Core Curriculum

Coarctation of the Aorta: Stenting in Children and Adults

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INTRODUCTION

Coarctation of the aorta includes a wide array of anatomic and pathophysologic variations, but all involve some form of narrowing of the aorta, resulting in pathologic obstruction of blood flow from the systemic ventricle to the systemic circulation. Coarctation occurs with a frequency of ~0.04% of live births and comprises about 7% of known congenital heart disease, making it the fourth most common lesion requiring surgical or catheter-based intervention [1].

Several classification systems have been used, including those distinguishing between infantile and adult types or simple and complex types, but these can be confusing and are not generally very useful. Of particular importance to the interventional cardiologist are the age and size of the patient, the location and morphology of the coarctation, and whether the lesion is native or recurrent.

Native Coarctation of the Aorta

The classic native form is generally described as a discrete juxtaductal narrowing of the proximal descending aorta (DAo). This obstructive lesion begins late in fetal cardiac development as an endovascular shelf that arises from the posterolateral aspect of the aorta opposite the insertion of the ductus arteriosus, and therefore might more accurately be described as a contraductal narrowing of the aorta (Fig. 1a). The vast majority of cases of coarctation involve associated intracardiac disease, although the associated lesions may be quite mild. In discrete lesions of the aortic isthmus, bicuspid aortic valve or decreased interpapillary distance of the mitral valve is most commonly implicated. The association of coarctation with Turner syndrome is hypothesized to result from neck webbing and subsequent distention of the thoracic ducts, which compress...
the ascending aorta, thereby obstructing flow to the transverse and distal arch [2].

A less common native form involves long-segment, tubular hypoplasia of the arch or a portion thereof (Fig. 1b). These defects generally occur in conjunction with more significant left heart obstructive lesions and ventricular septal defects.

Infrequently, coarctation can also occur in the ascending or abdominal aorta.

**Recurrent/Residual Coarctation of the Aorta**

With the considerable frequency of surgical and catheter-based interventions on the aorta for congenital heart disease, there is a sizable population of patients with residual coarctation or recurrence of coarctation subsequent to such interventions. These postintervention lesions warrant separate consideration with regard to treatment modalities and potential complications.

**INDICATIONS FOR TREATMENT**

Natural history studies have demonstrated that failure to treat coarctation of the aorta results in serious morbidity and mortality: of patients surviving the first year of life, the mean age of death without treatment is only 34 years of age [3]. We now believe that a blood pressure gradient from upper to lower extremities of greater than 20 mm Hg when taken at rest generally indicates the need for intervention. Three to 4% of patients with coarctation will have an aberrant right subclavian artery arising from the DAo, distal to the coarctation site, and so it is important to obtain pressure readings in both arms. Additionally, pressure differences of less than 20 mm Hg may warrant intervention if there is significant hypertension or blood pressure response to exercise more than two standard deviations greater than the mean, and especially, if there is left ventricular dysfunction or progressive hypertrophy.

**TREATMENT OF COARCTATION**

In 1944, the same year in which Dr. Alfred Blalock and Vivien Thomas performed their first repair of tetralogy of Fallot, Dr. Robert Gross and Dr. Clarence Crafoord each independently performed the first successful surgical repairs of coarctation of the aorta. During the ensuing four decades, surgery remained the only treatment for coarctation. In the late 1970s, percutaneous balloon angioplasty was described as a possible alternative to surgical repair, and in 1981, the first successful angioplasty was performed in a newborn [4]. Since that time, transcatheter interventions have become increasingly popular and in many cases have emerged as the treatment of choice.

Although balloon angioplasty in infants with native coarctation is almost always immediately therapeutic and can be appropriate in the acutely ill infant when...
surgery is inadvisable or unavailable, the rate of recurrence has been reported to exceed 50% and is generally thought to be unacceptable [5]. However, in this younger age group, in the context of recurrent coarctation after surgical correction of isolated lesions or for more complex disease including arch interruption or hypoplasia, balloon angioplasty compares more favorably to surgery with respect to both short-term and long-term outcome measures, and is widely considered the treatment of choice for these recurrent lesions [6,7].

**Balloon Expandable Endovascular Stents**

The early reports of use of a balloon-expandable endovascular stent to repair coarctation in an animal model demonstrated efficacy, safety, and the ability to enlarge the stent at a later time [8,9]. Expansion of a stent across the area of coarctation (CoA) offers several theoretical advantages over balloon angioplasty alone, the most important of which being that the radial support of the stent supports the vessel wall, thereby preventing recoil and residual or recurrent stenosis. Furthermore, while an angioplasty may require oversizing of the balloon to a diameter larger than the normal vessel to deliberately create an intimal tear that will improve vessel diameter, a stent never needs oversizing. Using a stent, the operator can effect a better and longer lasting result with less gross and histological trauma to the normal vessel wall than with a balloon alone.

**EQUIPMENT**

**Stents**

The earliest available stents for use in congenital heart disease were the Johnson & Johnson Palmaz 308 stents and their shorter counterparts, the P128 and P188 stents, collectively known as the “8-series” stents. These stents are no longer commercially available. The 308 was so-named, because the stent was 30 mm long prior to expansion and was recommended by the manufacturer for expansion between 8 and 12 mm. Likewise, the 128 and 188 were 12- and 18-mm long, respectively. Despite the manufacturer’s recommendations, these stents were known to be safely expandable to 18 mm. The 8-series stents were laser-cut from a rigid stainless steel tube, with straight slits interpolated along the length of the stent, and this cell design offers excellent radial strength. They had significant limitations for implantation in the DAo, as they are expandable to a maximum diameter of 18–20 mm, and therefore could never reach the size of a large adult aorta as the patient grows. Mean diameters of distal aortic arches in fully grown adults are 21.1 mm (±3.2) for women and 26.1 mm (±4.3) for men [10]. However, it is also believed that many patients with aortic coarctation have some degree of generalized aortic hypoplasia and will never achieve normal diameter.

In 1999, the FDA approved the J & J Palmaz XL 10-series stents: the 3110, the 4010, and the 5010. The first two digits indicate the stent length, i.e., 31-, 40-, and 50-mm long, and the last two digits indicate that the stent is designed to expand to a minimum of 10 mm. These stents made it possible to deliver long stents to the thoracic aorta that could be expanded later to a maximum diameter of 25–28 mm. They are laser-cut from a very rigid stainless steel tube, with straight slits interpolated along the length of the stent. Like the P308 stents, the cells of the Palmaz XL stents thus form a very strong closed diamond shape when the stent is expanded, except at the ends of the stent, where alternating open half-diamond cells are formed. The points at the ends of the stents, however, are less sharp than in the earlier 8-series stents. These larger stents do share with the P308 stents a problematic significant shortening by almost 50% when expanded to their full diameter (Fig. 2a).

The Palmaz Genesis XD stent is also laser-cut from stainless steel and has a closed cell design, but it has a sigma hinge interposed between the cells. The “S”-shaped sigma hinge allows the stent to flex around curves and also reduces shortening on expansion (Fig. 2b). The Genesis stents are available in multiple lengths, but cannot be expanded further than 18–20 mm, and thus are not appropriate for patients who are expected to grow to have a normal sized aorta [11]. However, 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 DAo. 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 ev3 IntraStent® LD Max™ stents were approved in 2002 (Fig. 2c). With an open cell design that significantly reduces stent shortening and rounded cell edges at the stent’s ends, these stents offer advantages over the Palmaz stents. They can be enlarged to 24–26 mm [12] and have radial strength only slightly less than the Palmaz stents at this diameter. The ev3 stents are made in lengths of 16, 26, and 36 mm.

Cheatham-Platinum stents manufactured by NuMed are not now available in the U.S., but have been used extensively in Europe and other areas with apparent success [13]. They are fashioned of platinum wire formed...
into rows of zigzags, which reduces shortening on expansion very significantly (Fig. 2d).

Balloons
Initially, all stents were hand-mounted on single large-diameter balloons for expansion and delivery within the coarctation. Large diameter single balloon catheters tend to expand first at their ends, and thereby evert the stent ends such that they protrude radially from the stent center. Deploying a stent in this orientation can cause injury to the vessel wall and may be a risk factor for development of aneurysm or dissection. One of the most important developments of equipment for delivery of large diameter stents has been the Balloon-in-Balloon (BIB) catheter (Fig. 3). These catheters have an inner balloon and a longer outer balloon that is double the diameter of the inner balloon. The BIB catheters are available in outer-balloon sizes of 8–24 mm. The BIB catheters offer the important advantage of opening the stent more uniformly along its length. They do, however, require a larger arterial sheath for introduction: with a stent hand crimped onto the balloon, it is necessary to upsize the long sheath by 1F size, greater than is necessary for the BIB catheter alone. Therefore, with hand-mounted stents, BIB catheters with outer balloon diameters of 8–14 mm require a 9F sheath, 16-mm catheters require a 10F sheath, 18–20 mm catheters require an 11F sheath, and 24-mm balloons require a 12F sheath. Thus, while 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 risk to the femoral artery at the access site.

Wires
Most operators find it imperative to use a long, stiff wire with a soft tip, such as a 260 cm Rosen wire or the Amplatz Super-Stiff wire. Balloons that track over

Fig. 2. (a) The Palmaz XL 10-series stents are sturdy and expandable to full adult size, but the stents shorten considerably with full expansion. (b) The “sigma” hinge in the Genesis stents allows the stents to flex around curves and prevents significant shortening on expansion, but these stents cannot be expanded beyond 18 mm. (c) The ev3 Intrastent Max LD is expandable to full size, is flexible and does not significantly shorten. (d) The C-P stents made by NuMed are made of platinum wire with rows of zigzags to allow full-size expansion with minimal shortening and good radial strength.
0.035-in. wires will be preferable. All BIB catheters are calibrated for use with 0.035-in. wires.

Sheaths

All hand-mounted stents require delivery through a long sheath, and there are several appropriate models, the most popular being the straight Cook RB-Mullins design sheaths, which have radiopaque tips and side-arm fittings for injections through the sheath to assist in positioning the balloon catheter over the coarctation site.

TECHNIQUE

There are multiple descriptions of technique for delivery of balloon expandable stents to the central aorta. It is our opinion that coarctation stenting ought only to be performed under general anesthesia, as it is a painful procedure, and patient movement at the time of stent deployment is hazardous to both the success of the procedure and health of the patient. Venous and arterial access is obtained, heparin administered to keep activated clotting time greater than 250 sec, and a right and left heart catheterization performed, including oximetric or thermodilution data necessary for calculation of the cardiac output, and a careful pullback measurement of the gradient across the site of coarctation. We also give a dose of intravenous antibiotic at this time. An aortic angiogram is performed in PA or left anterior oblique and lateral projections, either through a prograde angiographic catheter across the atrial septum and into the proximal aorta, or through a retrograde pigtail catheter passed through the CoA. In either case it is prudent to have a catheter with calibrated angiographic markers in the field of angiography for use in accurately measuring the CoA and the proximal and distal diameters of the vessel, and also the length of the lesion and distance to the brachiocephalic vessels (Fig. 4a–c). It is imperative that these measurements are accurate, since the stent and balloon will be chosen on the basis of this data, and even small errors can increase the probability of a complication significantly. After measurements are made and recorded, a Rosen or other very stiff wire is passed retrograde across the coarctation with the aid of an appropriate catheter, and the soft tip of this wire should be located deep in a subclavian artery. In lesions in the transverse arch, wire position in the right subclavian artery can help to keep the balloon and stent straight, while lesions in the DAo benefit from stenting with the wire in the left subclavian artery. Whichever subclavian artery is chosen, it is absolutely crucial to position the balloon distal to the subclavian artery that holds the wire, as failure to do so will cause the balloon to migrate forward out of the subclavian artery when it is inflated, and will certainly cause failure to deploy the stent in the desired location.

The stiff wire helps to form a rigid track for stabilization of the balloon and stent during deployment. One institution has reported 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 [14]. To reduce the small risk of vascular complications, it is reasonable to test the compliance of the coarctation lesion. We use a balloon that is 2 mm smaller in diameter than the intended stent, and we inflate this balloon to less than 4 atm. This maneuver is intended as a diagnostic measure, not as an angioplasty prior to stent placement [15]. If there is a significant waist remaining on the balloon, we will usually choose a slightly smaller balloon and postpone complete expansion of the stent until a second catheterization about 6 months later.

Choice of equipment at this point is of paramount importance and will depend on many factors. Unless the aorta is expected never to reach a large diameter with the patient’s somatic growth, the operator will have to choose a large diameter stent, limiting choices to a Palmaz 10 series stent or an ev3 stent. A NuMED C-P stent may also be used in areas outside the U.S. where this stent is available. The ev3 stents are more flexible, and therefore track better into areas of the aorta that are curved, but the stents have rounded ends that take less purchase in the vessel wall during deployment. The rounded edges cause less damage to the vessel, but this, at least theoretically, makes the stents more prone to migration, especially in lesions.
with a higher degree of compliance [12]. Most descriptions of coarctation stenting report use of a balloon no more than 1–2 mm larger in diameter than the proximal unaffected aorta. There is often poststenotic dilatation of the thoracic aorta distal to the coarctation, and we do not believe that attempts to size the stent to this part of the aorta are helpful. Many stents that are sized to fit in the aorta proximal to the lesion hang into this dilated poststenotic region without making significant contact with the vessel wall, but this has not been shown to be of any consequence (Fig. 5). As discussed earlier, in lesions with very low compliance on test balloon inflation, a smaller balloon should be chosen, with the aim to further dilate the stent at a later time.

Once the appropriate stent and delivery balloon are selected, the stent must be mounted on the balloon. It should be hand-crimped down onto the balloon. We use a piece of umbilical tape looped around the stent and balloon and pulled at both ends to help tighten the stent onto the balloon. Some operators slightly inflate the balloon, so that it grips the stent a bit more tightly, and some coat the balloon with a little contrast medium to help the stent stick to the balloon, but we do not find the latter measure necessary. Rather, proper wire position and sheath selection, careful mounting on the balloon, and careful advancement of the stent into and along the sheath will generally prevent stent migration on the balloon. Once the stent and balloon catheter are ready, the arterial sheath can be exchanged over the wire for a long sheath of appropriate size for delivery of the stent. The sheath is advanced across the coarctation over the stiff wire, and using a still frame from the aortogram as a “roadmap,” the balloon-mounted stent is advanced to its proper position across the coarctation site. 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.

Fig. 4. (a–c) Accurate measurements of the normal and pathologic segments of the aorta in multiple projections, preferably using calibration with a marker catheter, are crucial in determining the proper stent size and type, the appropriate balloon catheter, and the optimal location for stent deployment.
Just prior to inflation of the balloon, it is possible to decrease stroke volume, blood pressure, and pulse pressure significantly, either by administering adenosine or, as is our preference, by rapidly pacing the right ventricle with a pacing catheter. Rapid pacing of the ventricle has been described for balloon aortic valvuloplasty [16] and is also effective in treatment of coarctation. This can help to prevent blood flow in the aorta from pushing the balloon and stent distal to the coarctation during inflation. After placement of the pacing catheter in the right ventricle, we pace at 200–220 ppm, seeking to achieve a decrease in the pulse pressure to about 10 mm Hg and decrease in the systolic blood pressure to less than 100 mm Hg.

The inner balloon of the BIB catheter is inflated, and an angiogram can be performed either through the sheath or through an anterograde catheter in the proximal aorta to confirm position of the stent. When the stent is in good position, the outer balloon is inflated to fix the stent in the lesion (Fig. 6a–d).

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 a multitrack rail system angiographic catheter or a cut pigtail catheter can be advanced over the wire to the area just proximal to the stent, and a repeat angiogram is performed to assess the stent position and size and to survey for signs of vascular complications. A pullback should be repeated to obtain the poststent gradient with repeat calculation of the cardiac output, to demonstrate that conditions are not significantly different from the measured prestent conditions.

**RESULTS**

While treatment of coarctation of the aorta with balloon expandable endovascular stents is a technically challenging procedure, it is an extremely successful one [17–21]. A multicenter retrospective series of 588 procedures performed between 1989 and 2005 was conducted by the Congenital Cardiovascular Interventional Study Consortium (CCISC) [22] (Table I).

Of the 588 procedures, 580 (98.6%) were successful in reducing the gradient to less than 20 mm Hg or increasing the coarctation: DAo diameter ratio to at least 0.8. Among the successful cases, there was a mean reduction of the peak-to-peak gradient from 32.0 to 3.4 mm Hg, a mean increase in diameter from 7.4 to 13.9 mm, and a mean increase in CoA:DAo diameter ratio from 0.44 to 0.85. Of the eight unsuccessful procedures, the mean CoA:DAo ratio was 0.24, and 4 of the 8 were in patients with prestenting gradients of >60 mm Hg. Two patients developed an aortic dissection and rupture, and the procedures were terminated and emergent surgery undertaken.

**COMPLICATIONS**

There are various complications of coarctation stenting that merit discussion. In general, they can be classified into three categories: (1) technical, (2) aortic, and (3) peripheral vascular. There were a total of 84 complications reported by the CCISC, occurring in 69/588 (11.7%) cases.

**Technical Complications**

Technical complications include stent migration during the procedure, stent fracture, balloon rupture, and overlap of the brachiocephalic vessels.

Stent migration can result from balloon undersizing or oversizing or from balloon rupture. If the stent cannot be safely repositioned within the coarctation, it should be expanded in the safest location available, away from side branches if possible. If necessary, a second stent can be placed in the coarctation subsequently. The CCISC encountered 28/588 (4.8%) instances of stent migration. Thirteen of the 28 migrated stents were repositioned successfully and 8 required placement of a second stent to complete the procedure successfully. The remaining 7 procedures required no further intervention. Although there was not a statistically significant association with balloon oversizing, the data trended toward larger balloon size with 18/28
(64%) of the stent migrations occurring on balloons 15 mm or greater in diameter.

Known stent fracture occurred in the CCISC study in 6 patients, 4 occurring in CP stents, and 2 occurring in Genesis XD stents. Of the 6 patients, 5 required a second stent to treat recurrent obstruction resulting from the fracture.

Balloon rupture occurred in 13/588 (2.2%) in the CCISC cohort. This complication is most commonly seen when using Palmaz 8-series stents 9/13 (69%), and can result in other complications involving the aortic wall or secondary to embolization of balloon fragments, and if the balloon ruptures prior to full expansion, it will carry a high risk of causing stent migration.

There remains a debate over whether stent placement over the origin of one or more brachiocephalic vessels constitutes a complication at all. There have been no demonstrated harmful sequelae from doing so. The CCISC study included 61 cases of stent overlap of the brachiocephalic vessels. There were follow-up data on these patients to a mean of 3.1 years for a total of

Fig. 6. Use of the BiB catheter has added a significantly greater degree of control in coarctation stenting than previously used single balloon catheters. (a) The stent is advanced through a long sheath to the approximate location of the CoA. (b) An angiogram is performed through the long sheath to show the precise location of the stent with respect to the coarctation site. (c) The inner balloon is inflated and the angiogram repeated. (d) The outer balloon has been inflated, and the stent is in good position with no residual obstruction in the aorta.
TABLE I. Demographic Data From the Congenital Cardiovascular Interventional Study Consortium (CCISC) Multicenter Analysis of 588 Stent Placement Procedures for Coarctation of the Aorta

<table>
<thead>
<tr>
<th>Median age</th>
<th>15 yrs [0 mo–64.9 yrs]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedures on patients &lt;6 yr old</td>
<td>n = 40 (6.8)</td>
</tr>
<tr>
<td>Procedures on patients 6–10 yr old</td>
<td>n = 89 (15.7)</td>
</tr>
<tr>
<td>Procedures on patients 11–20 yr old</td>
<td>n = 302 (51)</td>
</tr>
<tr>
<td>Procedures on patients &gt;21 yr old</td>
<td>n = 154 (26.2)</td>
</tr>
<tr>
<td>No data</td>
<td>n = 3</td>
</tr>
<tr>
<td>Median weight</td>
<td>55.0 kg [1.8–145]</td>
</tr>
<tr>
<td>Patient diagnoses</td>
<td></td>
</tr>
<tr>
<td>Isolated coarctation</td>
<td>n = 244 (45)</td>
</tr>
<tr>
<td>Bicuspid aortic valve or Shone’s complex</td>
<td>n = 150 (28)</td>
</tr>
<tr>
<td>Vasculitis</td>
<td>n = 9 (1.7)</td>
</tr>
<tr>
<td>Procedures prior to year 2001</td>
<td>n = 227 (38.6)</td>
</tr>
<tr>
<td>Procedures after year 2001</td>
<td>n = 361 (61.4)</td>
</tr>
</tbody>
</table>

Values in square brackets indicate ranges.

186 patient-years showing no peripheral embolic events or flow disturbance, with the exception of one patient who had brachiocephalic vessel overlap with a covered stent.

Aortic Wall Complications

Procedural complications involving the aorta at or around the site of the coarctation include intimal tears, dissection, and aneurysm formation.

While stents do not need to be oversized with respect to the normal vessel diameter as do balloons for angioplasty alone, some degree of tearing of the intima in the exact region of the coarctation is expected, and perhaps necessary to achievement of a satisfactory result. In the vast majority of cases, this tear is tamponaded against the aortic wall by the stent struts. However, angiographic evidence of intimal tearing is a notable complication. The CCISC reported 8/588 (1.3%) angiographically evident intimal tears. Two patients required further intervention in the form of a second stent, one at the time of the procedure and one 10 months later after developing hemodynamically significant obstruction at the site of the tear.

Aortic dissection is a rare but serious complication of endovascular stent placement for coarctation of the aorta. Angiograms taken during and after the procedure should be surveyed carefully for evidence of dissection. Although emergent surgical intervention can be life saving in the case of severe dissections, dissections may be treated successfully with placement of additional stents, especially covered stents. We believe that it is important to maintain at least a small inventory of large diameter stents covered with polytetrafluoroethylene (PTFE) or a similar material for use in emergency situations. There are a number of commercially made covered stents, including the Wallgraft self-expanding stents (Boston Scientific), Gore’s self-expanding excluder stents, and the Atrium premounted balloon-expandable stents. It is also possible to hand-make large diameter balloon-expandable covered stents by sewing an expandable PTFE tube onto a Palmaz XL 10-series stent. These PTFE tubes can be expanded up to 28 mm.

Aortic dissection occurred in 9/588 (1.5%) cases in the CCISC study. One patient had dissection associated with stent migration, but the remaining eight cases occurred in the absence of other technical complications. Three patients had successful placement of covered stents to treat the dissection and did well. Three patients had medical management only in ICU settings and did well. Three patients were sent emergently to surgery and 2 of the 3 sustained significant neurologic injury, eventually expiring as a result of the complications. Statistically significant risk factors for dissection included age greater than 20 years, location in the abdominal aorta, utilization of prestenting angioplasty, and use of the CP stent.

Aortic aneurysm is infrequently encountered, but it may be a harbinger of aortic rupture, and is therefore a potentially dangerous complication of coarctation stenting. It can be seen at the time of the procedure or on interval follow-up (Fig. 7a and b). If a large or growing aneurysm is seen to form at the time of the stent placement, it may be stabilized with a covered stent to prevent progression and possible rupture [23,24]. Any evidence during the procedure of rupture, contained or otherwise, ought to be treated emergently with a covered stent. The CCISC study included 13 known cases of aneurysm, with a positive association with presten balloon angioplasty, although follow-up imaging was undertaken in only 160/588 (27%) cases, and clinical concerns led to follow-up imaging in many instances, therefore, making this group an unrepresentative sample. Because late aneurysm formation is a known complication, it is our recommendation that follow-up imaging by MRI or CT, or by catheterization if indicated, be undertaken in all patients 6 months after stent placement. Further studies with careful follow-up imaging will help to disclose the relationship between aneurysm formation and parameters such as the ratio between balloon diameter and coarctation diameter.

Peripheral Vascular Complications

Peripheral vascular complications include cerebral vascular accident, peripheral emboli, and injury to access vessels.

Neurologic events including cerebral vascular accident occurred in the CCISC group in 6/588 procedures.
The two patients who sustained severe neurologic injury associated with dissection of the aorta subsequently expired. Of the remaining four patients, three had CVA and recovered completely. The fourth patient had near-complete recovery. Other complications occurred in association with 5 of the 6 CVAs (two dissections, two cases of stent migration, and one case of balloon rupture). There was a positive association between CVA occurrence and older patient age.

Peripheral embolism occurred in only one case, in which it resulted in renal artery thrombosis. This was treated successfully in the catheterization laboratory with a local thrombolytic infusion.

Significant femoral vessel injury was reported in the CCISC study in 15/588 procedures (2.6%). One patient had placement of the arterial sheath above the inguinal ligament and developed a retroperitoneal hematoma requiring surgery. There was a positive association of femoral vessel closure with age less than 6 years. It is our practice, when there is loss of pulse after catheterization, to institute heparin therapy for 24 hr. If the pulse has not returned after 24 hr, or if the viability of the leg is a concern at any point, thrombolytic therapy or surgery may be indicated. In our institution, tissue plasminogen activator (tPA) is the agent of choice. There are several reported dosage schemes [25,26], and while tPA can be very effective in restoring femoral artery patency after catheterization, it also carries very significant morbidities [27]. It is still unclear what dosing offers the best balance between safety and efficacy.

Postprocedural Hypertension

A significant percentage of patients with coarctation will demonstrate hypertension immediately after the procedure. In our institution, patients with systolic blood pressures greater than 140 mm Hg or diastolic blood pressures greater than 90 mm Hg will have a radial arterial line placed and will be admitted to the intensive care unit, where continuous infusions of nitroprusside or esmolol, or both are administered. These patients are generally transitioned to enteral antihypertensive medications within 24 hr after the procedure.

CONCLUSIONS AND RECOMMENDATIONS

Although treatment of coarctation of the aorta with balloon-expandable endovascular stents is technically challenging, it is a relatively safe and extremely effective treatment modality when used carefully in appropriate patients. It is clear that further research including universal follow-up imaging is necessary to determine incidence of and risk factors for various complications. Disclosure and analysis of this data will dictate guidelines for safer and more successful procedures.

In the meantime, our recommendations are as follows: (1) Surgery is the treatment of choice for all native coarctation and balloon angioplasty is the treatment of choice for most recurrent coarctation in infants and children less than a year of age. (2) Between the ages of 1 year and the time when the child reaches a weight of 30–35 kg (usually 9–11 years of age for...
boys and girls), there is insufficient data to determine whether surgical intervention or balloon angioplasty is preferable for native lesions. It is likely that balloon angioplasty is the treatment of choice in this age group for recurrent coarctations. (3) In children weighing more than 35 kg who have not yet reached adult size, it is likely that the treatment of choice for native and recurrent lesions should be endovascular stent placement, as it has been demonstrated that these can be further enlarged at a later time to accommodate somatic growth of the patient. (4) In adult-sized adolescents and adult patients, stent placement is the treatment of choice for all lesions, native and recurrent. (5) In adults of advanced age, and in young adults with known vasculitis or other conditions associated with vasculopathy, of which Turner syndrome is one [28], particular care should be taken in stent placement, as these patients carry a high relative risk of life-threatening complications.

Furthermore, we are sure to see continued improvement in available equipment and techniques, which will result in better outcomes and which will allow us to utilize stents in treating a wider range of patients with coarctation of the aorta.

REFERENCES