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ORIGINAL ARTICLE / ÖZGÜN MAKALE

Transverse arch stenting and its effect on systemic hypertension

Transvers ark stentleme ve sistemik hipertansiyon üzerine etkisi

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ABSTRACT

Background: This study aimed to investigate the safety and efficacy of transverse aortic arch stenting and evaluate the course of hypertension and the act of arch stenting on systemic hypertension.

Methods: The transverse aortic arch stenting procedures between January 2007 and May 2023 were retrospectively analyzed. Detailed procedure information, technical aspects, pressure measurements, angiographic data, balloons and stents used, complications, and immediate results were examined. Early and mid-term results were assessed.

Results: Eighteen patients (10 males and 8 females; mean age: 14.5±5.3 years; range, 4 to 23 years) were included in the study, all of whom were hypertensive before the procedure. The mean weight was 56.8±19.6 kg. In seven patients, the stent struts had to be dilated due to the stent causing jailing at the entrance of nearby arch vessels. After stenting, there was a significant increase in arch diameter and a decrease in ascending aorta pressure and the pressure gradient across the aorta. There were no early mortality or major complications. Late migration of the stent was observed in one patient. Three patients became normotensive immediately after the intervention, and five became drug-free during the follow-up. The requirement for dual antihypertensive therapy was significantly reduced.

Conclusion: Residual transverse arch lesions may contribute to the persistence of systemic hypertension after coarctation treatment. Transverse arch stent implantation can be performed safely with favorable outcomes, facilitating better blood pressure control. However, it should be noted that these patients remain at risk for lifelong hypertension and should be closely monitored in this regard.

Keywords: Aortic arch stenting, hypertension, coarctation.

ÖZ

Amaç: Bu çalışma, transvers aortik ark stentlemesinin güvenilirliğini ve etkinliğini araştırmayı ve hipertansiyonun seyrini ve ark stentlemesinin sistemik hipertansiyon üzerine etkisini incelemeyi amaçladı.

Çalışma planı: Ocak 2007 - Mayıs 2023 tarihleri arasında gerçekleştirilen transvers aortik ark stentleme işlemleri retrospektif olarak incelendi. Detaylı prosedürel özellikler, teknik yönler, basınç ölçümleri, anjiyografik veriler, kullanılan stent ve balonlar, komplikasyonlar ve erken dönem sonuçlar incelendi. Erken ve orta dönem sonuçlar değerlendirildi.

Bulgular: On sekiz hasta (10 erkek, 8 kadın; ort. yaş: 14.5±5.3 yıl; dağılım, 4-23 yıl) çalışmaya dahil edildi ve bunların tamamı işlem öncesinde hipertansifti. Ortalama ağırlık 56.8±19.6 kg idi. Yedi hastada stentin yakındaki ark damarlarının girişinde tıkanıklığa neden olması sebebi ile stent hücrelerinin dilate edilmesi gerekti. Stentlemeden sonra ark çapında anlamlı bir artış ve çıkan aort basıncında ve aort boyunca basınç gradiyentinde bir azalma oldu. Erken mortalite veya majör komplikasyon görülmedi. Bir hastada stentin geç migrasyonu izlendi. Üç hasta işlemden hemen sonra normotansif duruma gelirken, beş hastada takip sırasında ilaç tedavisi kesildi. İkili antihipertansif tedavi ihtiyacı belirgin şekilde azaldı.

Sonuç: Rezidüel transvers ark lezyonları koarktasyon tedavisi sonrası sistemik hipertansiyonun sebat etmesine katkıda bulunabilir. Transvers ark stent implantasyonu olumlu sonuçlarla güvenli bir şekilde uygulanabilir ve daha iyi bir kan basıncı kontrolüne katkıda bulunur. Ancak bu hastalar yaşam boyu hipertansiyon riski altında olduğundan bu açıdan yakın kan basıncı takibi gerektiği dikkate alınmalıdır.

Anahtar sözcükler: Arkus aorta stenti, hipertansiyon, koarktasyon.

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Aortic coarctation, even if treated surgically or by transcatheter interventions, remains one of the most significant causes of morbidity and mortality, mainly due to systemic hypertension.[1,2] Despite successful treatment of anatomical narrowing, hypertension may persist in many patients.[2,3] Although the exact cause of persistent systemic hypertension in these patients is unclear, different reasons have been proposed.[3,4] Aortic arch and isthmus hypoplasia can be isolated lesions or may persist even after adequate coarctation surgery.[5] It is believed that transverse aortic arch (TAA) lesions (stenosis or hypoplasia) may play a role in the etiology of hypertension.[5-8]

Surgical repair is the primary treatment option for TAA lesions, while transcatheter balloon dilatation and stent implantation are alternative options.[5] A limited number of studies exist about stent implantation in TAA lesions.[5,9,10] This study focused on two main points: investigating the safety, efficacy, and outcomes of aortic arch stenting and evaluating the course of hypertension, blood pressure changes, assessed medication requirements, and the act of arch stenting to systemic hypertension.

PATIENTS AND METHODS

Patients who underwent percutaneous TAA stenting at the Siyami Ersek Thoracic and Cardiovascular Surgery Training and Research Hospital, Department of Pediatric Cardiology between January 2007 and May 2023 were retrospectively analyzed. Demographic features, clinical history, physical examination findings, blood pressure measurements, echocardiographic and radiological findings, medications, and indications for the interventions of all subjects were noted. Detailed information about the procedure, technical aspects, pressure measurements, angiographic data, balloons and stents used, complications, and immediate results were collected from catheterization reports. Additionally, angiographic records of all patients were reanalyzed by at least two experienced interventionists. Early and mid-term findings during the follow-up period were examined from file records. Pre- and postintervention ambulatory blood pressure monitoring records of the patients were also analyzed.

Regardless of any previous surgery or intervention, patients who underwent TAA stenting were included. Previous surgical or interventional procedures were noted in all patients. Systemic hypertension was defined as a systemic blood pressure of more than the 95th percentile at least twice for children and a blood pressure >140/90 mmHg for adults. Systemic hypertensive patients weighing >20 kg who did not require any additional surgery in terms of arch lesion and additional defect and with at least one of the following were taken to the catheterization laboratory: turbulent flow with a pressure gradient >2.5 m/sec (obtained with pulsed wave Doppler at any part of the aortic arch), a blood pressure difference of >10 mmHg between the right and the left arm, and aortic arch hypoplasia detected on computed tomography (<60% of ascending aortic diameter for proximal aortic arch and <50% for distal aortic arch). Stent implantation was performed if a pressure gradient <10 mmHg was detected on any level of the aortic arch at catheterization. Surgery was performed as the initial preference for patients weighing <20 kg.

Antibiotics for infective endocarditis prophylaxis were given before catheterization. All procedures were performed under deep sedation, and a 6 French (Fr) sheath was placed in the right femoral artery and vein. Heparin 100 IU/kg was given once vascular access was obtained, and additional doses were provided if needed to obtain an ACT level >250 sec. Pressure records of the ascending aorta, proximal aortic arch, distal aortic arch, and descending aorta were taken before and after the intervention. After the initial pressure

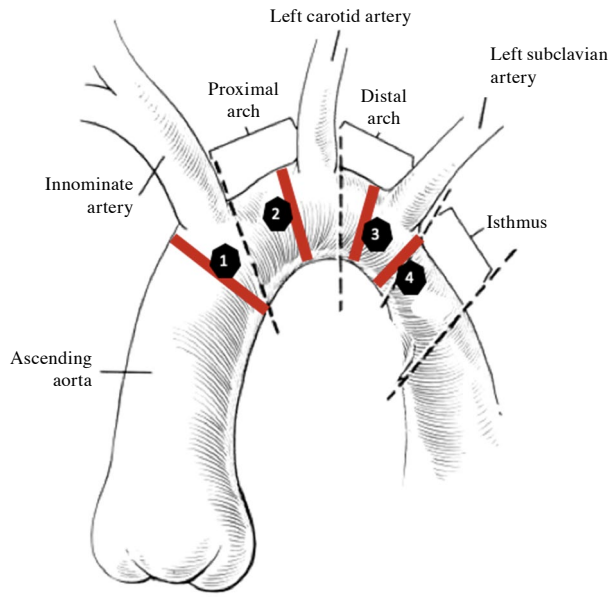

Figure 1. The aortic arch has been diagrammed with designated measurement points. Measurements include: 1) Ascending aorta diameter just before the innominate artery, 2) Proximal transverse arch diameter between the innominate and left carotid artery, 3) Distal arch diameter between the left carotid and left subclavian artery, 4) Isthmus diameter just after the left subclavian artery.

measurements, contrast injection was performed with a pigtail catheter in 70° and 30° left-anterior-oblique biplane projection, and arch diameters were measured. Ascending aorta diameter was measured just before the innominate artery, and the part of the arch diameters were as follows: the proximal transverse arch diameter between the innominate and left carotid artery, the distal arch diameter between the left carotid and left subclavian artery, and the isthmus just after the left subclavian artery (Figure 1). The lesion was described as hypoplasia if it was >5 mm.

The guidewire was parked in the ascending aorta, a temporary pacemaker was placed in the right ventricle, and stent implantation was performed during rapid ventricular pacing at a rate of 150 to 180/min depending on the patient's age through a pacing catheter placed in the right ventricle, and an initial 50% drop in systolic blood pressure during pacing was considered sufficient.

Transverse aortic arc stenting was defined as stent placement traversing any aortic arch vessel, with the primary intention of treating the narrowing or hypoplasia of the transverse aorta. The Cheatham-Platinum (CP) stent (NuMED Inc., Hopkinton, NY, USA) or AndraStent (Andramed GmbH, Reutlingen, Germany) were used as bare stents (Figures 2, 3). A Z-Med (NuMED, Hopkinton, NY, USA) or BIB (Balloon in Balloon; NuMED, Hopkinton, NY, USA) catheter with an outer diameter

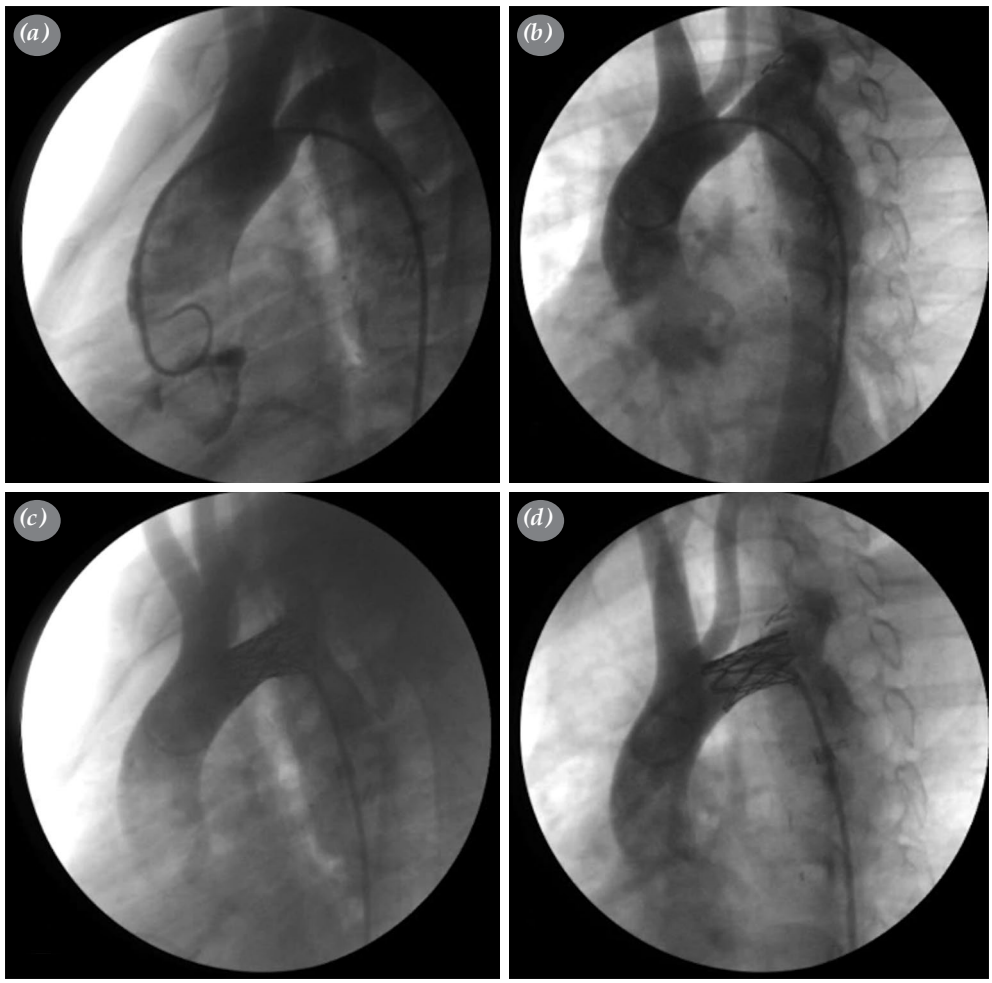

Figure 2. Aortic angiogram of a patient with repaired interrupted aortic arch in the neonatal period. The classical coarctation site had been well repaired without residual stenosis or gradient. **(a, b)** However, the segment between left carotid and left subclavian artery was hypoplastic with a 18 mmHg systolic gradient. **(c, d)** A 22 mm Cheatham platinum stent mounted on 12 mm Z Med balloon was implanted. After implantation of the stent only 2 mmHg pressure gradient was measured.

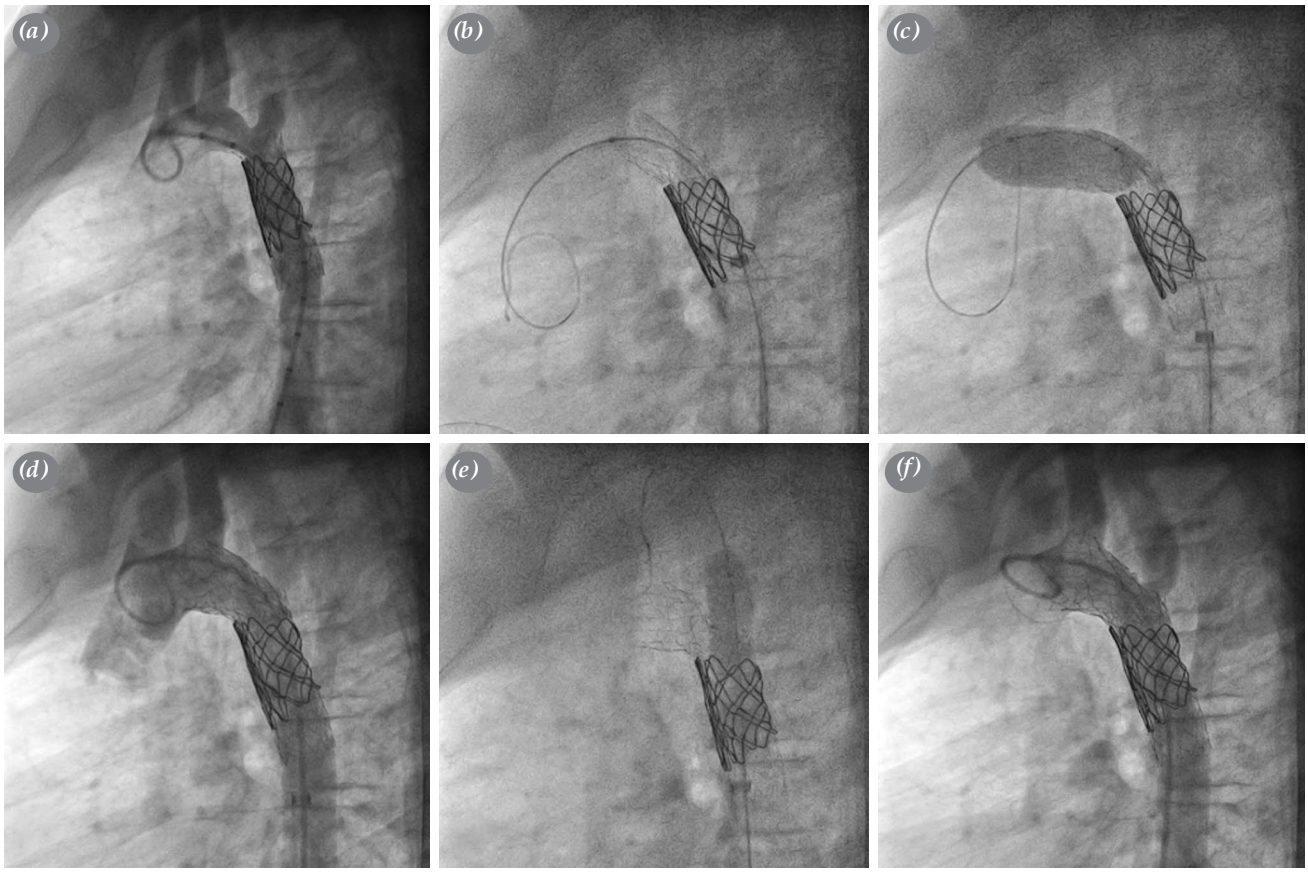

Figure 3. Angiographic views of a patient performed at different ages. **(a)** The patient had undergone stent implantation with a Cheatham-Platinum stent and AndraStents® at the age of six and eight, respectively. **(b)** Since the patient remained hypertensive with the presence of a narrow distal aortic arch with a 32-mmHg pressure gradient, a 30 mm AndraStent® XL mounted on a 14 mm Z Med balloon was implanted in the distal aortic arch when the patient was 13 years old. **(c)** After stent implantation, a 16 mm Tyshak balloon was used to flank its distal and proximal parts. **(d)** The left subclavian artery was intentionally jailed with relatively reduced contrast filling. **(e)** To enhance blood flow in the left subclavian artery, the stent struts were dilated with a 9 mm Z-Med balloon. **(f)** In the final angiogram, it is observed that the stenosis in the distal transverse arch has been resolved, and there is an increased blood flow in the left subclavian artery without any pressure gradient.

1 to 2 mm above the largest vessel diameter adjacent to the lesion was used for stent implantation. The stent length was decided according to the lesion length to cover the entire lesion completely. After stent implantation, a semicompliant balloon (Tyshak; NuMED Inc., Hopkinton, NY, USA, or VACS II; Osypka Inc., Rheinfelden, Germany) 1 to 2 mm larger than the initial balloon diameter was used to flank its distal and proximal parts and achieve the desired anatomical shape (Figure 3). A control angiogram was performed after the procedure, and jailing of the arch vessels was examined with particular caution. If any arch vessels were jailed, gradual dilatation of stent struts adjacent to these vessels was performed. Dilatation of the stent struts was carried out using semicompliant or noncompliant balloons, with a balloon diameter not exceeding the diameter of the cranial vessels after passing the guidewire between the stent struts (Figure 4). The procedure was accepted successfully with a decrease in the preprocedural pressure gradient (<10 mmHg) and an increase in the arch vessel of at least 50% of the initial diameter. Additionally, we administered aspirin to patients after the TAA stent implantation for six months.

Patients were regularly followed at six-month intervals, starting from the first month after the procedure. During follow-up, echocardiography and ambulatory pressure Holter monitoring were conducted. Additionally, routine computed tomography imaging was performed in the six-month follow-up.

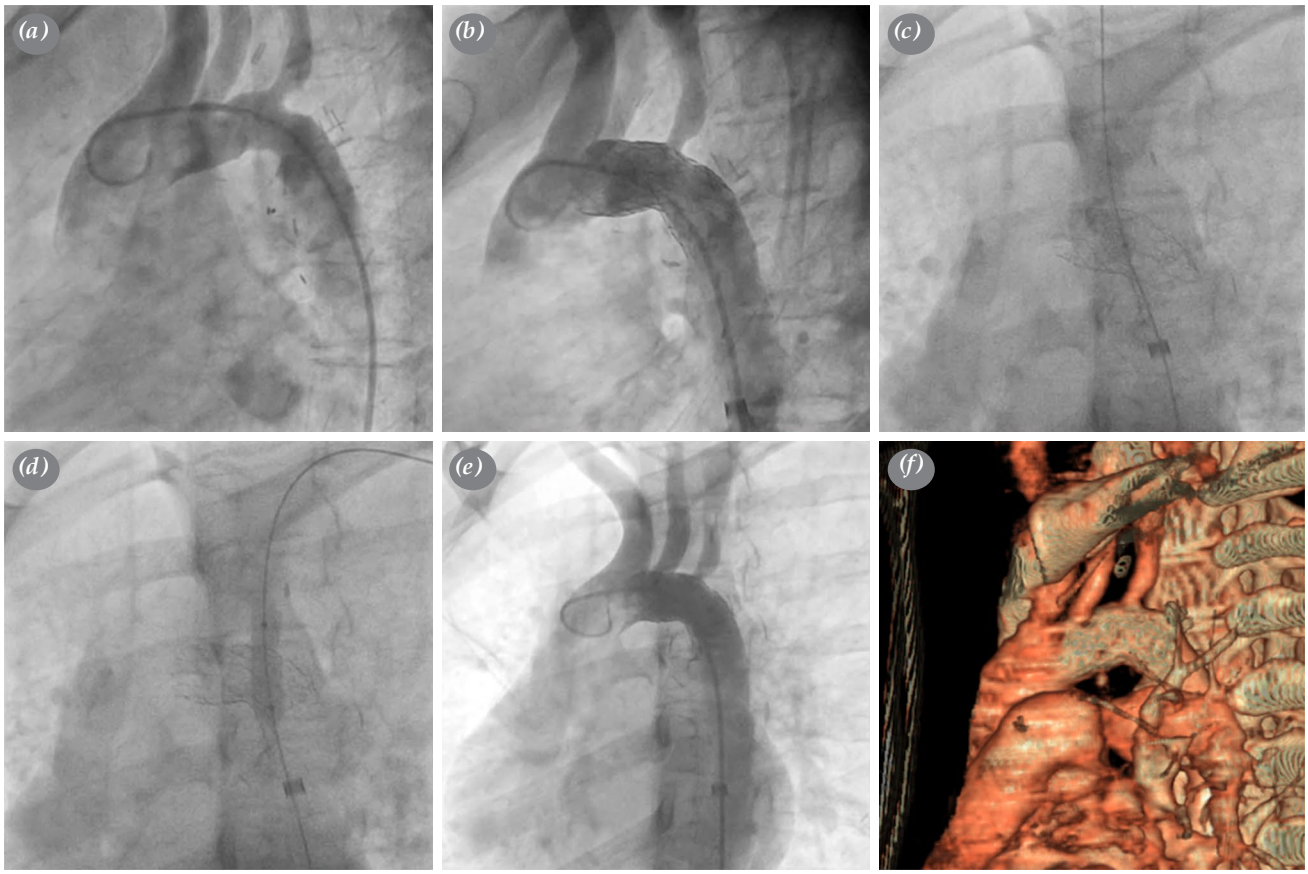

Figure 4. An 18-year-old female with a history of surgical coarctation repair at age 10. The coarctation site was well repaired without significant residual stenosis. **(a)** On aortic angiogram distal and proximal transverse arch obstruction with a 38 mmHg systolic pressure gradient was detected. **(b)** Also note the proximal left subclavian artery stenosis. A 35 mm XXL AndraStent® mounted on 18 mm BIB balloon was implanted to aortic arch. **(c, d)** Left carotid and subclavian artery was intentionally jailed by the stent. So, dilatation of stent struts adjacent to these vessels was performed with a 8 mm Z Med balloon. A 20 mm Tyshak balloon was used for post-dilation to ensure stent conformity to the anatomical arch and to achieve a better curve. **(e)** Control angiogram and **(f)** 3D reconstruction of post-procedure cardiac CT scan (six month after the procedure) revealed excellent filling of left carotid and subclavian artery.
BIB: Balloon in Balloon; CT: Computed tomography.

Statistical analysis

All analyses were performed using IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). Descriptive statistics were used for demographic data. Quantitative data were presented as mean ± standard deviation or frequency (%). Mean values before and after stent placement were compared using the paired samples t-test. A *p*-value <0.05 was considered statistically significant.

RESULTS

Coarctation stent implantation was performed on 355 patients in our center. Nineteen TAA stent procedures were performed in 18 patients (10 males and 8 females; mean age: 14.5±5.3 years; range, 4 to 23 years). Considering previous interventions for native (classically located) coarctation, transcatheter interventions were performed in 12, only surgery was performed in five, and both approaches were performed in the remaining two (Table 1). Hypertension was present before the procedure in all patients. Fourteen (77.7%) patients were already taking at least one antihypertensive medication before the intervention, six (33.3%) were on two drugs, and eight (44.4%) were on one medication (Table 1). Eleven patients were also found to have a bicuspid aortic valve. None of the patients had a Z-score above +3 regarding the diameters of the ascending aorta. Some patients had undergone multiple interventions or surgeries at different levels of coarctation before TAA stent placement. The mean

Table 1. Patients table on transverse arch stenting

Case No	Age at intervention (year)	Body weight at intervention (kg)	Initial diagnosis	History: Previous interventions (surgery, catheter intervention, etc.)			Non-invasive blood pressure before procedure	Medications used before procedure	Systolic BP (AAO) at cath before (mmHg)	Systolic BP (AAO) at cath after (mmHg)	AAO-DAO PG before (mmHg)	AAO-DAO PG after (mmHg)	Transverse arch diameter before (mm)	Transverse arch diameter after (mm)	F-U Duration (month)	24-h Ambulatory blood pressure in F-U	Medications in follow-up
				Surgery	Balloon	Stent											
1	23.0	68	CoA	+			170/100	BB, ACE	145	135	45	7	11.5	15.3	174	155/92	BB, ACE
2	9,1	21	IAA	+			145/85	BB	142	122	18	2	9.1	11.3	174	126/65	BB
3	13,1	40	CoA	+			135/75	BB	128	113	25	5	11.3	15.5	166	115/72	-
4	18,4	63	CoA	+	+		150/90	CC, ACE	141	133	34	7	14.5	18.0	92	135/82	ACE
5	11,5	48	CoA		+	+	155/90	BB, ACE	150	140	23	4	7.6	12.2	77	105/70	-
6	19,0	75	CoA		+		142/85	-	134	118	24	9	13.1	15.8	68	130/80	ACE
7	12,8	54	CoA			+	135/75	BB	132	120	34	6	7.5	14.3	63	120/ 80	-
8	9,2	33	CoA	+			133/80	-	105	95	24	2	7.8	13.3	60	112/71	-
9	18,0	88	TGA-VSD-CoA		+	+	140/88	BB	130	117	48	8	9.4	16.3	52	134/73	BB
10	19,5	55	CoA		+	+	155/95	CC, ACE	148	118	22	6	15.2	17.4	48	136/69	ACE
11	4,0	20	CoA				127/75	BB	141	137	41	8	5.1	10.0	48	102/64	-
12	9,6	45	Aortic isthmus atresia			+	135/80	-	120	108	43	8	6.9	10.5	40	112/62	-
13	16,7	74	CoA		+	+	140/80	CC	121	109	21	5	12.2	15.8	34	130/70	BB
14	13,4	71	CoA			+	137/75	ACE	129	115	25	3	11.9	14.4	27	122/61	-
15	13,2	57	CoA		+	+	140/75	BB, ACE	153	133	44	7	8.2	16.1	26	136/69	ACE
16	23,0	80	CoA		+		170/105	-	144	119	37	9	13.5	17.2	24	146/80	BB, ACE
17	18,0	74	CoA	+			145/90	BB, ACE	152	132	12	0	16.4	19.2	22	133/72	BB
18	10.3	39.5	CoA	+	+		135/75	CC	133	113	30	0	7.1	13.5	15	117/70	-

BP: Blood pressure; AAO: Ascending aorta; DAO: Descending aorta; PG: Pressure gradient; F-U: Follow-up; CoA: Coarctation of aorta; ACE: Angiotensin converting enzyme inhibitors; BB: Beta-blocker; IAA: Interrupted aortic arch; CC: Calcium canal blocker; TGA: Transposition of the great arteries; VSD: Ventricular septal defect.

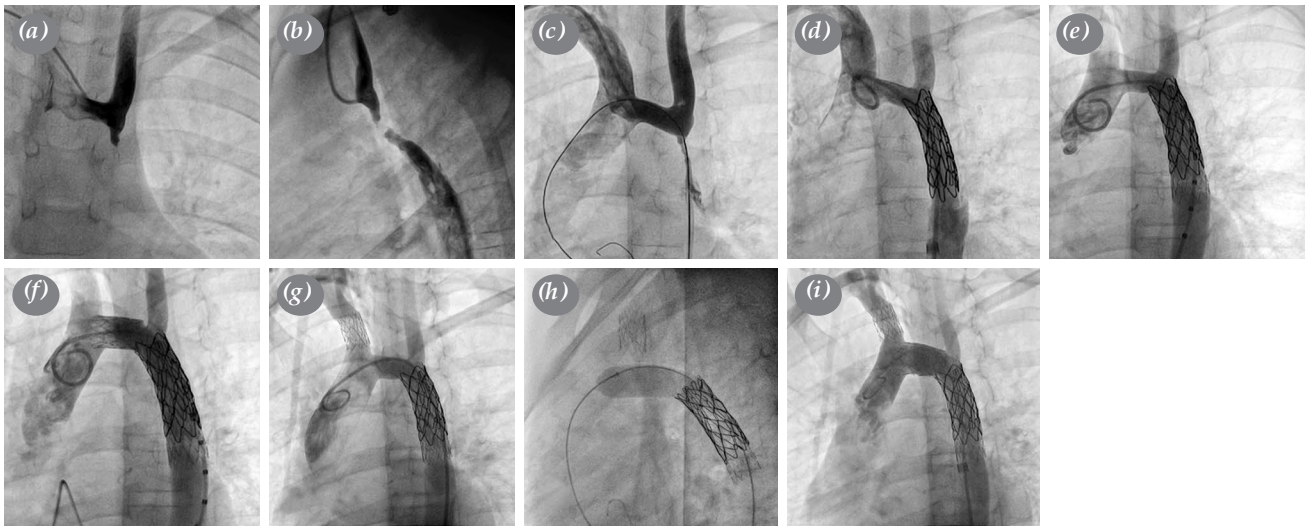

Figure 5. A seven-year-old female presented with isthmus atresia. **(a, b)** Contrast injection trough radial artery and descending aorta showed no passage. **(c)** Note that left subclavian artery was not observed. This is thought to be due to the left subclavian artery originating from the coarctation area. **(d)** After perforation and crossing the atretic segment with a chronic total occlusion guidewire a 39 mm covered CP was implanted. **(e)** One year later she underwent second stent implantation with an AndraStent® for re-coarctation. **(f)** Since she remained hypertensive with the presence of a narrow proximal aortic arch with a 19-mmHg pressure gradient, a 17 mm AndraStent® XL mounted on a 10 mm Z Med balloon was implanted in the proximal aortic arch. **(g)** At sixth month follow up it was noticed that the stent had migrated into the innominate artery. **(h)** A test was conducted with a 14 mm Tyshak balloon to assess the expansion capacity of the aortic arch and a second AndraStent® mounted on a 15 mm × 3.5 cm BIB balloon was successfully implanted.

time between the initial procedure and TAA stent implantation was 10.7±5.7 years (median: 9.7; range, 1.9 to 21.5 years).

The lesion was located in the distal aortic arch in 14 (77.7%) patients, in the proximal arch in three (16.7%), and in both the proximal and distal arch in one (5.6%) patient. The mean weight was 55.8±20 kg (median: 56 kg; range, 20 to 88 kg). All the stents were bare, including 15 (79.0%) AndraStents and four (21.0%) CP stents. The Z-Med balloons were used in 11 (61.1%) patients, while BIB balloons were used in seven (38.9%) patients. The ostium of the arch vessels had to be jailed for complete elimination of the gradient due to the anatomy of the arch in seven (38.9%) patients (three left carotid arteries, three left subclavian arteries, and one both). Stent struts were successfully dilated in all.

There was a statistically significant decrease in the mean ascending aorta systolic blood pressure before (144.8±11.67 mmHg) and after (126.8±13.6 mmHg) the procedure ($p<0.001$). After the intervention, the pressure gradient between the ascending and descending aorta decreased from a mean of 30.6±10.2 mmHg to 5.8±3.6 mmHg ($p<0.001$). The narrowest mean arch diameter increased from 10.4±3.2 mm to 14.8±2.5 mm ($p>0.001$). Immediate procedural success was 100%.

There were no early mortality or major complications, such as stroke, migration, dissection, or emergent surgical requirements. One patient had bradycardia and hypotension during the stent implantation and balloon inflation, which could be due to the possible consequence of the slow deflation of the balloon. Another patient developed hypotension during the procedure due to bleeding from the femoral artery sheath and required a blood transfusion.

The proximally implanted stent was detected in the innominate artery in one patient at the six-month outpatient control. In that patient, who had previously undergone stent implantation for isthmus atresia, transcatheter stent implantation was performed two years before the TAA stenting procedure. Transverse aortic arch stent implantation was performed using a 10-mm Z-Med balloon and 17-mm AndraStent, and the stent appeared to be in a good position the day after the procedure. The patient was discharged three days after the procedure. However, after six months, it was noticed that the stent had migrated into the innominate artery. The patient underwent catheterization. The migrated stent was stable in the innominate artery and

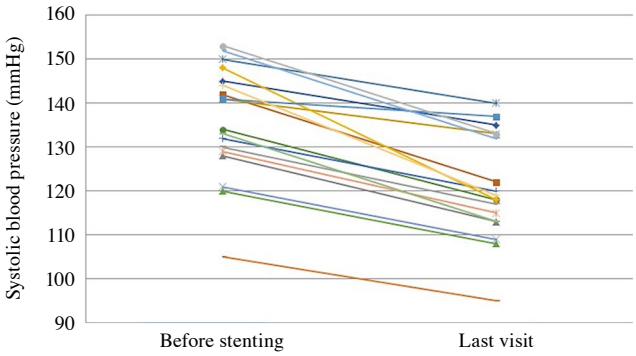

Figure 6. Individual change in systolic blood pressure before intervention and at follow-up.

was left there without any additional attempts. A test was conducted with a 14-mm semicompliant balloon to assess the expansion capacity of the aortic arch, and a 26-mm AndraStent mounted on a 15×3.5 cm BIB catheter was successfully implanted (Figure 5). This patient was followed without new complications for approximately three years.

Patients were followed for a mean of 67.2±50.6 months (median: 50 months; range, 15 to 174 months). A femoral artery pseudoaneurism, which resolved with external compression via a linear ultrasonography probe, was observed one week after the procedure in one patient. No aortic aneurysm was detected. Six patients required balloon redilatation of the stent due to somatic growth.

During follow-up, eight (44.4%) patients became normotensive and drug-free (Table 1 and Figure 6). Among patients with persistent systemic hypertension, a new antihypertensive treatment was started in three patients after TAA stenting. These patients had hypertension before the intervention but did not use antihypertensive drugs. In six patients under dual antihypertensive therapy before the procedure, a transition to monotherapy was successfully achieved in four cases during the follow-up period. According to the last evaluation during follow-up, 10 (55.5%) patients were taking antihypertensive drugs, two (11.1%) were on dual therapy, and eight (44.4%) were on monotherapy.

DISCUSSION

It was reported that even mild TAA hypoplasia may lead to persistent systemic hypertension.[8] Surgery is one of the treatment options for TAA and isthmus hypoplasia; however, it has disadvantages, such as complex bypass strategies, perioperative morbidity and mortality, and prolonged hospitalization. Furthermore, surgical intervention is often refused by surgeons and patients or their families in cases of mild hypoplasia. In such instances, medical treatment might be preferred for hypertension, but it often necessitates high-dose or multiple drugs.

Transcatheter balloon dilatation and stent implantation are considered treatment options for TAA lesions.[11,12] However, balloon dilatation is often ineffective in this patient group due to inappropriate anatomy (typically long tubular stenosis or hypoplasia) and elastic recoil.[7,12] Conversely, TAA stenting is a technically complex procedure that may entail serious complications.

There are few studies on TAA stenting in the literature.[5,9-11] The present study comprehensively evaluated this intervention from a technical standpoint and its effect on hypertension. Stent implantation was successfully performed in all patients, with no reported mortality or major complications during the acute period. Similar to findings in other studies, we observed a statistically significant decrease in systemic blood pressure, pressure gradient through the aorta, and an increase in TAA diameter.[5,9,10]

In our study, all patients were hypertensive before the TAA stenting procedure. However, the proportion of normotensive patients increased following stent implantation, with eight (44%) of 18 patients achieving a normotensive state during the follow-up period (Figure 6). Furthermore, among the six patients on dual antihypertensive medication at baseline, this number decreased to two during the follow-up period. Detailed data on blood pressure and antihypertensive medicines for each patient are presented in Table 1. Boshoff et al.[5] reported that 10 (50%) of 20 patients were normotensive during the follow-up after TAA stenting, which is similar to the findings of our study. Similar to our study, previous studies have also shown a decrease in the need for antihypertensive drugs after TAA stenting.[9,10] Certainly, TAA stenting does not eliminate the need for antihypertensives. It does not make patients completely normotensive because there are other reasons for the persistence of systemic hypertension in these patients, such as underlying renal adaptation, endothelial dysfunction, neurohormonal imbalances, or coexisting vascular abnormalities and baroreceptor disturbances.[13-16] No clear consensus exists in the literature on the choice of antihypertensive therapy in patients with coarctation. Angiotensin-converting enzyme inhibitors (ACEi), beta-blockers, or calcium channel blockers can be given as first-line therapy.[17,18] Our center prefers beta-blockers or ACEi as the first-line treatment. The

second drug is added if the first one is maximized and there is no response. We observed that after TAA stent implantation, blood pressure control was more easily achieved despite hypertension. This is particularly important since systemic hypertension contributes to the development of premature cardiovascular events.[4,19,20] Some authors have declared that a sustained 12 mmHg decrease in blood pressure for 10 years would prevent one death for every 11 patients.[21] There are no specific criteria for intervention in TAA lesions in the guidelines. We believe that if the patient is hypertensive and blood pressure cannot be controlled, stent implantation can be performed even in mild TAA hypoplasia, considering the benefit-harm balance.

Arterial hypertension in adulthood after aortic coarctation correction remains not fully understood. Hypotheses, including delayed age of correction, surgical technique, abnormal aortic arch shape, re-coarctation, and hypoplastic TAA, have been advanced in the literature.[22-24] Controversy surrounds the management of CoA patients with arch hypoplasia. While some authors advocate thoracotomy in most cases, even in the presence of arch hypoplasia, in anticipating of transverse arch growth after CoA repair, evidence suggests that incomplete relief of arch obstruction may lead to worse long-term outcomes.[25,26] Therefore, a more aggressive approach to arch surgery in aortic coarctation with arch hypoplasia appears reasonable for long-term prognosis.

Transverse aortic arch stent implantation is a complex procedure, and the proximity of the implanted stent to the head and neck vessels, along with the short landing zone, makes the procedure daunting due to the potential complications, such as migration, dissection, rupture, and stroke.[11,12,27] Transverse arch lesions differ from classical coarctation tissue, making them prone to complications due to this inherent difference.[12] However, there is a lack of clear data regarding which arch pathologies are more susceptible to complications. It is important to note that bare stenting in severe stenosis may pose a risk of rupture, whereas mild cases of hypoplasia may lead to concerns about migration. Theoretical risks of neurological complications exist in all arch lesions.

In our study, no mortality or early major complication was observed. However, late stent migration was noted in one patient. It is worth noting that both early and late stent migration cases have been reported after stent implantation in patients with coarctation.[28,29] Rapid ventricular pacing and balloon interrogation can prevent stent migration when implanting stents in TAA lesions.[9,12] We performed rapid right ventricular pacing during TAA stenting routinely. In their study, Pushparajah et al.[11] observed stent migration in two cases, suggesting that this may be attributed to the lack of rapid right ventricular pacing. In one patient in our study, the possible cause of migration could be inappropriate balloon selection during the first procedure, in which a balloon interrogation was not done. In the same case, a 10-mm balloon was used for the initial stent implantation, whereas the implantation was performed using a 15-mm balloon in the second procedure.

It is advisable to assess the expandability of the arch using semicompliant balloons before stenting.[12] This technique reduces the risk of migration by preventing undersizing and may prevent catastrophic complications, such as rupture or dissection, by reducing the risk of oversizing. On the other hand, reports are suggesting this preexpansion technique is an entity that increases the potential risks of the stenting procedure.[27]

We applied this method in our patient with stent migration and successfully implanted a new stent in the TAA. In our view, balloon interrogation and rapid right ventricular pacing during stent implantation in the TAA may increase the procedure's success and decrease the risk of severe complications.

Three different types of stents, including closed-cell, open-cell, and hybrid-designed stents, are used to treat great vessel stenosis. Closed-cell designed stents, such as CP stents, exhibit lower flexibility and conformity compared to open-cell or hybrid-designed stents.[14] Open and hybrid cell designs, characterized by the absence of connections, offer greater longitudinal flexibility of the cells, making them preferable for treating stenosis in TAA as they better conform to the arch shape.[14] Different stents have been used in the literature for TAA stenting.[9,10,27] Only the CP stents were used at the beginning of our study period, as only those were available in our laboratory. However, we preferred to use the AndraStent when it became available. AndraStent is a balloon-expandable, nonpremounted, cobalt-chromium peripheral stent with a hybrid (semiopen) cell design.[30] AndraStent has some advantages over the CP stent. Its material and design allow better tissue penetration, a better curve, and a lower crimping profile. The small hooks on the outer surface of the stent facilitate penetration and stabilization without significant damage to the aortic wall.[30] Additionally,

due to its hybrid design, it is easier to pass between the struts of the AndraStent and dilate it compared to the CP stent. Therefore, open and hybrid cell stents should be used in TAA lesions to mitigate the risk of jailing the aortic arch vessels and to provide the stent with a better curvature.

There is limited data on AndraStent usage in aortic coarctation. Some concerns are present about the small hooks on the outer surface of AndraStent, which can cause aneurysm or rupture. However, based on our experience with over a hundred patients in the last seven to eight years, none of them developed rupture or aneurysm after undergoing coarctation stenting with AndraStent.

If the lesion in TAA is limited only to the distal or proximal arch, a short stent is preferred, and jailing of the branch vessels is avoided as much as possible. In some lesions, jailing is not a complication but is an inevitable situation due to the anatomical structure of the arch. In such cases, balloon dilatation is required by passing through the stent struts. Both closed and open/hybrid designs should be used for adequate dilation.

Another worrisome situation in TAA stent implantations is the potential risk of developing early or late neurological complications. Jailing of the arch vessels (with four patients involving the left carotid artery) was observed in seven patients in our study. In these patients, balloon dilatation of the stent struts was performed, and no neurological complications were observed in any of them in the early or late term. Pushparajah et al.[11] reported an acute stroke in one patient and attributed it to the interventions during managing the migrated stent. Theoretically, the likelihood of thrombotic events is low due to using large-diameter stents. Nevertheless, we administer aspirin to patients after the TAA stent implantation for six months. More data concerning the postimplantation use of antiaggregates for TAA stents is needed.

There are some limitations to this study. This is a single-center study involving a limited number of patients, and therefore, a definitive recommendation cannot be made regarding the approach strategy for this complex patient subgroup. Multicenter studies with a larger cohort and longer follow-ups will help overcome these limitations. Additionally, routine pre- and postprocedural exercise studies are yet to be conducted; therefore, information about the response of normotensive patients to exercise is needed.

In conclusion, despite surgical and interventional therapies for aortic coarctation, residual transverse aortic arch lesions may contribute to the persistence of systemic hypertension. The current series supports that transverse aortic arch stent implantation can be performed safely, resulting in favorable outcomes without significant complications. Open/hybrid cell stents should be preferred for transverse aortic arch lesions. Stent implantation can facilitate better control of these patients' blood pressure. However, it should be noted that these patients remain at risk for lifelong hypertension and should be closely monitored in this regard.

Ethics Committee Approval: The study protocol was approved by the University of Health Sciences Hamidiye Scientific Research Ethics Committee (date: 03.11.2023, no: 23/575). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from the patients and/or parents of the patients.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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