Cardiovascular Revascularization Medicine 39 (2022) 66–72

Contents lists available at ScienceDirect

Cardiovascular Revascularization Medicine

Endovascular Stent Repair of Aortic Coarctation in a Developing Country: A Single-Center Experience☆

Mouafak Homsi [a], Maya El Khoury [b], Caroline Hmedeh [a], Mariam Arabi [b], Issam El Rassi [c], Ziad Bulbul [b], Fadi Sawaya [d], Fadi Bitar [b], Fady Haddad [a,*]

[a] American University of Beirut Medical Center, Department of Vascular Surgery, Lebanon
[b] American University of Beirut Medical Center, Department of Pediatrics and Adolescent Medicine, Children Heart Center, Lebanon
[c] American University of Beirut Medical Center, Department of surgery, Children Heart Center, Lebanon
[d] American University of Beirut Medical Center, Department of Medicine, Lebanon

ARTICLE INFO

Article history:
Received 15 June 2021
Received in revised form 10 October 2021
Accepted 21 October 2021

Keywords:
Coarctation of aorta
Congenital heart disease
Endovascular stenting
Developing countries

ABSTRACT

Background/Purpose: CoA remains one of the most common congenital heart diseases and is associated with significant morbidity and mortality and if untreated. We aim to evaluate the safety, feasibility, and outcomes of endovascular stenting of Coarctation of the aorta (CoA) in a developing country with limited resources and compare it to available benchmarks.

Materials/Methods: A retrospectively review of all patients who underwent endovascular stent repair of aortic coarctation at our tertiary center since 2009 was done.

Results: 18 patients were identified, sixteen had native CoA, while two had recurrent CoA. mean age at the time of procedure was 21.2 ± 9.8 years (range 10–45 years), and 12(66%) patients were males. The mean follow-up duration was 4 ± 2.8 years. Post stenting, the average ascending-to-descending aorta systolic gradient decreased by 42.9 ± 20.4 mmHg ($p < 0.001$). After the intervention, 13(72.2%) patients achieved normal BP while 5(27.8%) had residual hypertension. Fourteen patients received bare-metal stents, and four had covered stents. Attempted stent implantation was successful in all patients. Our procedural success rate was 94%. On follow-up, no dissections or aneurysmal changes were detected, four patients underwent re-expansion of the stent, one patient with suboptimal stenting result required surgery 6 months after stenting, and two patients had minor post-operative complications.

Conclusions: Endovascular stenting for de-novo or recurrent CoA in children and adults at a tertiary center in a developing country is feasible and safe with outcomes comparable to developed countries. A multidisciplinary team approach is paramount in achieving good results and low complication rates in limited-resource settings.

1. Introduction

Coarctation of the aorta (CoA) remains one of the common congenital heart disease (CHD), with an estimated incidence of 3 in every 10,000 live births [1] and accounts for ~5–7% of all CHD cases [2,3]. It may be found as an isolated lesion or associated with other congenital heart abnormalities, most commonly a bicuspid aortic valve or other non-cardiac lesions, like cerebral aneurysms in up to 10% of patients [4,5]. Most CoA cases are diagnosed during the neonatal and infancy periods and undergo corrective surgery; however, many cases are unrecognized until late childhood or adulthood, with 25% of the cases recognized beyond 10 years of age. Unrepaired coarctation of the aorta is associated with significant morbidity and mortality, and if left untreated, has approximately 90% mortality by age 50 [1].

CoA treatment remained surgical until the early 1980s, when transcatheter therapy with balloon angioplasty (BA) was introduced as an alternative treatment option [6]. Although the immediate technical results were overall satisfactory, the BA mechanism involves controlled tearing of the aorta's intimal and medial walls that may predispose to aneurysm formation later, especially when treating native CoA. Also, access complication and iliofemoral stenosis were significantly more common in BA than surgery, and a high incidence of re-stenosis for BA patients [7]. CoA's stenting was introduced in 1991 [8–11], and by providing a rigid endovascular scaffold, the stents maintained improved

☆ **Disclosure:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.This study was approved by the institutional review board of the American University of Beirut.

* Corresponding author at: Department of Surgery, Division of Vascular and Endovascular Surgery, American University of Beirut Medical Center, Cairo Street, Hamra District, Beirut, Lebanon.
E-mail address: fh16@aub.edu.lb (F. Haddad).

https://doi.org/10.1016/j.carrev.2021.10.010
1553-8389/

vessel diameter. With the continuous improvements of the stenting techniques, CoA treatments' direction has shifted to embrace stenting vs. other options (BA or surgery). CoA's endovascular stenting was found to have a lower coarctation recurrence, better immediate outcomes, and lower aortic wall complications and superior hemodynamic results [2,12,13]. Although few studies directly compared surgery to stenting of CoA, the available data suggest at least non-inferiority of the stenting procedure with faster recovery and less bleeding complications but planned re-intervention was more likely in the group of stented patients [14,15]. Nowadays, stenting is considered the preferred treatment option for adolescent and adult patients with native or re-CoA. Stent implantation in young children remains controversial due to the need for frequent re-dilation to accommodate the growing aorta, although new stents are being developed to treat younger children with promising results [16].

We report a descriptive study looking at the patients treated with endovascular stenting of a native or recurrent CoA at the Children's Heart Center at the American University of Beirut – Medical Center (AUBMC), a tertiary referral center in a developing country. The primary objective of this study is to evaluate and review the safety, feasibility, complications, and outcome of this procedure, compare our results to those reported from developed countries, and share the lessons learned from our experience in this cohort in a limiting resource setting.

2. Materials and methods

2.1. Population and data collection

We retrospectively reviewed the in-hospital and outpatient department documentations of all patients who underwent cardiac catheterizations for endovascular stent repair of a native or recurrent aortic coarctation at the Children's Heart Center and Vascular & Endovascular division at the American University of Beirut-Medical Center (AUBMC) from January 2009 till December 2019. The collected data from the medical records included demographic data, imaging data, procedural and clinical data and imaging at the time of intervention, and all later follow-ups. This study was approved by our Institutional Review Board.

2.2. Indication for intervention

Interventional therapy was indicated in patients with a non-invasive blood pressure difference > 20 mmHg between upper and lower extremities regardless of symptoms, but with upper limb hypertension, pathological blood pressure response during exercise, or significant LV hypertrophy. Hypertensive patients with ≥50% aortic narrowing relative to the aortic diameter at the diaphragm level were also considered for treatment [17–19]. Patients weighing less than 25 kg were not eligible for the intervention.

All patients with CoA had undergone an integrated imaging assessment with CT or MRI and angiography of the aortic arch and the ascending and descending aorta before coarctation stenting, as it is mandatory to obtain a detailed description of the lesion to plan the appropriate intervention. All cases were reviewed during a multidisciplinary meeting before intervention.

2.3. Procedure steps

All cases were done percutaneously at the Cardiac Catheterization Unit under general anesthesia. The trans-femoral artery (FA) approach under ultrasound guidance was the standard approach; brachial access was obtained only in particular cases when crossing the CoA segment from the descending aorta was not achieved. The utilization of the brachial access allowed antegrade catheterization of the CoA with exteriorization of the wire through the femoral artery sheath. Intravenous heparin was administered per body weight, achieving an activated clotting time (ACT) greater than 200 s. A 5F selective catheter (multipurpose or right Judkins) was advanced into the descending aorta, followed by advancing a soft-tipped wire (e.g., Glide wire) through the CoA site. Once the catheter is advanced into the ascending aorta, it is replaced over the wire by a pigtail catheter. The pressure gradient across the CoA was measured. Aortography was performed to measure the narrowest diameter, the length of CoA, isthmus, brachiocephalic vessels, and to guide the selection of the balloon's size and stent to be used.

The decision on the balloon's diameter on which the stent was mounted was based on the diameter of the transverse distal arch and isthmus; the diameter did not exceed the distal transverse arch diameter. It is important to note that post-stenotic dilatation is expected; however, we did not use this diameter as a reference for the final balloon size selection. A stiff wire (usually an Amplatz super or extra stiff exchange guidewire) was advanced and secured in the ascending aorta or the right subclavian artery. A long sheath (at least 75-cm) (usually Mullins sheath/Cook Medical) was advanced from the FA site and placed across the CoA segment to deploy the stent. The selected stent was manually crimped onto a selected high-pressure balloon, usually *Z*-Med (NuMed Corp., Hopkinton, NY, USA) or Cristal (Balt, Montmorency, France). Less often, pre-mounted stent were used (like with covered stents). Pre-dilatation with a low-profile balloon was performed in cases with tight narrowing. The stent/balloon assembly was advanced through the long sheath over the stiff wire and positioned across the CoA site before the sheath was withdrawn gently to uncover the stent/balloon completely. Angiography was performed to check the stent's position across the CoA before inflation of the balloon catheter. Upon confirmation of a good position, the balloon was inflated to expand the stent, broadening the narrowed segment. After that, the pressure gradient across the stent was measured, and angiography was performed. Post-dilatation of the stent with a larger balloon can be performed if CoA relief was deemed suboptimal. In adults with tight CoA, we are usually satisfied initially with a diameter of 14 mm at the site. Post-dilatation of the stent was done after that as needed. Initial use of a smaller balloon to deliver the stent followed by dilatation with a large balloon allowed us to use smaller long sheaths. In the latter part of the study, we started to use vascular closure devices, i,e Perclose Proglide system, to assist in achieving hemostasis when 12F sheath was used.

Procedural success was defined as an immediate reduction of peak-peak systolic gradient <20 mmHg, improvement in vessel caliber >80% of the normal adjacent aortic arch, and freedom from unplanned repeat intervention. In addition, technical success was defined as stent deployment in the desired optimal location in addition to the aforementioned closing pressure gradient ≤20 mmHg across the stenosis. The procedure was performed by a team of a pediatric interventional cardiologist with a vascular/endovascular surgeon or adult interventional cardiologist.

Both covered and uncovered stents were used in our population. More/uncovered stents were used in the earlier part of the study period due to availability, and for short lesions where the stent would cover significantly the origin of the subclavian artery. Uncovered stents were placed in eleven patients; namely, six uncovered Cheatham-Platinum (CP) stent (NuMed, Hopkinton, NY, USA) and five Palmaz (Cordis Endovascular, Warren, NJ); while seven patients received covered stents including four covered CP stents, two Advanta V12 (Getinge, USA), and one BeGraft (Bentley, Hechingen Germany). Closing hemodynamic stability was achieved by applying direct pressure at the access point, while a Perclose ProGlide™ (Abbott Vascular, US) closure system was electively used in 4 patients.

2.4. Follow-up

Patients were asked to follow up at 1 week, 1 month, and 6 months after the intervention and every year thereafter. Echocardiography was done routinely at follow-up to assess the stent patency, gradient, presence of dissection, aortic stiffening, or aneurysmal changes. Other

imaging like CT, MRI, or angiography were reserved only upon a clinical indication. Patients with persistent hypertension continued their antihypertensive medications and were restricted from contact sports for 1 month after the procedure. Patients were also placed on antiplatelet low-dose aspirin for 3 to 6 months regardless of stent type and followed endocarditis precautions 6 months after stent placement. No dual antiplatelets were required for any of the patients.

2.5. Statistical analysis

All collected data were entered into SPSS v24 for analysis. Descriptive data were reported using frequency, mean, range, and standard deviation. Comparison of means was done by Student's *t*-test, and qualitative data was compared by Chi-square. Statistical significance was set for a p-value < 0.05.

3. Results

3.1. Population characteristics

A total of 18 patients underwent stent repair of an aortic coarctation at our center since 2009 and over 10 years; 16 were native CoA while two patients were operated on for a recurrent CoA (one patient with prior surgical repair followed by BA and another patient with prior BA). The mean age of our patients at the time of procedure was 21.2 ± 9.8 years (range 10–45 years), the average weight was 65.2 ± 20.5 kg (range 26–96 kg), and 12 (66%) were males. The mean follow-up duration in our population was 4 ± 2.8 years (range 1 month–10 years), and only one patient was lost to follow-up postoperatively. Three patients completed intermediate follow-up (3–18 months) while 14 patients completed long-term follow-up (>18–60 months). Demographic and initial presentation data is presented in [Table 1]. Only four patients diagnosed with CoA in the eligible age group were opted for open repair due to associated lesions like aneurysmal arch or Shone's complex throughout the study duration.

The most common initial presentation at the time of diagnosis was an incidental finding of elevated blood pressure during a routine check-up in 8 (44%) patients. Other presentations included complaints of worsening dyspnea in 3 (16.5%) patients, an episode of syncope in 2 (11%) patients, and worsening of chronic uncontrolled HTN in 2 (11%) patients. The mean systolic blood pressure (SBP) of our patients at initial presentation was 155.1 ± 7.9 mmHg. Ultrasound evaluation found most patients (83.3%) to have other concurrent cardiac abnormalities. Bicuspid aortic valve was the most common defect detected in 10 (55%) of our patients; 7 (38.8%) patients had other valvular defects (one with relatively hypoplastic tricuspid valve, three with mild mitral insufficiency, one with mild mitral stenosis, and two with mild aortic valve insufficiency), three (16.7%) patient had cardiac septal defects (one with small ASD and two with muscular VSDs one of which underwent transcatheter device closure of VSD later), and one patient had a cerebral aneurysm.

Pre-operative measurments on radiographic imaging in the population showed a mean coarctation diameter of 5.1 ± 1.6 mm (range 2–7 mm) (Supplementary Table 1), ascending aorta diameter of 25.9 ± 6.1 mm, aortic distal arch diameter of 18.3 ± 3.3 mm, left subclavian artery diameter of 10.2 ± 2.6 mm, coarctation isthmus diameter of 13.6 ± 4.2 mm, isthmus length of 17.2 ± 7.8 mm (range 5–31 mm), and descending aorta diameter of 20.4 ± 4.9 mm (range 12–29 mm).

Table 1
Basic demographic of our population.

Variable		Patients ($n = 18$)
Coarctation status	Native CoA	16 (89.9%)
	Recurrent	2 (11.1%)
Time interval between diagnosis and operation	Within 6 months	13 (72.2%)
	Within 2 years	3 (16.7%)
	Late procedure after childhood dx	2 (11.1%)
Males		12 (66.6%)
Age at diagnosis (mean ± SD)		19.5 ± 11.3
Age at operation (mean ± SD)		21.2 ± 9.8
Weight at operation (mean ± SD)		65.2 ± 20.5
Initial presentation at diagnosis	Incidental asymptomatic HTN	8 (44.4%)
	Chronic Worsening HTN	2 (11.1%)
	Syncope	2 (11.1%)
	Progressive dyspnea	3 (16.7%)
	Headache	1 (5.5%)
	Childhood Dx	2 (11.1%)
Associated cardiac anomalies at diagnosis	BAV	10 (55.6%)
	Other valvular anomalies	5 (27.8%)
	Septal defects	3 (16.7%)
	Cerebral aneurysm	1 (5.5%)

3.2. Procedural characteristics

The stents were successfully placed across the CoA in all patients. There was a mean increase in diameter across the coarctation post-stenting of 7.6 ± 3.2 mm (CI [5.9–9.1], $p < 0.001$) (Supplementary Table 1). The mean pressure gradient recorded in our cohort during cardiac catheterization across the coarctation was 49.7 ± 15.9 mmHg before the stenting. There was a mean decrease of 42.9 ± 20.4 mmHg (CI [31.6–54.2], $p < 0.001$) in the pressure gradient post-stenting. All patients except one had a reduction in the peak pressure gradient (PPG) to less than 20 mmHg. Eight patients had no residual gradient following the endovascular stenting; 9 patients had a peak-peak gradient (PPG) of less than 15 mmHg, and one patient had a residual PPG of 29 mmHg. After the intervention, 13 (72.2%) patients achieved normal BP while only 5(27.8%) had residual HTN. The mean decrease in SBP postoperatively was 22.4 ± 19.5 mmHg (CI [12.8–32.1], $p < 0.001$). Post-operatively, a significantly lower proportion of patients required two or more antihypertensive agents to control their BP compared pre-operatively (4 (22%) vs. 8 (44.4%), $p < 0.001$) (Table 2 and Supplementary Table 1).

Seven of the patients had complete ankle-brachial index (ABI)'s data recorded both pre and post operatively, and all but one had normalized their value post procedure. ABIs were not part of a routine protocol, so data was not available on all patients or was incomplete.

3.3. Acute complications

Two acute complications were found in our population. One peripheral complication was an external iliac femoral occlusion, related to the difficulty recovering the balloon, which was stuck at the tip of the sheath. The other complication was a spleen and kidney infarct, for which a patient was re-admitted to the hospital 1 day after initial discharge post-op.

Table 2
Post-operative outcomes.

Variable	Pre-stenting (n = 18)	Post-stenting (n = 18)
Patients with HTN	18 (100%)	5 (27.8%)
Mean systolic blood pressure (mmHg)	155.1 ± 7.9	132.7 ± 16.9
Mean pressure gradient across the CoA (mmHg)	49.7 ± 15.9	6.3 ± 7.9
Patients on ≥2 HTN medications	8 (44.4%)	4 (22.2%)

3.4. Follow-up

On intermediate and long-term follow-up, no aortic dissections or aneurysmal changes were found in any of our patients. Four patients underwent planned re-expansion of their stents while one patient required major surgical reintervention with ascending to descending aorta conduit 6 months after the stenting.

3.5. Echocardiography

Before the procedure, echocardiography revealed 61% of patients to have mild LVH, 11% had moderate LVH, 11% had mild LV dilatation, 5.5% had both mild LVH and mild LV dilatation, and 5.5% had mild LVH with moderate LV dilatation. All patients had a normal range of left ventricular ejection fraction. After the intervention, 28% of patients were found to have minimal LVH on follow-up echocardiography, including those found to have moderate LVH pre-procedure, and 16.6% were found to have mild left ventricular dilatation.

4. Discussion

Coarctation of the aorta is a congenital disease that spans over different age groups depending on the time of discovery, presentation, and severity of associated symptoms. It is likely to require follow up over time possibly requiring different and multiple treatment modalities. Balloon angioplasty or surgical treatment of smaller children (<25 kg), mainly when end-to-end anastomosis can be performed, continues to be the procedure of choice in this group. However, those interventions still carry a recurrence rate of 15–25% [2] and a reintervention rate in the range of 11% [20]. Stenting of coarctation which has higher technical success and durability is preferably reserved to a later stage in adolescence or adult life when the vessel growth have reached closer to mature adult size [20].

4.1. Diagnosis

Coarctation of the aorta is a treacherous disease that is often undiagnosed [21]. Although the diagnosis of coarctation of the aorta in older patients is easy, the diagnosis is often missed or delayed. Two of our adult patients were already being treated for long-standing uncontrolled hypertension on a multidrug regimen (3 meds, and 5 meds respectively) when the diagnosis was made. In fact, even in older children, coarctation of the aorta is missed in about 85% of coarctation patients referred to a hospital for murmurs or hypertension. Most are asymptomatic until later in life, although a few may have intermittent claudication. If left untreated, 50% of patients die under 30 years of age and few survive beyond 50 years of age.

4.2. Technique

We embraced the endovascular stenting option as the treatment of choice for patients with CoA weighing of more than 25 kg. Our technique evolved with the change in the stent material and technology [22]. Our current practice consists of percutaneous access under Ultrasound guidance. We initially performed both brachial access for angiographic control and femoral access for the procedure; upon subsequent cases, we were satisfied with single femoral access only. Brachial access was helpful in difficult lesions to cross in antegrade fashion [Fig. 1]. Other groups have also reserved dual access for complex cases like in arch hypoplasia [22].

We utilize a soft-tipped 0.035 wire (e.g., Glide wire) advanced through a 4 or 5F angled tip catheter to cross the CoA site (Multipurpose, or a Judkins Right). This is followed by a complete arch angiography depicting the anatomy. Occasionally, with very tight CoA lesions with difficulty in crossing, we use a 0.014 in. guide wire to cross and usually loop and park the wire in the ascending aorta; we then perform pre-dilatation using a lower profile balloon before changing to the 0.035 wire [Fig. 2]. The choice of final sheath size depended on the planned balloon and stent diameter. Balloon mounted bare metal stent requires a 2 French larger sheath than is necessary for the dilatation balloon. We deployed the stent initially over an undersized balloon [Fig. 3], followed by post dilatation to the desired diameter [Fig. 3], which allowed us to utilize a smaller long sheath size. Overall our sheath size was limited to 10F or less in most of cases (11 out of 18), while the remaining 7 were 12F. This helped achieve hemostasis with direct compression in 14/18 patients; we used vascular closure devices to replace the traditional mechanical compression in the remaining four cases with no complications later in the cohort. The use of manual compression to achieve hemostasis after removing a femoral arterial sheath lowers the cost of the procedure in limited-resource settings.

4.3. Technical success

Attempted stent implantation was successful in all our patients. Our procedural success rate was 94% comparable to the 92% and 96% procedural success rates reported in the COAST II trial [23] and the Congenital cardiovascular interventional study consortium (CCISC) [24] respectively. One of our patients who underwent stenting for a recurrent CoA following surgical repair of CoA at the age of 2 years and balloon dilatation at age 11 years had a residual peak systolic gradient of 29 mmHg and persistent HTN post-operatively with suboptimal dilatation of the stent, probably due to severe neointimal hyperplasia and fibrosis [Fig. 4]. This patient underwent surgical repair with ascending to descending aortic conduit a few months following stenting of his

Fig. 1. Stepwise images from a patient where brachial access was required due to difficult anatomy: a) Blind stump. b) Road map from Brachial. c) Pin whole lumen crossed. d) Final post stent.

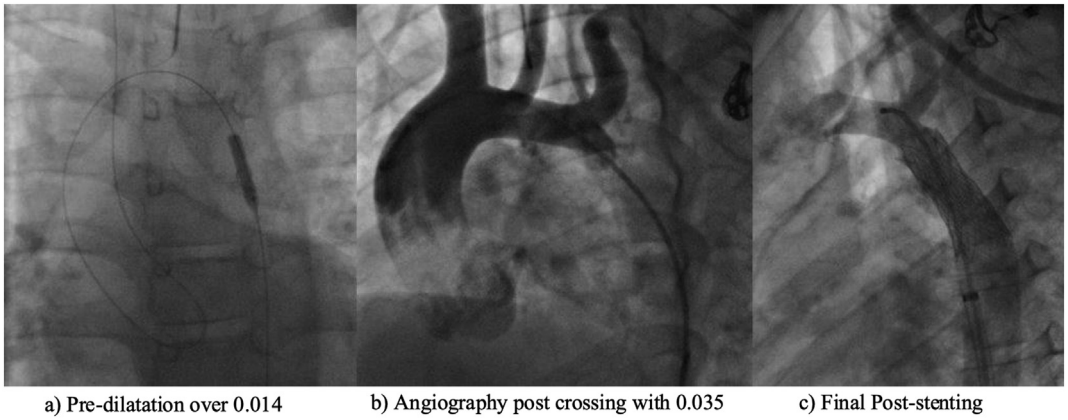

Fig. 2. Stepwise approach to the dilation of a tight lesion.

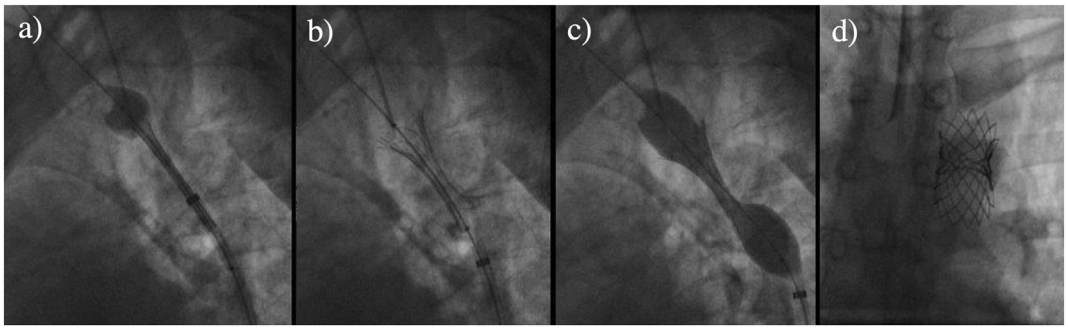

Fig. 3. Step-wise opening of a CP stent: a) Initial opening of distal end. b) First undersized stent opened (10 mm). c) Dilatation to optimal diameter (16 mm). d) Stent fully deployed on AP projection.

CoA. One of our patients who underwent CoA stenting had a moderate-sized muscular VSD that was closed percutaneously with a VSD device.

4.4. Procedural outcomes (BP, PG, cardiac status)

In a recent study on 43 patients undergoing stent repair for native and recurrent CoA there was a compound decrease in means systolic pressure of 16 mmHg at first follow-up that was sustained on longer-term follow up [25].Similarly, we had a significant reduction in the mean SBP post-stenting 22.4 ± 19.5 mmHg in our populations with a post-operative mean SBP of 132 ± 16.9 mmHg maintained at follow-up (Fig. 5). This reduction in SBP help significantly reduces the risk of cardiovascular events for the patients and the relative risk for developing coronary artery disease later on in life and is comparable to the COAST [23] and CCISC [24] results. Furthermore, a higher proportion of our patients maintained normal BP on less than two antihypertensive agents after stenting compared to preoperatively (77.8% vs. 55.6%, $p < 0.001$). All patients with moderate LVH and moderate LV dilatation showed improvement to mild LVH and LV dilatation respectively. Overall, LV hypertrophy was noticed to improve more after COA stenting

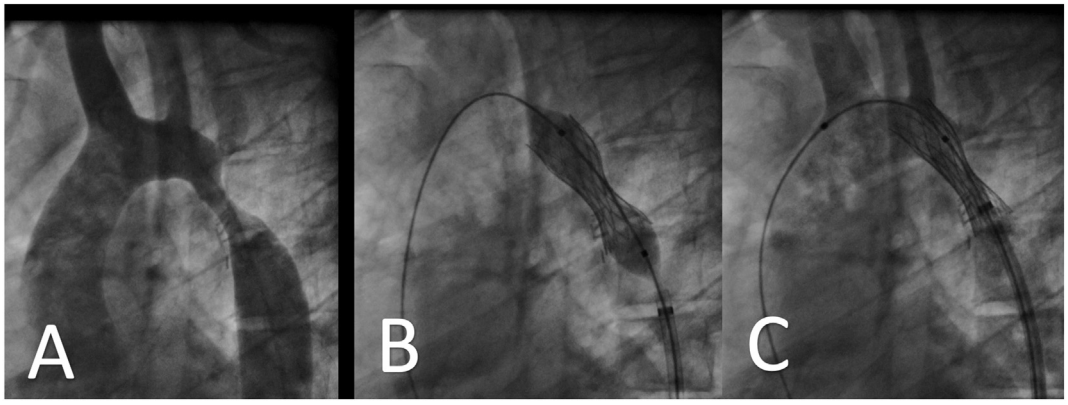

Fig. 4. Interval images from the patient with unsuccessful intervention: A) Baseline status post-surgical repair at 2 years and balloon at 11 years. B) Persistent waist resistant to dilatation. C) Residual stenosis with slight cephalad stent migration.

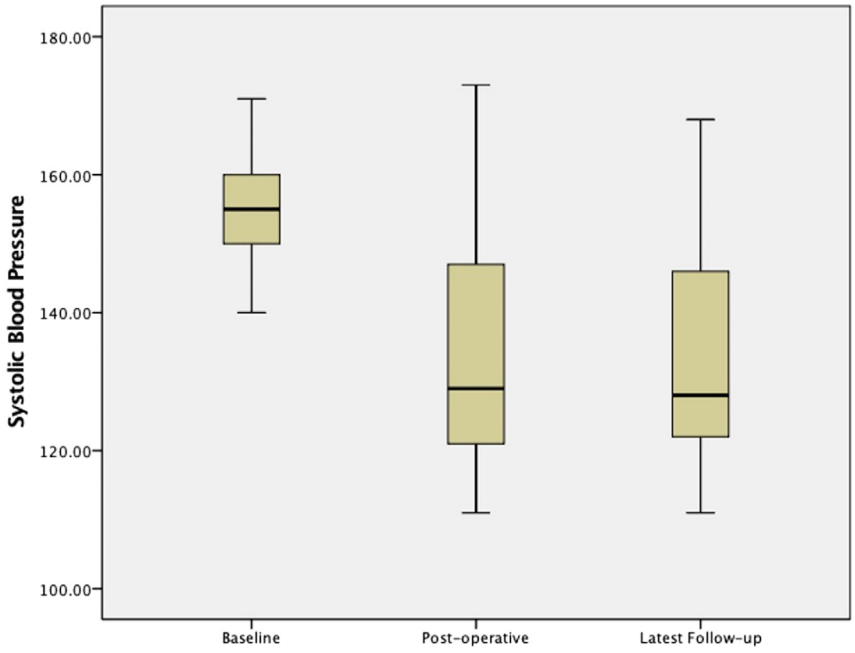

Fig. 5. Mean systolic blood pressure (Baseline vs post-operative *p*-value: <0.001).

than LV dilatation, where mild cases did not change after the procedure. Those findings are comparable to the observations reported in the literature [26].

4.5. Complications

We encountered an external iliac femoral artery occlusion in one patient. The balloon in this case was stuck at the tip of the long sheath and could not be advanced or retrieved which necessitated removing the whole system together; this likely resulted in injury and subsequent thrombosis of the access site. Fluoroscopy was done intra-operatively after complete removal of the system and no extravasation was found. This patient developed leg pain and paresthesia in the post-operative period revealing a complete occlusion of the iliac artery on ultrasound requiring a thrombectomy. This is commensurate with other stenting series reporting 4.2% of peripheral complications [22,23,27]. One other unique complication we had was a spleen and kidney infarct. This patient presented to the emergency department 1 day after initial discharge for left upper quadrant and shoulder pain and CT angiography revealed a wedge hypodensity resembling an infarct in the spleen and a small infarct in the left kidney. The patient responded well to analgesics and, aspirin without anticoagulation and was discharged after 3 days of observation in good condition.

4.6. Reintervention

Four patients underwent re-expansion of the stent either as part of an intentionally staged approach or to compensate for somatic growth during the study period. To note, two of the patients who required the angioplasty had persistent HTN post-op and a residual gradient across the stent of 11 and 14 mmHg respectively while the other two had normal BP and no residual gradient post-op. Three patients had bare-metal stents and one that had re-dilatation of an Advanta V12 covered stent. Our results are comparable to Forbes et al. [12] and to a recent study by Ylinen et al. where 4(31%) out of 13 patients treated with stenting required later reintervention, that occurred 1–2 years following the primary stent placement, and was distributed into one balloon angioplasty, one surgical repair, and two stent placement [28]; however, while all their reinterventions occurred 1–2 years of the primary stent placement, our patients had their reinterventions later, two at 3 years, and two at 5 years post-op.

4.7. Covered vs non-covered stents

It has been proposed that the use of covered stents reduces the risk of aneurysms, dissection, and rupture. The COAST II trial, which used the covered CP stent for the treatment and/or prevention of acute wall injury in native or re-CoA involved a total of 158 patients. The PPG decreased from 27 mmHg to 4 mmHg. The overall success rate was 92%. There was no AWI, repeat intervention, or death [29]. However, in a randomized trial of 120 patients with severe native CoA, there was no difference in the rate of re-CoA and pseudoaneurysm formation after 31 months of follow-up between patients who underwent implantation using a bare-metal stent and those with a covered stent, and this result was similar to what previously has been published in case reports and small series [30]. Nevertheless, covered stents offer the advantage of excluding any stretch-induced wall trauma from the aorta's endoluminal aspect, particularly in the catastrophic event of aortic rupture as revealed by the COAST II trial [29]. Our practice has evolved with time, and we prefer to use the covered stents at our center when they are available.

Overall, our volume of 18 cases spans over 10 years. Though we have a busy Cardiac intervention service, the load in a single center of CoA remains rather relatively modest. A study from the Nationwide Inpatient Sample in the US looking at outcomes related to volume showed that high volume centers (ones with >3 cases per year) fared better in terms of composite outcomes of complications, cost and LOS [27]. The hospitals with ≥3 procedures annually had a significantly lower incidence of complications (9.5% vs. 23.0%) compared to the hospitals with <3 procedures annually (*p*-value 0.002) [27]. Despite doing less than 3 cases per year, the incidence of our complication rate was on the lower side of 5.6%. The contributing elements towards our acceptable complications include cooperation between a multidisciplinary team, embracing the technology progresses, including but not limited to moving to covered stents and using closure techniques and proper pre-operative planning and imaging, case selection with close observation for potential complications and early recognition and intervention

and keeping sheath size as small as possible especially in the younger age group.

5. Conclusion

Endovascular stenting for de novo or recurrent coarctation in children and adults at a tertiary center in a developing country is feasible and safe with acute, intermediate, and long-term outcomes comparable to those reported in developed countries, despite modest volumes. A multidisciplinary team approach was paramount in achieving good results and a low complication rate.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.carrev.2021.10.010.

CRediT authorship contribution statement

Mouafak Homsi: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Maya El Khoury:** Data curation, Investigation, Writing – original draft, Writing – review & editing. **Caroline Hmedeh:** Data curation, Formal analysis, Investigation. **Mariam Arabi:** Investigation, Methodology. **Issam El Rassi:** Investigation, Methodology. **Ziad Bulbul:** Investigation, Methodology. **Fadi Sawaya:** Investigation, Methodology. **Fadi Bitar:** Conceptualization, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Fady Haddad:** Conceptualization, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

None.

Acknowledgement

Dr. Fady Haddad and Dr. Fadi Bitar had equal contributions as corresponding authors and supervisors over this project.

References

[1] Harris KC, Du W, Cowley CG, Forbes TJ, Kim DW, CCIS Consortium. A prospective observational multicenter study of balloon angioplasty for the treatment of native and recurrent coarctation of the aorta. Catheter Cardiovasc Interv. 2014;83:1116–23. https://doi.org/10.1002/ccd.25284.

[2] Zussman ME, Hirsch R, Herbert C, Stapleton GE. Transcatheter intervention for coarctation of the aorta. Cardiol Young. 2016;26:1563–7. https://doi.org/10.1017/s1047951116001694.

[3] Pádua LMS, Garcia LC, Rubira CJ, de Oliveira Carvalho PE. Stent placement versus surgery for coarctation of the thoracic aorta. Cochrane Database Syst Rev. 2012. https://doi.org/10.1002/14651858.cd008204.pub2.

[4] Connolly HM, Huston III J, Brown Jr RD, Warnes CA, Ammash NM, Tajik AJ. Intracranial Aneurysms in Patients with Coarctation of the aorta: a Prospective Magnetic Resonance Angiographic Study of 100 Patients. Elsevier; 2003; 1491–9.

[5] Donti A, Spinardi L, Brighenti M, Faccioli L, Leoni C, Fabi M, et al. Frequency of intracranial aneurysms determined by magnetic resonance angiography in children (mean age 16) having operative or endovascular treatment of coarctation of the aorta (mean age 3). Am J Cardiol. 2015;116:630–3. https://doi.org/10.1016/j.amjcard.2015.05.030.

[6] Singer MI, S MI, D TJ. Transluminal Aortic Balloon Angioplasty for Coarctation of the Aorta in the Newborn; 1982.

[7] Mendelsohn AM, Lloyd TR, Crowley DC, Sandhu SK, Kocis KC, Beekman III RH. Late follow-up of balloon angioplasty in children with a native coarctation of the aorta. Am J Cardiol. 1994;74:696–700. https://doi.org/10.1016/0002-9149(94)90312-3.

[8] O'Laughlin MP, Perry SB, Lock JE, Mullins CE. Use of endovascular stents in congenital heart disease. Circulation. 1991;83:1923–39. https://doi.org/10.1161/01.CIR.83.6.1923.

[9] Cowley CG, Orsmond GS, Feola P, McQuillan L, Shaddy RE. Long-term, randomized comparison of balloon angioplasty and surgery for native coarctation of the aorta in childhood. Circulation. 2005;111:3453–6. https://doi.org/10.1161/CIRCULATIONAHA.104.510198.

[10] Tretter JT, Jones TK, McElhinney DB. Aortic wall injury related to endovascular therapy for aortic coarctation. Circ Cardiovasc Interv. 2015;8:e002840. https://doi.org/10.1161/CIRCINTERVENTIONS.115.002840.

[11] Forbes TJ, Gowda ST. Intravascular stent therapy for coarctation of the aorta. Methodist Debakey Cardiovasc J. 2014;10:82. https://doi.org/10.14797/2Fmdcj-10-2-82.

[12] Forbes TJ, Kim DW, Du W, Turner DR, Holzer R, Amin Z, et al. Comparison of surgical, stent, and balloon angioplasty treatment of native coarctation of the aorta: an observational study by the CCISC (Congenital Cardiovascular Interventional Study Consortium). J Am Coll Cardiol. 2011;58:2664–74. https://doi.org/10.1016/j.jacc.2011.08.053.

[13] Carr JA. The results of catheter-based therapy compared with surgical repair of adult aortic coarctation. J Am Coll Cardiol. 2006;47:1101–7. https://doi.org/10.1016/j.jacc.2005.10.063.

[14] Yeaw X, Murdoch DJ, Wijesekera V, Sedgwick JF, Whight CM, Pohlner PG, et al. Comparison of surgical repair and percutaneous stent implantation for native coarctation of the aorta in patients ≥ 15 years of age. Int J Cardiol. 2016;203:629–31. https://doi.org/10.1016/j.ijcard.2015.11.052.

[15] Hamdan MA, Maheshwari S, Fahey JT, Hellenbrand WE. Endovascular stents for coarctation of the aorta: initial results and intermediate-term follow-up. J Am Coll Cardiol. 2001;38:1518–23.

[16] Grohmann J, Sigler M, Siepe M, Stiller B. A new breakable stent for recoarctation in early infancy: Preliminary Clinical Experience. Catheter Cardiovasc Interv. 2016;87:E143–50. https://doi.org/10.1002/ccd.26393.

[17] Stout KK, Daniels CJ, Aboulhosn JA, Bozkurt B, Broberg CS, Colman JM, et al. AHA/ACC guideline for the management of adults with congenital heart disease: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. J Am Coll Cardiol. 2018;73:1494–563. https://doi.org/10.1016/j.jacc.2018.08.1029 2019.

[18] Baumgartner H, Bonhoeffer P, De Groot NM, de Haan F, Deanfield JE, Galie N, et al. The Task Force on the Management of Grown-up Congenital Heart Disease of the European Society of Cardiology (ESC): ESC Guidelines for the management of grown-up congenital heart disease (new version 2010). Eur Heart J. 2010;31:2915–57. https://doi.org/10.1093/eurheartj/ehq249.

[19] Marshall AC, Perry SB, Keane JF, Lock JE. Early results and medium-term follow-up of stent implantation for mild residual or recurrent aortic coarctation. Am Heart J. 2000;139:1054–60. https://doi.org/10.1067/mhj.2000.106616.

[20] Erben Y, Oderich GS, Verhagen HJ, Witsenburg M, van den Hoven AT, Debus ES, et al. Multicenter experience with endovascular treatment of aortic coarctation in adults. J Vasc Surg. 2019;69:671–679.e1. https://doi.org/10.1016/j.jvs.2018.06.209.

[21] Hoffman JI. The challenge in diagnosing coarctation of the aorta. Cardiovasc J Afr. 2018;29:252–5. https://doi.org/10.5830/CVJA-2017-053.

[22] Butera G, Manica JLL, Marini D, Piazza L, Chessa M, Filho RIR, et al. From Bare to Covered: 15-year single center experience and follow-up in trans-catheter stent implantation for aortic coarctation. Catheter Cardiovasc Interv. 2014;83:953–63. https://doi.org/10.1002/ccd.25404.

[23] Meadows J, Minahan M, McElhinney DB, McEnaney K, Ringel R. Intermediate outcomes in the prospective, multicenter Coarctation of the Aorta Stent Trial (COAST). Circulation. 2015;131:1656–64. https://doi.org/10.1161/CIRCULATIONAHA.114.013937.

[24] Holzer R, Qureshi S, Ghasemi A, Vincent J, Sievert H, Gruenstein D, et al. Stenting of aortic coarctation: acute, intermediate, and long-term results of a prospective multi-institutional registry—Congenital Cardiovascular Interventional Study Consortium (CCISC). Catheter Cardiovasc Interv. 2010;76:553–63. https://doi.org/10.1002/ccd.22587.

[25] van der Burg JJ, Warmerdam EG, Krings GJ, Meijboom FJ, van Dijk AP, Post MC, et al. Effect of stent implantation on blood pressure control in adults with coarctation of the aorta. Cardiovasc Revasc Med. 2018;19:944–50. https://doi.org/10.1016/j.carrev.2018.03.018.

[26] Sezer S, Narin N, Ozyurt A, Onan S, Pamukcu O, Argun M, et al. Cardiovascular changes in children with coarctation of the aorta treated by endovascular stenting. J Hum Hypertens. 2014;28:372–7. https://doi.org/10.1038/jhh.2013.119.

[27] Bhatt P, Patel NJ, Patel A, Sonani R, Patel A, Panaich SS, et al. Impact of hospital volume on outcomes of endovascular stenting for adult aortic coarctation. Am J Cardiol. 2015;116:1418–24. https://doi.org/10.1016/j.amjcard.2015.07.066.

[28] Ylinen MK, Tyni VE, Pihkala JI, Salminen JT, Sairanen H, Sarkola T. Procedural risk factors, incidence and timing of reintervention after treatment for native coarctation of the aorta in children: a population-based study. Eur J Cardiothorac Surg. 2019;55:564–71. https://doi.org/10.1093/ejcts/ezy252.

[29] Taggart NW, Minahan M, Cabalka AK, Cetta F, Usmani K, Ringel RE, et al. Immediate outcomes of covered stent placement for treatment or prevention of aortic wall injury associated with coarctation of the aorta (COAST II). JACC Cardiovasc Interv. 2016;9:484–93. https://doi.org/10.1016/j.jcin.2015.11.038.

[30] Sohrabi B, Jamshidi P, Yaghoubi A, Habibzadeh A, Hashemi-Aghdam Y, Moin A, et al. Comparison between covered and bare Cheatham-Platinum stents for endovascular treatment of patients with native post-ductal aortic coarctation: immediate and intermediate-term results. JACC Cardiovasc Interv. 2014;7:416–23. https://doi.org/10.1016/j.jcin.2013.11.018.