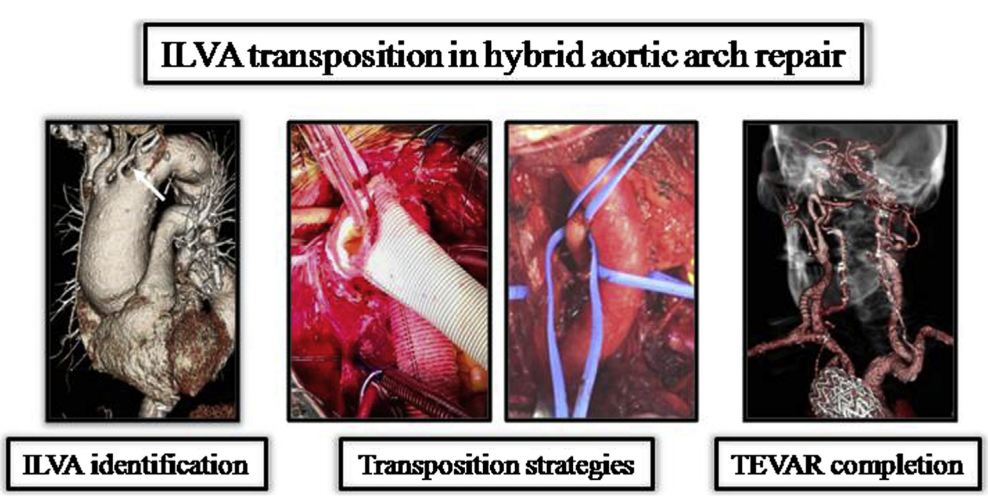

FIGURE 5. ILVA transposition strategies during hybrid aortic arch repair with TEVAR. *ILVA*, Isolated left vertebral artery; *TEVAR*, thoracic endovascular aortic repair.

the patient to optimize the hemodynamic status and limit the ischemic insult to the spinal cord after such demanding operation. This concept has gained popularity in other interventions, open or endovascular, for similar extensive aortic diseases.[32-34] In contrast, a single-stage approach was chosen for cervical debranching and TEVAR. We believe this is an expeditious intervention, and coverage of the ILVA from the arch may helped to prevent a blowout syndrome from that stump.[5,16]

A final comment should be made regarding interesting epidemiologic data, which is the prevalence of arch vessels anomalies in some patients with thoracic aortic pathologies. Specifically, multiple studies reported a higher prevalence of arch vessels anomalies in patients with dissections when compared with controls.[35] In our experience, the prevalence of vertebral arteries variants was significantly higher in patients with aortic arch pathologies if compared with those with descending thoracic lesions. However, although we treated 3 patients with aortic dissection, the small number of patients and the absence of a comparative group in our experience prevent us from drawing any type of definitive conclusions. There is no evidence supporting that ILVA predisposes to cardiovascular disorders, but most thoracic aortic pathologies were treated in our cohort, as also occurred in the Yale experience.[3,36]

Study Limitations

There are obvious limitations in our case series. The study is retrospective, the cohort is small, and there was no control group. These characteristics and the rarity of such anatomic variants do not allow us to make definitive statements or recommendations from a clinical or technical point of view. Nevertheless, these issues are typical and common in all studies reporting on rare conditions, and this is the first case series reporting on surgical management of such clinical scenario. We hope future larger registry or studies will help to better address such a challenging situation of aortic arch surgical repairs.

CONCLUSIONS

Although ILVA is not a frequent occurrence, it also is not rare. Although it may increase the time of intervention and technical difficulties during open aortic arch graft replacement or "zone 2" TEVAR with cervical debranching (Figure 5), ILVA transposition was feasible, safe, effective, and durable. Clinical indication and technical strategy need to be better addressed in aortic surgery guidelines.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: hybrid aortic arch repair, isolated left vertebral artery, vertebral artery transposition

APPENDIX E1

Thoracic aortic graft
- Stent-graft
- TAG/C-TAG (WL Gore and Associates, Flagstaff, Ariz)
- Captivia (Medtronic Vascular, Santa Rosa, Calif)
- Relay (Bolton Medical, Sunrise, Fla)
- Arch graft replacement
- Hemashield Platinum (Maquet Getinge Group, Rastatt, Germany)

Left subclavian artery management
- Occlusion plug
- Amplatzer (St Jude Medical, St Paul, Minn)
- Carotid-subclavian bypass
- Propaten (WL Gore and Associates, Flagstaff, Ariz)
- Omniflow II (Le Maitre Vascular, Burlington, Mass)