Technique of interventional repair in adult aortic coarctation

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Surgical treatment of aortic coarctation has increased life expectancy and reduced mortality. Unfortunately, the average lifespan after repair remains only 35 to 50 years, and significant morbidity persists as a result of aneurysm formation, hypertension, accelerated coronary disease, and stroke. Follow-up studies have revealed restenosis rates of 30% and persistent hypertension at rest and during exercise, sometimes with compromised cardiac function. The less invasive nature of nonsurgical repair using transcatheter therapies has led to balloon angioplasty and, recently, stent implantation as an emerging concept for the treatment of aortic coarctation. This review focuses on advances in the management, current indication, and techniques of interventional repair in aortic coarctation. (J Vasc Surg 2010;51:1550-9.)

Advances in surgical treatment of coarctation of the aorta have increased life expectancy and reduced mortality. Unfortunately, the average lifespan after open surgical repair remains 35 to 50 years, and significant morbidity persists as a result of aneurysm formation, hypertension, accelerated coronary disease, and stroke.[1] In addition, follow-up studies have revealed restenosis rates of 30% and persistent hypertension at rest and during exercise, often resulting in compromised cardiac function. The less invasive nature of nonsurgical repair with transcatheter therapies has led to balloon angioplasty and, recently, stent implantation as an emerging concept for the treatment of aortic coarctation. Transcatheter studies conducted during the last 2 decades have focused on the feasibility of treatment and assessing the ability of these devices to reduce the gradient across the coarctation. This article focuses on current indications and techniques of interventional repair in adult aortic coarctation.

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INDICATION FOR TREATMENT AND PATIENT SELECTION

Indications for relief of obstruction, even in asymptomatic adult patients, have included clinically determined radial-femoral arterial pulse delay or a catheter-derived peak-to-peak gradient of >20 mm Hg at rest or >30 mm Hg after exercise. However, relief of aortic coarctation may still be indicated in the presence of lower gradients if radiologic evidence shows significant collateral flow, left ventricular dysfunction, or progressive hypertrophy, or if concomitant anatomic (aortic valve, aortic aneurysm, coronary or carotid atherosclerosis) procedures are being considered. The benefit and appropriate threshold for intervention is less clear in patients with moderate coarctation, which usually occurs in the context of a previous surgical repair. These patients often have significant resting hypertension or may only exhibit hypertension during exercise.

Cardiovascular specialists generally agree that percutaneous balloon angioplasty, with or without stent implantation, is a preferred treatment for recurrent postsurgical aortic coarctation in the absence of confounding features such as aneurysm or pseudoaneurysm formation, or significant coarctation that affects the adjoining arch arterial branches. However, percutaneous treatment for unoperated aortic coarctation in the adult remains more controversial.[2]

For localized discrete narrowing of the native aorta, balloon angioplasty, with or without stent placement, is now an acceptable alternative to surgical repair as a primary intervention but is still considered less suitable for long-segment or tortuous forms of coarctation. Because early surgical mortality can be 5% to 10% in individuals with significant comorbidity or severe left ventricular dysfunc-

Fig 1. Noninvasive assessment of aortic pathology in a patient with severe coarctation. A composite of volume-rendered images obtained from a 64-slice multidetector CT angiogram is presented. **A**, Classic anatomic features including discrete aortic narrowing (*arrow*) and hypoplastic aortic arch are clearly visualized in lateral projection. **B**, Note the detailed display of the collateral network and a concomitant ectasia of the ascending aorta (*ASC*). *Indicates the right internal mammarian artery

tion, catheter-based repair has emerged as the preferred therapeutic option in this subgroup of patients. Many centers now reserve surgery for patients who are unsuitable for percutaneous treatment or who have undergone unsuccessful endovascular repair.[3]

NONINVASIVE IMAGING OF AORTIC PATHOLOGY BEFORE INTERVENTION

Before endovascular therapy for aortic coarctation, each patient requires a detailed assessment of the anatomy and physiologic pattern of the obstruction and associated lesions. In practice, this includes complete visualization of the aorta and its branches by contrast-enhanced magnetic resonance (MR) angiography (MRA) or computed tomography (CT) scan. Although indications may overlap, both imaging modalities allow detailed delineation of vascular pathology by dedicated postprocessing routines, including 3-dimensional (3D) reconstruction, multiplanar reformation, or maximum-intensity projection. A 3D reconstruction can identify the precise location and complex anatomy of coarctation and demonstrates its relationship to supra-aortic branches, presence of isthmus hypoplasia, and the extent of collateral networks (Fig 1). Reformatted images in any desired plane can be used to obtain precise measurements of the aorta for therapeutic decision making before cardiac catheterization. The obvious advantages of multidetector CT include rapid image acquisition and its potential to screen for vascular calcification, whereas MRA is often preferred in young patients who will require multiple follow-up examinations because it offers high spatial resolution to characterize aortic wall properties but avoids radiation and iodinated contrast agents.

EQUIPMENT FOR CATHETER-BASED INTERVENTIONS

With improvements in technology, various endovascular stents have become available for the treatment of coarctation (Fig 2). Stents may generally be subdivided into balloon-expanded or self-expanding devices, with covered stents recently added to the therapeutic armamentarium. In 1999, the United States Food and Drug Administration (FDA) approved the Palmaz XL 10-series stents (Cordis, Endovascular, Miami, Fla), ranging up to 50 mm in length. These stents made it possible to deliver long stents to the thoracic aorta that could be expanded later with growth of the aorta to a maximum diameter of 25 to 28 mm. They are laser cut from a very rigid stainless steel tube, with straight slits interpolated along the length of the stent. The Palmaz XL stents form a very strong closed diamond shape when the stent is expanded, except at the ends of the stent, with alternating open half-diamond stent cells. These stents demonstrate significant shortening by almost 50% when expanded to their full diameter.

The Palmaz Genesis XD stent (Cordis Endovascular, Miami, FL) is also laser cut from stainless steel and has a closed-cell design; however, it has a S-shaped sigma hinge interposed between the cells, which allows the stent to flex around curves and reduces shortening on expansion. The Genesis stents are available in multiple lengths but cannot be expanded further than 18 to 20 mm. Unless the aorta is expected to reach a diameter significantly greater than 18 mm, the radial strength and flexibility of the Genesis stent make it an excellent option for treatment of lesions that lie across the curve between the transverse arch and the descending aorta.

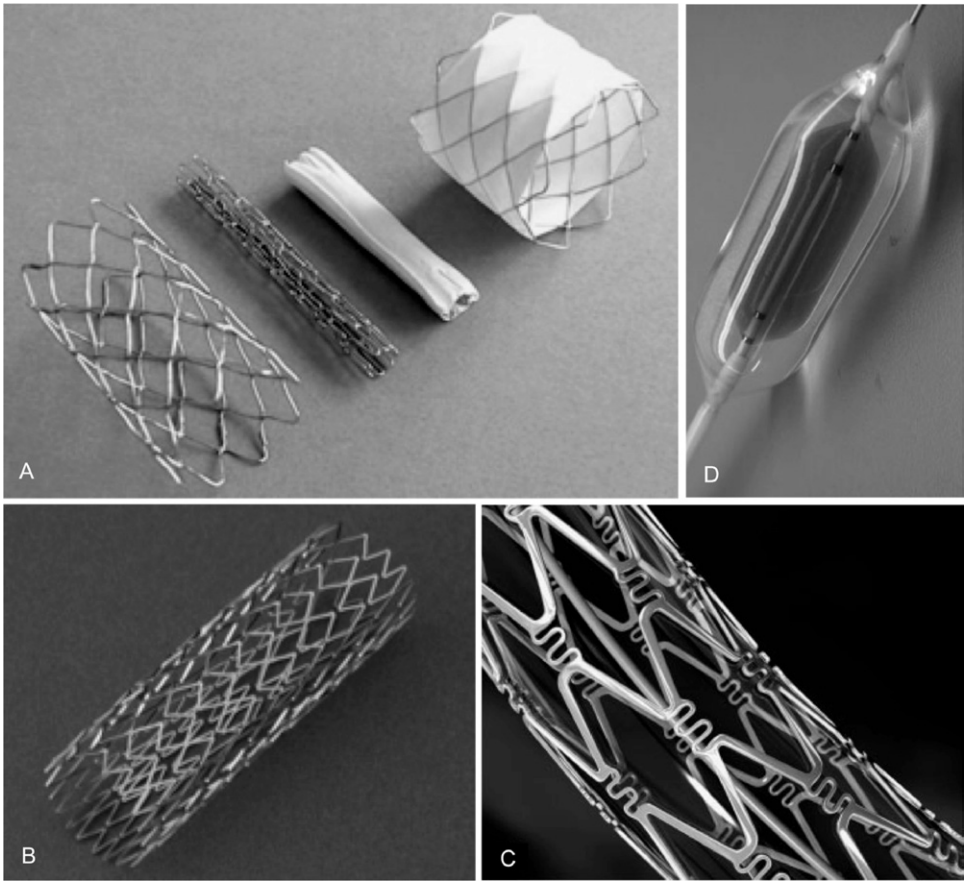

Fig 2. A selection of endovascular devices are currently available for the transcatheter repair of adult coarctation. **A,** The CP stents by NuMed are made of platinum wire with rows of zigzags to allow full-size expansion with minimal shortening and good radial strength. **B,** The ev3 Intrastent Max LD is expandable to full size, is flexible, and does not significantly shorten. **C,** The "sigma" hinge in the Genesis stents allows the stents to flex around curves and prevents significant shortening on expansion; however, these stents cannot be expanded beyond 18 mm. **D,** The NuMED Balloon-in-Balloon catheter allows even expansion of a hand-mounted stent for safer and more reliable stent positioning.

The Palmaz Genesis covered stent is a closed-cell stainless steel balloon-expandable stent covered with expanded polytetrafluoroethylene. The stent has an expansion range of 10 to 18 mm and retains the features of the first Genesis stents, such as the possibility of insertion in curved vessels with good radial strength. Palmaz stents, with their closed-cell design, have essentially no flexibility at all and will fail to conform to the contour of the aortic arch.

The Palmaz XL 10 series remained the only large stents available until the IntraStent LD MaxTM stent (ev3 Endovascular Inc, Plymouth, Minn) was approved in 2002. With an open-cell design that significantly reduces stent shortening and rounded cell edges at the ends, these stents offer advantages over the Palmaz stents. However, the stent may take less purchase in the vessel wall during deployment because of its rounded edges, making it, at least theoretically, more prone to migration, especially in lesions with a higher degree of compliance. The ev3 stents can be enlarged to 24 to 26 mm and have radial strength only slightly less than the Palmaz stents at this diameter; lengths of 16, 26, and 36 mm are available.

Cheatham-Platinum (CP) stents (NuMED Inc, Hopkinton, NY) are not yet available in the United States but have been used extensively in Europe, with apparent success. The balloon-expandable stents are made of a framework of platinum-iridium wire laser-welded in a zig-zag pattern with additional gold soldering to each weld spot to add extra strength. With its rounded margins, the CP stent is designed to minimize aortic wall trauma. The CP covered stent, currently not available in the United States, is a balloon-expandable stent with an expanded polytetrafluoroethylene sleeve. This stretches with the stent to its maximum diameter of 24 mm, and this may be accompanied by a foreshortening of up to 40% of the initial length of the stent.

The OptiMed Sinus-XL stent (OptiMed, Ettlingen, Germany) is a self-expanding nitinol (shape-memory) stent that is laser cut without welding. It was designed with

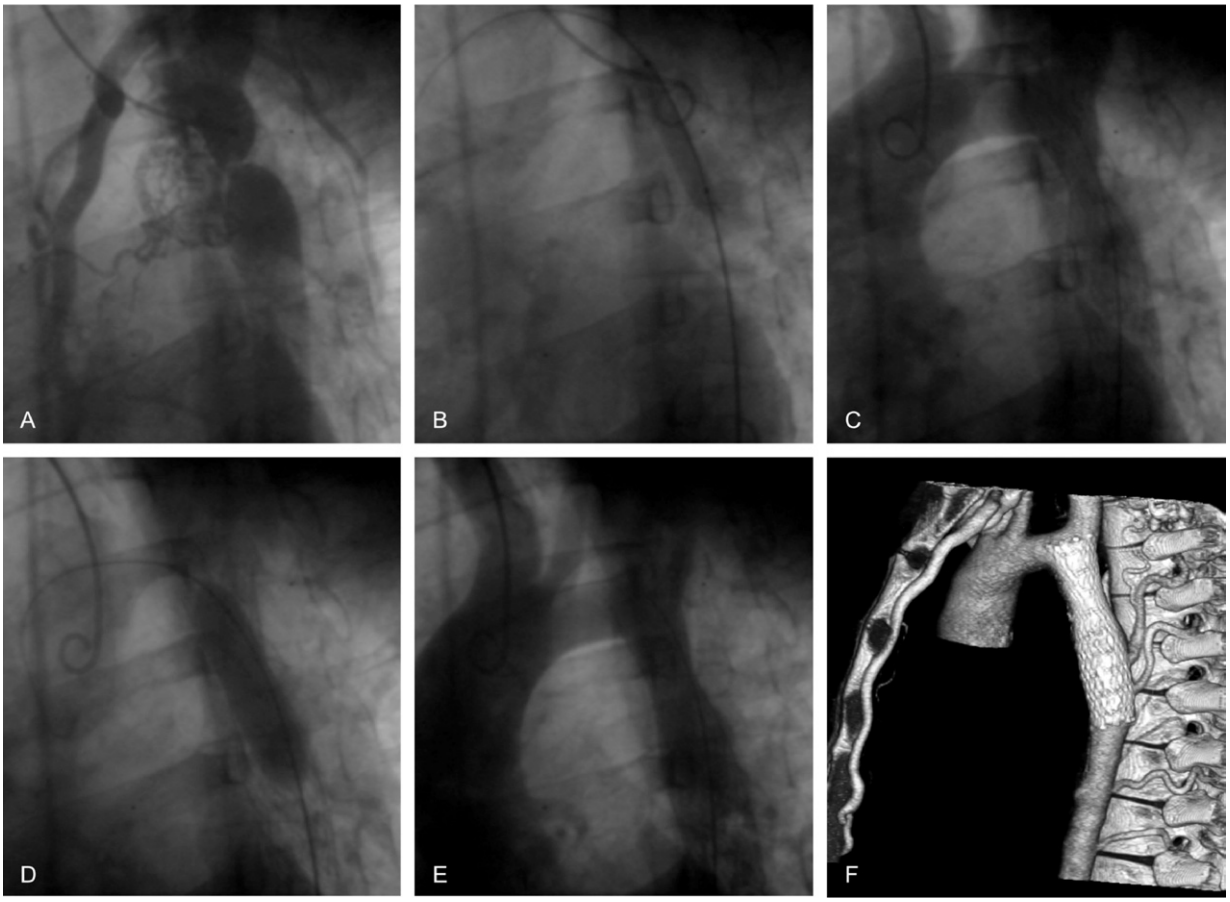

Fig 3. Serial aortograms in the left oblique projection depict **(A)** severe primary coarctation before angioplasty, **(B)** predilatation angioplasty, **(C)** implantation of a 28-mm self-expanding nitinol Sinus-XL stent, and **(D)** postdilatation angioplasty. **E,** Significant increase in isthmus diameter from 3 to 24 mm is seen in the final aortogram and was reconfirmed (**F**) by computed tomography angiography 3 months after stent deployment.

sufficient flexibility to allow easy placement. Its radial force is appropriate for deployment in fibrous, calcified lesions, and the absence of foreshortening allows precise coverage (Fig 3).

One of the most important technical refinements for delivery of large-diameter stents has been the NuMED Balloon-in-Balloon (BIB) catheter (Fig 2). These catheters have an inner balloon and a longer outer balloon that is double the diameter of the inner balloon and are available in outer-balloon sizes of up to 24 mm. They offer the important advantage of opening the stent more uniformly along its length, thereby eliminating the risk of unintended stent protrusion that has been documented by the use of single balloons. BIB catheters require a larger arterial sheath for introduction, however, which needs to be upsized by 1F if a hand-crimped balloon is mounted on the balloon. Thus, although BIB catheters prevent stent flare and offer more precise control over stent placement, single-balloon catheters are still sometimes preferable in smaller patients to reduce the risk of femoral artery injury at the access site.

TRANSCATHETER APPROACH FOR REPAIR OF ADULT COARCTATION

Basic technique for stent placement. There are various descriptions of delivery techniques to the central aorta in patients selected for transcatheter repair of adult coarctation.[4] Procedures are routinely performed under local anesthesia and sedation in a cardiac catheterization laboratory with dedicated fluoroscopic guiding capabilities. Once the percutaneous access to the femoral artery is established, intravenous heparin is administered to keep activated clotting time >250 seconds.

A pigtail or multipurpose catheter with a Terumo 0.035-inch hydrophilic wire is advanced to navigate through the coarctation. Once the pigtail catheter reaches the proximal ascending aorta, an angiogram is performed in

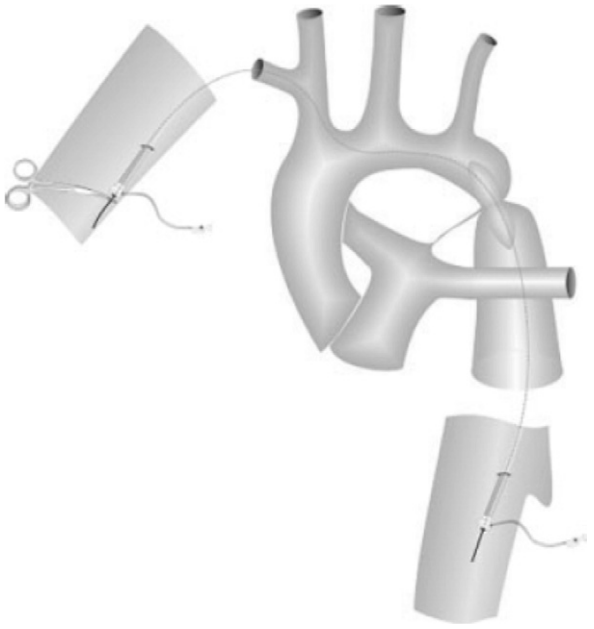

Fig 4. Schematic representation of the "arterial railway." An extra-stiff guidewire is advanced from the femoral artery to the right subclavian artery. This wire is snared in the innominate artery, exteriorized through the right brachial sheath, and fixed in place with a hemostat clamp at both ends. The railway provides an extremely stable platform, allowing minimal movement of the balloon/stent assembly during deployment. This strategy may decrease the risk of stent malposition and could be particularly useful in anatomically complex cases.

anterior or left anterior oblique and lateral projections. After delineation of vascular anatomy, a stiff wire is passed retrogradely across the coarctation with the aid of an atraumatic guiding catheter, with the soft tip of this wire located deeply in the left subclavian artery or in the ascending aorta.

In lesions of the transverse arch, the wire position in the ascending can help to keep the balloon and stent straight, whereas lesions in the descending aorta may benefit from stenting with the wire in the left subclavian artery. Generally, the stiff wire forms a rigid track for stabilization of the balloon and stent during deployment. In subatretic, heavily calcified, or recurrent lesions, stepwise predilatation angioplasty might become necessary, whereas one should generally try to avoid unprotected predilatation to reduce the inherent risk of consecutive wall injuries. Moreover, a technique for snaring and externalizing the distal end of the wire from the right brachial artery to form a very stable "railway" for use in the stent delivery can be applied in difficult cases (Fig 4).[5]

Once the appropriate stent and delivery balloon are selected, the stent must be carefully hand-crimped onto the balloon, and a long arterial sheath of the appropriate size can be exchanged over the wire for proper delivery of the stent. The sheath is then advanced across the coarctation by road mapping assistance. Choice of a balloon that is barely longer than the stent, establishment of a stable wire position that keeps the stent straight during deployment, and use of a BIB catheter will generally prevent technical complications such as balloon rupture and stent migration.

Before the balloon is inflated, it is recommended to decrease stroke volume by rapid right ventricular pacing to prevent device displacement from pulsatile cardiac forces. The inner balloon of the BIB catheter is inflated, and an angiogram can be performed through the sheath or through an anterograde catheter in the proximal aorta to confirm position of the stent. With the stent in the desired position, the outer balloon is inflated to fix the stent in the lesion. Once the stent is expanded, both the outer and inner balloons are deflated as rapidly as possible, and RV pacing is terminated.

The balloon catheter is removed and the pigtail catheter can be advanced over the wire to the area just proximal to the stent, to perform a repeat angiogram and assess stent position and size and check for signs of vascular complications. A pullback should be repeated to document any residual poststent gradient. Gentle postdilatation with an appropriately sized low-pressure balloon should be performed to abolish any residual gradient; diameter reduction by $<50\%$ should also be followed by balloon molding to obtain satisfactory results even though any gradient had disappeared.

Of note, accumulated data suggest that both aggressive prestent angioplasty and repeated postdilatation of the stent contribute to the overall risk of aortic wall injury.[6-8] Patient age also appears to be an important risk factor for major complications, particularly if the aorta is calcified with reduced resilience to expansion.[9] In consequence, it may be more prudent to aim for hemodynamic success rather than immediate angiographic resolution of the stenosis in those patients (Fig 5).

Oversizing of balloons should generally be avoided, and our practice is not to try to flare the stent ends to fully oppose the stent to the aortic wall because this often requires the use of a larger balloon. Whether nonadherence of the stent at the proximal and distal ends will be of any long-term consequence is unknown at present. Stent overlap of brachiocephalic vessels may constitute a theoretic risk but is technically unavoidable in certain cases of transverse arch or proximal isthmic obstruction.

Self-expandable stent for adult coarctation. Self-expanding elastic stents with moderate radial forces are highly likely to accommodate both compliance and functional integrity of the diseased aorta, considering that both classic surgery and implantation of stiff balloon-mounted stents markedly alter the biologic properties of the aortic wall. Conversely, self-expanding stents expose the coarctation segment to the gentle but constant radial force of nitinol, a process likely to create less local trauma even when adjunctive low pressure is applied after dilation. Stenting with self-expanding devices works by stretching and scaffolding rather than tearing the aorta, which may account for the observed lower short-term instances of aortic wall complications.

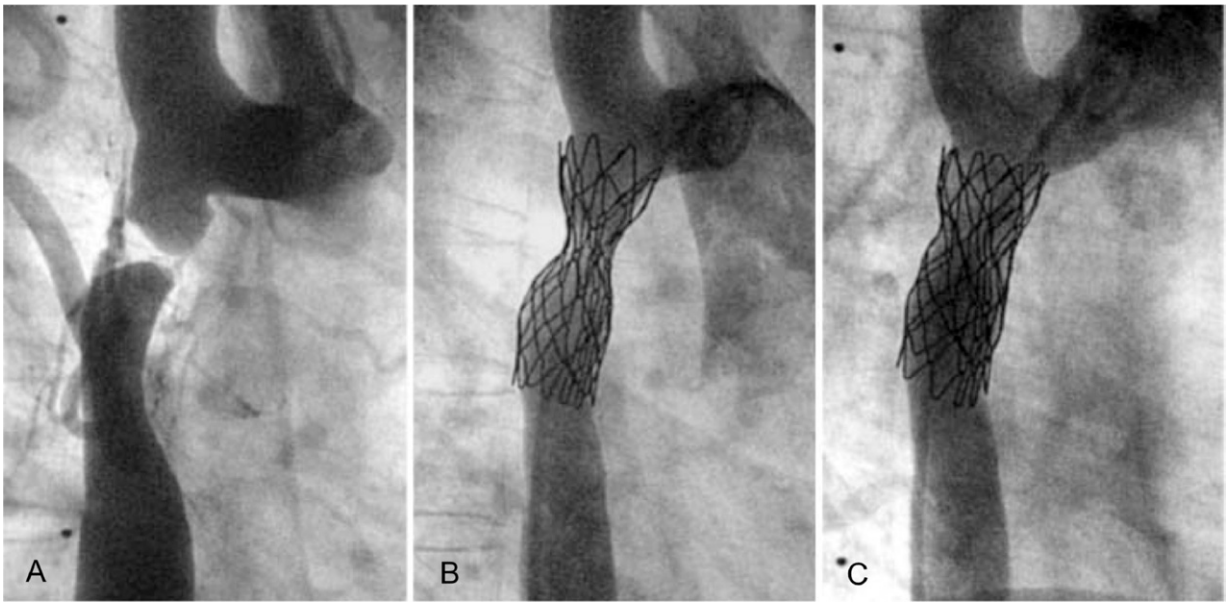

Fig 5. Implantation of a 39-mm covered Cheatham platinum (CP) stent for the treatment of subatretic aortic coarctation. **A,** Composite of two frames of the same angiogram (early and late phase). The procedure was performed in two steps: **(B)** first, the stent was implanted with only moderate dilatation of the subatretic area; **(C)** after 6 months, the stent was definitively dilated to completely relieve the stenosis.

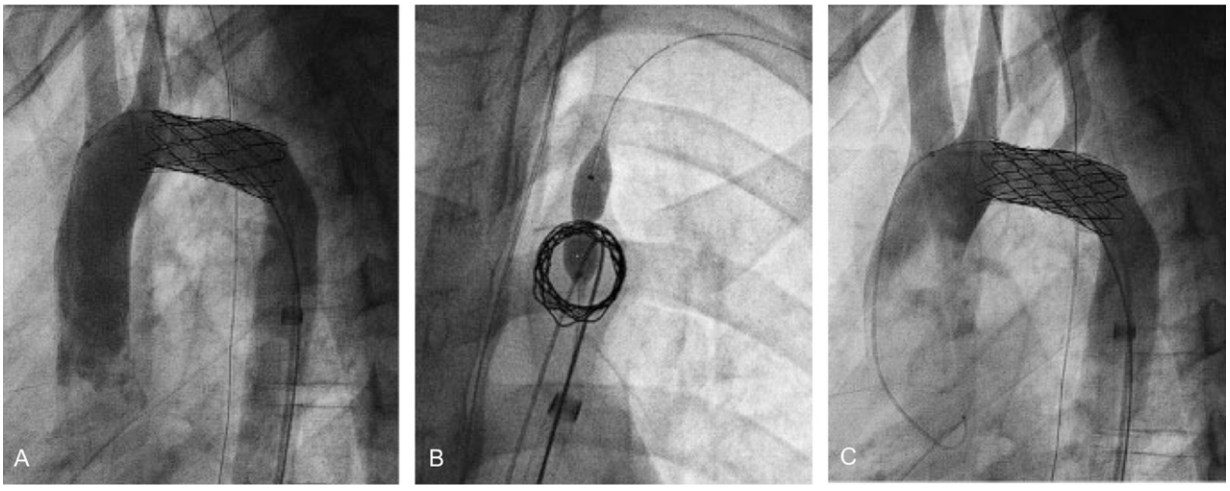

Fig 6. Delivery of a covered stent inside a previously implanted bare stent is shown. **A,** A Left anterior oblique angiogram after stent deployment demonstrates occlusion of flow to the left subclavian artery. **B,** During recannulization of the left subclavian artery, perforation of a covered stent with the stiff end of coronary wire was followed by dilation with a coronary balloon. **C,** Postprocedural angiogram shows excellent result, with brisk flow to the left subclavian artery.

Although intuitively promising, few investigators have reported on the application of self-expandable stents for transcatheter repair of aortic coarctation. In the Tyagi et al[10] report, self-expanding nitinol stents were deployed in 16 patients without periprocedural aortic wall complications. Authors from the Teheran Heart Center recently confirmed this observation. No aortic wall injuries were documented in their series of 21 patients treated with self-expanding nitinol stents.[11] In our unpublished series of 31 patients, precise placement of a flexible Sinus-Aorta nitinol stent was successful in all cases and no wall complications were documented (Fig 3). On aggregate, preliminary data suggest that transcatheter repair of primary aortic coarctation with self-expanding nitinol stents is highly ef-

Table I. Outcome after bare stent implantation for adult coarctation

Study, year	*Pts. No.*	*Native CoA No.*	*Mean age, years*	*Follow-up*	*Pressure gradient, mm Hg*		*Procedural complication*	*Adjunctive procedures*	*Comments*
					Before	*After*			
Chessa,[7] 2005	71	52	22	Median, 36 mo	39 ± 15	4 ± 6	8.40%	5.60%	BES; 30-day mortality: 1.4%; no late death
							3 stent migration	2 BA for ReCoA	
							1 aortic hematoma	1 CS for Re-CoA	
							2 femoral PSA	1 CS for ReCoA/An	
Mahadevan,[28] 2006	35	24	31	12 mo for 22 pts.	28 ± 15	4 ± 4	20.00%	8.60%	BES; no early or late death; BP reduced from 142 ± 79 to 125 ± 71 at 12 mo
							2 stent migration	3 BA for residual CoA	
							2 minor stroke		
							3 aortic wall compl		
Thanopoulos,[27] 2008	46	25	33	60 mo for all pts	58 ± 17	7 ± 5	4.30%	43.40%	BES; no early or late death
							1 stent migration	20 BA for residual CoA: serial dilatation concept	
							1 femoral PSA		
Haji-Zeinali,[11] 2009	21	19	19	16 ± 12; median, 14	57 ± 20	1 ± 2	14.30%	4.80%	SES; no early or late death; BP reduced from 160 ± 23 to 128 ± 8 at 12 mo
							3 stent migration	1 SES for ReCoA	

CoA, Coarctation; *BA,* balloon angioplasty; *BES,* balloon-expandable stent; *BP,* blood pressure; *CS,* covered stent; *PSA,* pseudoaneurysm; *ReCoA,* recurrent coarctation; *SES,* self-expending stent.

fective, enabling precise deployment even in challenging aortic conditions.

Application of covered stents. Covered stents have been used to address problems associated with aortic wall injury by balloon angioplasty and bare stent placement. They are preferentially placed in patients with an aortic wall aneurysm, with a tight primary coarctation and risk of rupture, in the presence of an associated arterial duct, and in older patients in whom the vessel wall is barely compliant.[12-15] As was recently demonstrated, serial repeat dilatation of an underdeployed covered stent is feasible and can be considered as a strategy for adult coarctation in which there is a concern that deployment to a normal size may result in aortic rupture.[16] Given the reported cases of aortic dissections and rupture, covered stents should be readily available in the catheterization laboratory for undelayed treatment of vascular emergencies potentially complicating transcatheter repair.[6,17,18] The placement of endovascular stent grafts has also been considered a valuable therapeutic option for aneurysms forming late after surgical repair of aortic coarctation.[19] The main challenges with a covered stent are attributed to larger sheath size and potential occlusion of supra-aortic branches. Occlusion of the left subclavian artery is well tolerated; however, an intact vertebrobasilar system should be documented before the procedure.[20] Although coverage of arterial branches is undesirable, modification strategies exist to restore native flow, including flaring of the end of the stent into the affected vessel or dilation of graft material through stent cells[21] (Fig 6).

PROCEDURAL RISKS AND POTENTIAL COMPLICATIONS

Intraprocedural deaths related to aortic rupture and dissection appear to be very infrequent,[2,8] but complications do occur after stent placement. In particular, various authors have observed device migration and vascular injuries at the site of arterial cannulation. In a multi-institutional registry encompassing 588 procedures from 1989 to 2005,[8] stent migration was documented in 4.8%. Migration is commonly believed to result from balloon oversizing and undersizing or is considered a sequela of balloon rupture. Stent fractures were rarely documented (1.0%), but a second stent for recurrent obstruction was required in most

Table II. Results after adult coarctation repair with covered stents

Study	*Pts. No.*	*Age years*	*Native CoA No.*	*Aneurysm formation No.*	*Pressure gradient, mm Hg*		*Aortic complications*	*Restenosis or serial redilation*
					Before	*After*		
Tzifa,[31] 2006	30	28 ± 18	14	8	36 ± 20	4 ± 4	Dissection, spontaneously resolved (n = 1)	4 (serial dilatation)
Butera,[32] 2008	33	6-66	20	2	20-75, median 39	0-12, median 0	None	1
Tanous,[33] 2008	22	39 ± 14	14	6	29 ± 17	3 ± 5	Aortic tear treated with an additional covered stent (n = 1)	3
Bruckheimer,[16] 2009	22	8-39	22	0	29 ± 9	7 ± 7	Aortic tear treated with an additional covered stent (n = 1)	9 (serial dilatation)

CoA, Coarctation of the aorta.

cases. Although extremely rare, aortic rupture resulting in death has been recently reported from experienced centers,[22] and we are aware of acute dissection in 1.6% of patients treated endovascularly for aortic coarctation.[8] Therefore, covered stents should be readily available in the cardiac catheterization laboratory, as should onsite surgical support to facilitate urgent treatment of vascular emergencies complicating endoluminal procedures.

With respect to access site, a 2.6% incidence of femoral artery injuries was reported. Recently, peripheral vascular complications have been reduced by using closure devices, with immediate hemostasis almost always achieved, even in heparinized patients. Cerebrovascular accidents have been documented in <1% of patients after transcatheter repair of coarctation. Although the exact etiology of cerebrovascular complications remains speculative in most cases, they have been related to technical complications, such as stent migration, balloon rupture, aortic dissection, and rupture, as well as progressive atheromatous disease in elderly hypertensive patients.[8]

IMMEDIATE AND LONG-TERM RESULTS AFTER TRANSCATHETER REPAIR

Although gradient reduction after balloon dilatation is generally acceptable, the procedural outcome is suboptimal in up to 9% of patients, with a gradient of ’20 mmHg.[23,24] Interestingly, restenosis in adult patients who have been treated with balloon dilation is relatively rare when the gradient has been reduced to <10 mm Hg after the procedure.[25,26] Late aneurysm formation has been documented in up to 20% of patients in initial series but most remain hemodynamically insignificant and are followed up conservatively. In contrast to primary coarctation, reported outcomes on balloon angioplasty have been less favorable in patients treated for recurrent stenosis after previous open repair.

Stenting has rapidly become the mainstay of endovascular treatment for adult coarctation in many institutions, with nearly complete resolution of gradients in both unoperated and recurrent stenotic lesions (Table I). Theoretically, stent implantation may overcome some of the shortcomings of balloon dilatation for aortic coarctation because the metal scaffolding can reduce the incidence of acute elastic recoil as well as late restenosis due to more complete elimination of gradient in the high-velocity-flow arterial system.[7,11,27,28] Another potential benefit with primary stent implantation is the ability to address longer segment coarctations, which typically have a poorer outcome after balloon angioplasty alone. Stents may also reduce the incidence of residual intimal tears and subsequent aneurysm formation by allowing both the use of smaller dilation balloons as well as graded inflations in staged procedures.

Although follow-up with detailed imaging of the stented area is often incomplete in the published series, it appears from the available data that aneurysm formation occurs in <5% of patients after this procedure.[29] A recent large multi-institutional study addressed the procedural and intermediate-term outcomes in nearly 600 patients aged >4 years. Procedural success with predominantly bare metal stents was 98%, acute complications occurred in 14%, and there were two procedurally related deaths.[8]

Today, some authors emphasize the role of covered stents as a preferred strategy for endovascular repair in adult coarctation.[30] Covered stents have been used in the treatment of primary and recurrent coarctation with apparent success, including in older patients with challenging anatomy (Table II). The rate of recoarctation is low despite many of the individuals in these studies having undergone prior surgical and interventional procedures; thus far, aneurysm formation has not been detected at intermediate-term follow-up.[16,31-33]

Generally, endovascular relief of coarctation gradients results in a profound reduction in ambulatory blood pressure,[34] with demonstrable reductions in left ventricular mass[35] and improvement in left ventricular functional indices.[36] However, despite some reduction in blood pressure, up to one-third of patients will remain hypertensive after endovascular repair, and left ventricular dysfunction is not completely abolished in all cases.[37-39] Persistent hypertension after coarctation repair results from an interplay of several factors, including recoarctation, endothelial dysfunction, arch morphology, and vascular and ventricular

stiffness. Targeting these factors will be important in the long-term prevention of vascular disease in patients with repaired coarctation.

CONCLUSIONS

Treatment of coarctation of the aorta with balloon angioplasty or endovascular stents may be technically challenging, but it is relatively safe and extremely effective when used carefully in appropriate patients. Further research that includes universal follow-up imaging is necessary to determine the incidence of complications and the nature of risk factors. At present, in the absence of randomized trials, it is premature to conclude that stent implantation is generally superior to balloon dilation in moderate-to-severe coarctation and recoarctation. Nevertheless, in view of the favorable short-term and intermediate-term results, stent implantation is rapidly becoming the preferred treatment option for adult coarctation. Long-term results are being awaited.

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