Percutaneous Treatment of Adult Isthmic Aortic Coarctation
Acute and Long-Term Clinical and Imaging Outcome With a Self-Expandable Uncovered Nitinol Stent

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Background—To present perioperative and long-term results of percutaneous treatment of adult isthmic coarctation of the aorta by means of a self-expandable closed-web uncovered nitinol stent (Sinus-XL, Optimed, Esslingen, Germany).

Methods and Results—Preoperative, perioperative, and long-term clinical and computed tomographic angiography data were collected and analyzed prospectively. A total of 52 consecutive patients were treated with the Sinus-XL stent. Mean age was 36.6 (21–67) years, peak invasive trans–coarctation of the aorta gradient was 54.7±9.9 mm Hg, and upper body hypertension unresponsive to medical treatment was present in all patients. Mean stent diameter and length were 24.2 mm (22–28 mm) and 70.4 mm (40–80 mm), respectively. Eight patients (15.4%) required coarctation of the aorta predilatation. All patients underwent poststent dilatation with a noncompliant balloon. Postoperative peak gradient (3.3±2.5 mm Hg) was reduced significantly (P<0.001) and minimal aortic diameter was increased significantly (4.6±1.9 vs. 18.6±2.5 mm; P<0.001). All patients were discharged home (mean hospitalization, 3.5 days). At follow-up (47.6 months; 12–84), 1 (1.9%) noncardiovascular mortality was reported. Aortic computed tomography confirmed the absence of stent collapse and secondary migration and documented stability in aortic diameter (18.3±2.7 mm). Thirty patients (57.7%) were completely weaned-off antihypertensive medications and their use dropped from 2.6 to 0.9 drugs/patient (P<0.001). Ankle-brachial pressure index increased from 0.75 to 0.98 (P<0.001).

Conclusions—Adult coarctation of the aorta treatment by means of a self-expandable uncovered stent is safe and durable. The peculiar stent design maintains adequate localized radial strength over time with minimal trauma on the adjacent aortic wall and negligible device-related complications. Blood pressure control optimization is immediate and persistent even at long-term follow-up. (Circ Cardiovasc Interv. 2015;8:e001799. DOI: 10.1161/CIRCINTERVENTIONS.114.001799.)

Key Words: adult ▪ aortic coarctation ▪ percutaneous transluminal angioplasty ▪ stents

Coarctation of the aorta (CoA) is one of the most common congenital heart defects and makes up ≈5% to 8% of all congenital cardiac and vascular malformations.1–3 The main treatment indication of CoA is a relevant prestenotic hypertension with a peak-pressure gradient of >20 mm Hg. The perioperative mortality of surgical repair of isolated CoA in early adulthood is <1%. Although the functional result is usually good, there is an ≈9% rate of postoperative suture aneurysms and later restenosis.4–11 In older candidates, perioperative complications caused by degenerative changes in the aorta may occur and lead to transient or permanent neurological deficits.4–11 A promising extension of the therapeutic armamentarium for the treatment of adult CoA arose with the introduction of endovascular reconstruction methods.

See Editorial by Horlick and Benson

In the present work, we summarize our experience with percutaneous treatment of CoA of the adult using a self-expandable uncovered stent. We focus on the acute perioperative results and the long-term clinical and computed tomographic (CT) angiography findings trying to identify the durability of the functional and anatomic gains of the procedure.

Methods

The series includes patients who were treated consecutively from March 2002 to June 2009 within the same institution. All patients had adult type native CoA. A self-expanding uncovered nitinol stent (Sinus-XL, Optimed, Esslingen, Germany) was used in all patients. None of the patients had been submitted previously to conventional surgery. Patients with tubular hypoplasia at the level of the CoA were excluded from this type of treatment and were addressed either to conventional surgery or to percutaneous intervention with covered stents.

Institutional review board approval for the study was obtained and subjects gave informed consent.

Preinterventional Diagnostics

A CT angiography was performed to assess aortic, neck, and peripheral access vessels anatomy. In the majority of cases, diagnostics were supplemented by MRI of intracranial vessels to rule-out cerebral
WHAT IS KNOWN

• Catheter-based treatment of aortic coarctation has experienced a significant expansion in recent years.
• Although performing aggressive balloon angioplasty of an adult aortic coarctation may be all that is required, there are numerous other studies advocating the use of stents, most of which involve balloon-expandable stents.

WHAT THE STUDY ADDS

• This is the largest published experience with primary placement of a self-expanding uncovered stent (Optimed XL) with subsequent stent-protected balloon angioplasty to treat aortic coarctation in adult patients.
• Clinical and imaging follow-up showed that immediate arterial blood pressure control and anatomic correction of the coarctation were present in the majority of patients and persisted at long-term follow-up.

Aortic Analysis

The necessary information to plan the stenting was obtained through evaluation of the CT data. At first, we evaluated a 3-dimensional representation of the entire aorta, which provided a rapid assessment of the main anatomic features (Figure 1A and 1B). We focused on the severity and localization of the CoA and its position in relation to the neck vessels and distal aortic arch.

We also evaluated the quality of the aortic proximal and distal landing zone focusing on the presence of calcific and atherosclerotic lesions and poststenotic dilatation. In fact, all these conditions may hamper stent sealing, wall apposition, and may lead to increased aortic fragility. Reformatted multiplanar reconstructions were used for quantitative analysis of the aortic diameter at defined measurement points and to determine the degree of stenosis (Figure 2).

In specific, to better identify the pathoanatomic features of the CoA, our approach routinely included multiplanar reconstruction images precisely perpendicular to the long axis of the coarcted segment. These images are of focal importance to identify the eventual presence of a CoA shelf and to exclude true tubular hypoplasia. We started from the basic CT axial images where we identified the approximate height and position of the CoA. At this stage, sagittal and coronal views were generated automatically by the image viewer application (we adopted OsiriX). The orientation of the axial plane was then corrected simultaneously in the sagittal and coronal view so to produce a short axis image that was exactly perpendicular to the long axis of the segment of coarcted aorta. In this dedicated plane the hemodynamic orifice could be easily identified and differentiated from an eventual CoA shelf (Figure 1C and 1D). Both anatomic areas could be measured using the application tools (Figure 1D).

Finally, a multiplanar and 3-dimensional representation of the pelvic axis to detect state and diameter of the peripheral access vessels was considered mandatory.

Selection of stent diameter was based on sizing of the proximal landing zone. We considered the segment of the aorta immediately proximal to the CoA, and possibly free from any calcific and atherosclerotic degeneration, as the proximal landing zone. In our experience, this segment of aorta was most often located at the level of the distal edge of the left subclavian artery ostium (Figure 2). A stent 10% to 15% larger than the diameter of the proximal landing zone was then chosen. Moreover, to avoid a mismatch between proximal and distal landing zones, whenever a poststenotic dilation was present, we chose a stent with a length that was sufficient to reach a distal landing zone with a diameter corresponding to that of the proximal landing zone.

Stent Features

The Sinus-XL is a self-expanding uncovered nitinol stent with a closed-cell design (Figure 3) with a sufficiently high radial force to treat native CoA. It has a range of sizes from 16 to 34 mm in diameter and 30 to 100 mm in length. The stent is delivered within a 10F introducer and over a 0.035-inch guiding wire. The biaxial structure of the outer sheath allows to overcome even extreme vascular kinking, maintaining high flexibility and atraumatic profile. Peculiar features of the stent include a coaxial pull-back system, an excellent radio-opacity, thanks to tantalum markers and a minimal length loss after complete release. Moreover, the stent has an antijump feature to maintain a stable position even while the distal extremity of the stent is deployed, without sudden jumps of the stent (Figure 3).

Interventional Procedure

All procedures were performed either in a standard catheterization laboratory or in a hybrid operating room. Patients received intravenous analgesia and moderate sedation. A bolus of 5000 IU of heparin was administered intravenously. A 6F pigtail catheter was placed into the aortic arch through the right brachial artery. We preferred this approach to the radial artery in the majority of patients. In fact, the brachial artery allowed for larger introducers, often required for eventual bail out procedures in case of inadvertent stent dislocation, and also for easier antegrade crossing of the CoA, whenever it was required (see below). A first angiography was performed to map the aortic arch, neck vessels, and thoracic aorta (Figure 4). A 10F sheath was placed in the common femoral artery. With the aid of a pigtail or multipurpose catheter, a hydrophilic guidewire was advanced from the femoral access along the aorta through the CoA. The coated wire was then exchanged over a catheter with a stiff guidewire. Whenever retrograde passage of the CoA was not possible as a result of the complex anatomy and degree of kinking and stenosis, the CoA was overcome antegradely from the brachial artery. The guidewire was then lassoed in the thoracic aorta and externalized through the femoral introducer.

The stent was advanced along the stiff guidewire and across the CoA. A starting position was achieved through a second aortography. A stepwise fine-tuned release of the proximal part of the stent was started by gently pulling the outer sheath, holding the support system while monitoring the position of the stent through interventional contrast injections (Figure 4). Once the proximal segment of the stent was opened, fine adjustments of the final deployment position were still possible by gently pulling the stent support system. After complete release of the stent, the support system was removed. Depending on the primary result and the detailed knowledge of the preoperative anatomy, a stent-protected angioplasty of the remaining stent waist using a noncompliant high-pressure balloon was performed (Figure 4). The noncompliant balloon we used to postdilate the stents was the Maxi LD (Cordis Corporation, FL). The maximum balloon size was in reference to the proximal landing zone and the outer contour of the CoA shelf (Figure 1). In particular, the smaller of the 2 values was used as a reference to choose the correct balloon. The balloon was inflated to its nominal size based on fluoroscopic imaging and without taking inflation pressures into account. If the residual gradient was <10 mm Hg, no further dilation was performed, regardless of the fluoroscopic images. In any case further ballooning, whenever required, was performed using the same balloon size and without exceeding the above-mentioned references.
A final angiography via the brachial artery was the documentation of the anatomic procedural result (Figure 4). A dual antiplatelet therapy with aspirin and clopidogrel was maintained for the first 6 months after stent implantation. Patients were generally discharged home after evaluation of the postintervention CT angiography imaging.

Data Collection and Statistical Analysis

All demographic and clinical data were collected and analyzed prospectively. The follow-up duration was 47.6±23.0 months (12–84 months) and all patients considered in this study had at least a 12-month clinical follow-up. All patients underwent routine ambulatory visits (after 1 month, 6 months, and every year) and staged telephone interviews to investigate on their clinical status and the level of their blood pressure control and medication intake. Data were confirmed with the referring cardiologists and family physicians. Data are presented either as means±SD or as medians. Ranges and rates are also presented.

Pre- and postprocedural clinical and imaging findings were compared. Differences between pre- and postoperative variables were tested using the paired Student t test and the Wilcoxon signed-rank test. Comparisons among the preoperative and follow-up measurements were performed using repeated measures ANOVA. A P value <0.05 was considered statistically significant. Kaplan–Meier survival analysis was performed. The statistical calculations were performed using the SPSS 11.0 software.

Figure 1. Computed tomographic assessment of aortic coarctation. Images are obtained from the original data set of axial images of the same patient. Preoperative 3-dimensional reconstruction (A and B) of coarctation of the aorta (CoA; dashed black circle). C to F, Multiplanar reconstruction (MPR) of the aorta with narrowing at the isthmic region (white arrows). C and D, MPR views perpendicular to the coarcted segment. These MPR views are obtained specifically to identify the eventual presence of a CoA shelf. In fact, dashed black and dashed white circles delimit, respectively, the hemodynamic orifice of the CoA and the outer limit of the CoA shelf. When opting for a postdilatation in such patients with CoA shelf, the maximum balloon size should be in reference to the proximal landing zone and the outer contour of the CoA shelf (dashed white line) sizes. The smaller of the 2 values is used as a reference to choose the correct balloon. LCCA indicates left common carotid artery; LSA, left subclavian artery; and TBC, truncus brachiocephalicus.

Figure 2. Reformatted multiplanar image: (1) ascending aorta; (2) aortic arch; (3) left subclavian artery; (4) isthmic coarctation of the aorta (CoA); (5) descending thoracic aorta distal to CoA; and (6) thoracic aorta at diaphragm level. PLZ indicates proximal landing zone.

Figure 3. The Sinus-XL stent (Optimed, Esslingen, Germany). A, Partial stent unsheathing (B) particular of the 10-F application sheath and coaxial pull-back system; (C) radiopaque markers at distal tip; (D) distal markers with antijump system; and (E) fully unsheathed stent.
Results

Preoperative Demographic and Clinical Data
A total of 52 consecutive patients were treated. Demographic and morbidity data are summarized in Table 1. Arterial hypertension of the upper half of the body was reported in all patients, despite maximal antihypertensive treatment with ≥3 drugs (diuretic, β-blocker, angiotensin-converting enzyme inhibitor, and a vasodilating agent).

Table 2 summarizes the preoperative aortic CT findings. All patients had an isthmic CoA. No patient had complex intracardiac malformations, prior surgery, and percutaneous interventions in the transverse or descending thoracic aorta.

Perioperative Results
Table 3 summarizes the perioperative and in-hospital outcome data. A total of 53 self-expanding stents have been implanted with an average diameter of 24.2±27 mm and a mean length of 70.4±1.5 mm. Eight patients (15.4%) required primary balloon angioplasty of a subaortic CoA before placement of the stent. In 1 patient, a caudal dislocation of the stent was noticed and a second stent had to be implanted overlapping with a good procedural result. After release of the self-expanding nitinol stent, a balloon angioplasty for optimal adaptation of the stent body was performed in all patients.

A significant reduction of the invasive pressure gradient from 54.7±9.9 to 3.3±2.5 mm Hg was obtained (P<0.001) and in none of the patients a residual trans-CoA rest gradient >10 mm Hg was reported. In the same session elective coronary intervention was performed in 4 patients (7.7%).

Iatrogenic Complications
In 1 patient with hypoplasia of the iliac-femoral vessels, an iatrogenic femoral artery dissection was treated through graft interposition.

One patient developed protracted hypotension and diffuse thoracic pain few hours after intervention. An emergency CT confirmed the clinical diagnosis of a contained aortic rupture with a left-sided hemothorax. A covered thoracic endoprosthesis was implanted emergently to seal off the contained rupture. The further clinical course was uneventful. The overall perioperative morbidity was 6.8%. No conversion to open surgery, neurological complications, and in-hospital mortality were reported. The intensive care unit length of stay was 19.3±5.6 hours. Overall hospitalization was 3.5±1.7 days. A predischarge thoracic CT confirmed a gain in the minimum CoA diameter from 4.6±1.9 to 18.6±2.5 mm (P<0.001).

Clinical Long-Term Follow-Up: Events and Survival
Table 4 summarizes follow-up events. During the 47.6±23.0 months (12–84 months) of follow-up, no cardiovascular death occurred. Three patients (5.8%) with bicuspid aortic valve and aortic ectasia at the time of stenting required ascending aorta and aortic valve replacement for further ascending aorta enlargement and worsening of aortic valve function. In 3 patients (5.8%), interventional treatment of coronary artery stenosis (2; 3.8%) and symptomatic internal carotid stenosis (1; 1.9%) was required. The 1-, 3-, and 5-year event-free survival after interventional correction of CoA was 96.2±2.7, 88.7±4.9, and 82.2±6.3%, respectively (Figure 5).

Clinical Long-Term Follow-Up: Blood Pressure Control
At follow-up, systemic blood pressure values and antihypertensive medications intake were investigated directly by outpatient visits and phone interviews, as well as personal telephone contact with the referring cardiologist and family doctor. The highest value between the left and right arm arterial blood pressure measurements was recorded. This was done in all 52 patients in the preoperative and follow-up phases.

Patients with systolic resting blood pressure values >140 mm Hg and diastolic values >90 mm Hg were classified as hypertensive. According to this definition, all patients had preoperative hypertension. The systemic blood pressure before intervention was 162.2±3.7 mm Hg in the overall population. After CoA treatment, brachiocephalic blood pressure at discharge dropped to 139.2±12.4 mm Hg (P<0.001). Later measurements showed a sustained improvement in blood pressure control at 12 months (128.1±10.6 mm Hg) and in the late follow-up after 47.6±23.0 months (126.4±10.5 mm Hg; P<0.001 versus immediate postoperative). Similarly, we recorded a drop in diastolic blood pressure (preoperative 95.3±7.1 mm Hg versus immediate postoperative 88.4±6.9 mm Hg; P<0.001). At 12 months or long-term follow-up, diastolic values were still reducing to 84.7±7.2 and 82.8±6.5 mm Hg, respectively. The majority of patients (30/52; 57.7%) did not require any antihypertensive treatment after the procedure. A further 16 patients...
P 18.5±2.7 mm was reported (stable expansion of the aortic isthmus from an initial 4.6±1.9 to 18.5±2.7 mm was reported ($P<0.0001$; Table 5; Figure 6).

Aortic CT Imaging at Follow-Up
As part of the protocol, high-resolution CT of the thoracic aorta was performed at discharge, 6 months, and 24 months after surgery. Table 5 summarizes the findings. No cases of stent fracture, collapse, recoil, and secondary migration were observed. A stable expansion of the aortic isthmus from an initial 4.6±1.9 to 18.5±2.7 mm was reported ($P<0.0001$; Table 5; Figure 6).

| Table 1. Baseline Clinical Characteristics of the Patient Population |
|-----------------|-----------------|
| **Demographic data** |
| No. of patients | 52 |
| Primary (native) isthmic stenosis | 52 (100%) |
| Age, y | 36.6±14.6 (21–67) |
| Body mass index, kg/m² | 23.9±4.1 (19.8–27.4) |
| Antihypertensive medication | 100 (100%) |
| **Clinical symptoms** |
| No subjective symptoms | 10 (19.2%) |
| Claudication | 21 (40.4%) |
| Dyspnea | 19 (36.5%) |
| Angina pectoris | 8 (15.4%) |
| Cephalgia | 7 (13.5%) |
| **Cardiovascular comorbidities** |
| Brachiocephalic hypertension | 52 (100%) |
| Concentric LV hypertrophy | 19 (36.5%) |
| Bicuspid aortic valve | 10 (19.3%) |
| CAD | 9 (17.3%) |
| Compensated CKD | 8 (15.4%) |
| Impaired LVEF | 7 (13.5%) |
| COPD | 4 (7.7%) |
| Aortic valve replacement | 3 (5.8%) |
| Type 2 diabetes mellitus | 2 (3.8%) |
| Aortic ectasia | 2 (3.8%) |
| CVD | 2 (3.8%) |
| Situs inversus | 1 (1.9%) |
| Arteria lusoria | 1 (1.9%) |

Data are expressed as rates and mean±SD with relative ranges. CAD indicates coronary artery disease; CKD, chronic kidney disease; COPD, chronic pulmonary obstructive disease; CVD, cerebrovascular disease; and LVEF, left ventricular ejection fraction.

(30.8%) were still taking 1 antihypertensive medication. The minority of patients (6/52; 11.5%) remained hypertensive at follow-up in spite of CoA treatment and maximal medical therapy. However, even in these cases, we recorded individually improved blood pressure control under partially reduced concomitant medications intake. Overall, the therapeutic goal of normalization of blood pressure was achieved in 88.5% of those treated. Moreover, at 24 months there was no suspicion of aortic restenosis, and a transaortic gradient >10 mm Hg was never reported. In addition, we confirmed the normalization of the ankle-brachial index (preoperative median 0.75 versus 24-month follow-up 0.98; $P<0.001$) that confirmed the steadily maintained improvement of distal aortic perfusion.

Procedural Safety
The safety of percutaneous treatment of CoA has greatly improved, thanks to sophisticated intervention strategies and developments in the field of stent technology. However, as with all endovascular therapies, there is a burden of perioperative adverse events that may involve the strictly technical aspects of the procedure or result in iatrogenic complications (mainly in the native aorta and peripheral vessels).12 From a technical standpoint, the risk of stent migration, stent fracture, and balloon rupture has to be considered.13 Multi-institutional studies report a 4.8% rate of stent migration that will require, in 75% of the cases, additional stent implantation.14 More recent studies suggest an incidence of intraoperative stent migration between 0% and 14.3%. Intraprocedural stent migration is mainly because of an incorrect sizing or balloon rupture when using balloon-expandable stents. Adjunctive interventional techniques such as the balloon-in-balloon catheter and rapid ventricular pacing have optimized the implantation of balloon-expandable stents.15–17

Migration of self-expanding stents is rare, thanks to a gradual release and partial repositionability, even in anatomically complex situations. Moreover, the self-expanding stent Sinus-XL has a so-called antijump system at its distal end (Figure 3) that allows for a distal tip capturing and controlled opening of the last part of the stent, without sudden jumps within the native aorta. Using Sinus-XL stents, we observed 1 single case (1.9%) of distal stent migration in the early stages of our experience.

Balloon ruptures were reported at a rate of 2.2% in the Congenital Cardiovascular Interventional Study Consortium. This occurrence may lead to aortic wall lesions, embolization of balloon fragments, and stent migration.14 Stent fractures are observed more rarely (1.0%) and result from focal aortic recoil. In the majority of cases implantation of a second stent is necessary.18,19

Although rare, aortic rupture and dissection have been reported during stenting for adult CoA.14,20,21 For this reason, covered aortic stents should always be available when

| Table 2. Preinterventional Analysis of Computed Tomography Data of Aorta |
|-----------------|-----------------|
| Length of stenosis | 26.7±12.4 mm |
| Diameter of stenosis | 4.6±1.9 mm |
| Subatretic lesion (<3 mm diameter) | 11 (21.2%) |
| Calcification of the aortic arch | 7 (13.4%) |
| Hypoplastic aortic arch | 9 (17.3%) |
| Poststenotic dilation | 10 (19.2%) |
| Prominent collateral vasculature | 50 (96.2%) |
| Ascending aorta (sinus aortae) | 36.5±6.8 mm |
| Aortic arch distal of CCA | 21.4±3.9 mm |
| Exit of left subclavian artery | 22.8±5.1 mm |
| Proximal descending aorta | 31.8±9.3 mm |
| Aorta at level of diaphragm | 23.5±4.7 mm |

Data are expressed as rates and mean±SD. CCA indicates common carotid artery.

Discussion

Procedural Safety
The safety of percutaneous treatment of CoA has greatly improved, thanks to sophisticated intervention strategies and developments in the field of stent technology. However, as with all endovascular therapies, there is a burden of perioperative adverse events that may involve the strictly technical aspects of the procedure or result in iatrogenic complications (mainly in the native aorta and peripheral vessels).12 From a technical standpoint, the risk of stent migration, stent fracture, and balloon rupture has to be considered.13 Multi-institutional studies report a 4.8% rate of stent migration that will require, in 75% of the cases, additional stent implantation.14 More recent studies suggest an incidence of intraoperative stent migration between 0% and 14.3%. Intraprocedural stent migration is mainly because of an incorrect sizing or balloon rupture when using balloon-expandable stents. Adjunctive interventional techniques such as the balloon-in-balloon catheter and rapid ventricular pacing have optimized the implantation of balloon-expandable stents.15–17

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Although rare, aortic rupture and dissection have been reported during stenting for adult CoA.14,20,21 For this reason, covered aortic stents should always be available when
treating these patients, as reported in our experience. Literature data indicate that an aggressive balloon angioplasty of the native aorta and repeated dilatations of the stent contribute to the overall risk of iatrogenic aortic wall damage. Particular attention should be paid when treating elderly patients with calcified or hypoplastic vessels with reduced elasticity. In this context, the further improvement and miniaturization of the instrumentation used have led to a significant reduction in iatrogenic complications, even in more complex cases.

Although reliable data on long-term effectiveness of adult CoA stenting are not yet available, endovascular therapy has already become the treatment of choice in patients with ventricular dysfunction, advanced age, and other serious comorbidities.

**Correction of Arterial Hypertension**

Only recent studies have shown that correction of CoA in adulthood will lead to arterial pressure control, ventricular mass reduction, and ventricular function improvement. In our experience, 88.5% of the treated patients had normalization of their resting blood pressure and 57.7% could terminate antihypertensive medications. It should be emphasized that hypertension and left ventricular hypertrophy may persist in up to a third of treated patients. In fact, the increase in aortic wall intrinsic stiffness may all be the cause for the persistently increased left ventricular pressure loads.

**Performance of Self-Expanding Nitinol Stents**

As previously stated, the Sinus-XL stent is a self-expanding, laser-cut nitinol stent. Nitinol is a nonmagnetic alloy of nickel and titanium. It has a shape memory and after being deformed returns to its original shape on being reheated. Thanks to its sinusoidal structure (closed-cell design), the Sinus-XL stent may develop, once unfolded, a high radial force maintaining a desirable level of flexibility. In this way, a constant and
moderate radial force is exerted within the aortic isthmus, respecting compliance and functional integrity of the diseased native aortic wall and resulting in the alleged low incidence of stent-associated aortic complications.

In addition, the Sinus-XL stent offers a coaxial pull-back system, an antijump mechanism, a minimal stent shortening, and an excellent radiopaque feature that may all contribute to its precise, controlled, and stable deployment. Thanks to all these functional improvements, intraprocedural migration of second generation stents has become extremely rare.44–46

Finally, the Sinus-XL system only requires a 10F application kit and, for this reason, a sufficient hemostasis of the arterial access site can be achieved, in 98.1% of patients, by simple mechanical compression.

In spite of these promising features, self-expanding stents have been used rarely to treat patients with adult CoA. Tyagi et al47 reported on the application of the self-expanding stent Memotherm (Bard-Angiomed, Karlsruhe, D) in 16 patients with CoA, without evidence of iatrogenic damage to the aortic wall. Haji-Zeinali44 could provide similar results using the Sinus-XL stent in 21 patients.

To the best of our knowledge, we are presenting the largest experience with such a stent in the treatment of adult CoA. Although we reported a rate of aortic iatrogenic lesions of only 3.8%, we should reflect on this potentially treacherous complication. In fact, when using bare stents, a gradient-controlled angioplasty should be preferred to a complete dilatation of the stent, especially whenever a subatretic aortic isthmus is present. The aortic wall tear that we reported happened in the early stage of our experience and possibly resulted from erroneous postballooning with an oversized balloon. From that time on we also started to consider the outer contour of the CoA shelf in the postballooning sizing (Figure 1). In fact, in our experience, the stenosed aortic segment most often results from the presence of a fibrotic septum rather than from a sole hypoplasia of the aorta. In this context, although the aorta is per se hypoplastic in the coarctation tract, timely analysis of the CT imaging may reveal both a hemodynamic orifice and a somewhat larger CoA shelf (Figure 1). When opting for a postdilatation, correct balloon sizing should keep into consideration the smaller between the proximal landing zone and the outer contour of the CoA shelf (Figure 1). Using this strategy, we were able to prevent further aortic complications and abolish any significant residual gradient.

Use of Covered Stents for CoA

The use of covered stents to treat CoA should be advised in special conditions such as coexistent aortic aneurysm,48 tubular hypoplasia,49 aortic isthmus stenosis with persistent patent ductus arteriosus, as well as in elderly patients with a calcified aortic wall. Using serial dilation of covered stents, reconstruction to a physiological aortic diameter can be achieved with reduced iatrogenic complications, even in patients with high risk of aortic rupture.27 For elderly patients (>65 years) with anatomically complex lesions, the CP covered stent (Cheatham Platinum) is considered the device of choice.27,28

Table 5. Aortic Diameter Determined by Computed Tomography at Baseline, Discharge, After 6 Months, and 24 Months

<table>
<thead>
<tr>
<th></th>
<th>Baseline (n=52)</th>
<th>Discharge (n=52)</th>
<th>6 mo (n=49)</th>
<th>24 mo (n=40)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascending aorta (sinus aortae), mm</td>
<td>36.5±6.8</td>
<td>36.3±6.8</td>
<td>36.9±6.8</td>
<td>37.8±7.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Aortic arch distal of CCA, mm</td>
<td>21.4±3.9</td>
<td>22.0±4.2</td>
<td>21.9±3.2</td>
<td>21.5±5.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Exit of left subclavian artery, mm</td>
<td>22.8±5.1</td>
<td>22.8±5.1</td>
<td>23.3±4.7</td>
<td>23.1±5.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Minimum diameter of CoA, mm</td>
<td>4.6±1.9</td>
<td>18.6±2.5</td>
<td>18.1±3.1</td>
<td>18.5±2.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Proximal descending aorta, mm</td>
<td>31.8±9.3</td>
<td>31.7±6.3</td>
<td>32.5±5.3</td>
<td>32.4±9.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Aorta at level of diaphragm, mm</td>
<td>23.5±4.7</td>
<td>25.1±6.8</td>
<td>23.9±4.4</td>
<td>24.3±7.1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Comparisons among the preoperative and follow-up measurements were performed using repeated measures ANOVA. Data are expressed as mean±SD. CCA indicates common carotid artery; and CoA, coarctation of the aorta.
At the present, there are no comparative studies evaluating bare metal stents versus covered stents for the percutaneous treatment of CoA. For this reason, the correct strategy should be planned according to the local expertise and operator preference. The main drawbacks of covered stents are the requirement for larger introducers and the potential risk for inadvertent occlusion of the neck vessels during stent release.

**Conclusions**

Catheter-based treatment of CoA has experienced a significant expansion in recent years. Although performing aggressive balloon angioplasty of an adult CoA may be all that is required, there are numerous other studies advocating the use of stents. In the present article, we limit ourselves to propose primary placement of a self-expanding uncovered stent with subsequent stent-protected balloon angioplasty to treat CoA in adult patients. As shown in our experience, the peculiar stent design preserves adequate localized radial strength over time, maintaining appropriate aortic isthmus gain with minimal trauma on the adjacent aortic wall and negligible device-related complications. These conditions will lead to immediate arterial blood pressure control that, in the majority of patients, persists and optimizes even at long-term follow-up.

**Disclosures**

None.

**References**


Percutaneous Treatment of Adult Isthmic Aortic Coarctation: Acute and Long-Term Clinical and Imaging Outcome With a Self-Expandable Uncovered Nitinol Stent
Stephan Kische, Giuseppe D’Ancona, Yannik Stoeckicht, Jasmin Ortak, Albrecht Elsässer and Hüseyin Ince

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