EDITORIAL COMMENT

Stent Implantation for Aortic Coarctation: The Treatment of Choice in Adults?*

Eric Rosenthal, MD, FRCP
London, United Kingdom

Balloon dilation is widely accepted to be the treatment of choice for recoarctation of the aorta after previous surgical repair. There is a lower morbidity than with repeat surgery and a high success rate (1). Native coarctation is also successfully treated with balloon dilation, but is generally avoided in the first 6 to 12 months of life owing to a high incidence of recoarctation and femoral artery damage (2). In older children and adults, it is widely used despite concerns that dissection and rupture are more of a risk than in recoarctation, where scarring and adhesions from previous surgery may better support the aortic wall (3). However, acute rupture has been reported after balloon dilation for recoarctation (4). In the longer term, concerns exist about aneurysm formation and recoarctation—though these also occur after surgical repair for coarctation (5,6).

Balloon dilation relieves the aortic obstruction by tearing the coarctation shelf with variable extension into the media. Tears into the adjacent “normal” aortic wall may reflect an inherent weakness in the aorta in patients with coarctation (7). If extensive, these tears can lead to acute rupture or dissection and chronic aneurysm formation. The rationale for stent implantation is that over dilation of the coarctation segment is unnecessary, thus avoiding major transmural tears while at the same time the stent struts will splint any smaller tears against the aortic wall, preventing progressive dissection and aneurysm formation. Additionally, the acute elastic recoil of the coarctation segment, which contributes to a suboptimal initial result and late recoarctation, is prevented by stent implantation, leading to a greater relief of obstruction than with balloon dilation alone.

Endovascular stent implantation is now increasingly used in place of balloon dilation for both native coarctation and recoarctation in older children and adults (8–14). There is a much smaller experience in infants and small children. As in many areas of medicine, the evolution from one form of treatment to another is not based on controlled trials, and the evidence base is largely from observational studies.

The study by Hamdan et al. (8) in this issue of the Journal is the third report of stent implantation for aortic coarctation with a series of more than 30 patients (8–10). Two smaller series of 17 patients each, an abstract of 15 patients and a few single-figure studies and case reports make up the current literature (11–14). Hamdan et al. (8) present encouraging short- and intermediate-term results in 33 children and adults with a low morbidity and no mortality. In one patient with a long segment recoarctation, stent implantation was accomplished, but it was not possible to dilate the stents to abolish the gradient, and surgical repair was performed. Two other patients required surgery—one for a retroperitoneal bleed and one to remove a fragment of ruptured balloon. A clinically significant decline occurred in the coarctation gradient, with a reduction in the systolic blood pressure. Before the procedure 71% of the patients were hypertensive; following stent implantation only 26% remained hypertensive.

Technicities of stent implantation. The technique of stent implantation into the aorta has changed little since its introduction in 1991 (15): a long, stiff guide wire is passed across the lesion, followed by a long sheath through which the stent balloon assembly is passed. After sheath withdrawal the stent is deployed by inflating the balloon. The study by Hamdan et al. (8) illustrates some of the difficulties of stent placement. In three patients, stents were suboptimally positioned owing to migration of the partially expanded stent in two patients or balloon rupture in one patient and then fully dilated in an innocuous position. A good outcome was obtained in two of these patients by implantation of a second optimally positioned stent. All but one of the stents used in the study were P308 or P188 Palmaz stents (Johnson & Johnson Interventional Systems, Warren, New Jersey) with a theoretical maximum diameter of 18 mm, and they have been the most commonly used stents in congenital heart disease (15). Larger maximum diameter Palmaz stents of at least 25 mm (P4014 and P5014) are now available and may be more appropriate for some adult aortas (11,12).

These longer stents (4 and 5 cm) also shorten less at the diameters needed, thus improving the accuracy of stent deployment and reducing the need for overlapping stents in long segment obstructions. The outstanding advantage of these stents is the radial strength, which prevents elastic recoil, but the stent itself does not conform well to curved vessels as might be necessary when approaching the isthmus and proximal transverse aortic arch. The edges of these stents are sharp and can cause the balloon to rupture (five in the Hamdan et al. [8] series). Newer stent designs, including platinum stents that are magnetic resonance imaging-compatible and stents with rounded ends, are becoming available (8). During balloon expansion of the stent, infar-
tion pressures are usually kept below the rated burst pressure of the selected balloon catheter. High pressures may be needed for dilation in recoarctation, and Hamdan et al. (8) used a pressure of 25 atm in one patient without successfully overcoming the stenosis. The burst pressure of the aorta in these circumstances is unknown, and high pressures should be used cautiously. An inflation pressure of 12 atm during stent implantation in a patient with recoarctation resistant to balloon dilation has been accompanied by acute rupture and near exsanguination (O’Sullivan J., personal communication, 2001). Rapid re-inflation of the balloon controlled the situation, and emergency surgery was needed. “Test dilation” of the coarctation before stent implantation is used by some to confirm lesion compliance, though this inflation may also cause vessel wall damage (10,11).

**Graded or immediate full dilation of the stent.** Hamdan et al. (8) used an initial balloon of twice the coarctation diameter and then additional balloons to a diameter not exceeding the diameter of the isthmus or descending aorta at the diaphragm. This strategy allowed the use of a slightly smaller sheath for the initial stent balloon assembly to be followed by larger balloons through the same sheath. Larger balloons were also used to flare the distal end of the stent in the poststenotic dilated aorta to promote complete endothelialization of the stent. While flaring makes the angiographic picture aesthetically more pleasing, it is not clear whether this is necessary. Where there is significant poststenotic dilation, it is possible that flaring may result in the sharp edges of the stent being forced into the distal aortic wall at an angle to the lumen. No acute aneurysm formation or dissection was seen, however, so full dilation of the coarctation stent at the first procedure and flaring of the stent ends proved an effective strategy in this series. Although in the majority of reports the investigators have aimed to dilate the stent to the perceived appropriate diameter immediately, some have advocated deliberate underdilation of the coarctation segment with later elective redilation after endothelial lining of the stent has occurred and medial tears have healed (11,13). This recommendation evolved after aneurysms were observed when dilating the stent to its full diameter acutely. Given the results in this series, it may be reasonable to undertake full expansion of the stent in patients with milder forms of coarctation (where there is an increased risk of stent migration if the stent is not fully expanded) and employ a graded dilation strategy in those with severe coarctation.

**Aneurysm formation.** The incidence of aneurysm formation after balloon dilation and after surgery varies in the literature according to the methodology used for its detection (6). A single randomized study revealed a higher incidence after balloon dilation (5). Whereas an excessive balloon size is commonly thought to be the culprit, other technical factors (balloon rupture, catheter recrossing of the dilated area) and the nature of the aortic wall may also be responsible. Stent implantation, by avoiding the use of excessively large balloons, and by abolishing the natural elastic recoil of the coarctation segment, should be able to treat the coarctation effectively without aneurysm formation. Hamdan et al. (8) did not detect any aneurysms but only recatheterized four of their patients, and in two the stents were further dilated so late angiography after the final intervention was only obtained in two patients. Marshall et al. (10) recatheterized 16 of 33 patients who had milder degrees of recoarctation before stent implantation, but redilated the stents in eight patients so angiography after the last intervention was only obtained in eight patients—none of whom had aneurysms.

In addition, Suarez de Lezo et al. (9) recatheterized 30 of 48 patients at a mean of 25 months and detected two new aneurysms—an incidence of 7%. To avoid repeat angiography, contrast-enhanced spiral computerized axial tomography has been used for follow-up imaging, but this exposes the patient to additional radiation (11,13). Therefore, magnetic resonance imaging would be ideal, but there is a degree of artefact produced by the stent, and it is unclear how accurate it will be for detecting small aneurysms that might dictate the need for closer surveillance (16). The true incidence of aneurysms will only be known when angiography or computerized tomography (or more advanced magnetic resonance imaging) is performed as a routine after the final dilation. Imaging may need to be repeated over the years. Management of these aneurysms if expanding may require surgical resection of the stented coarctation/aneurysm segment with an interposition graft. An alternative would be the deployment of a covered stent inside the stented coarctation to exclude the aneurysm (17). Currently, these stents require >20F sheaths and surgical access to the iliac vessels to implant. In smaller aneurysms, it has been possible to implant vascular occlusion coils between the stent struts to promote thrombosis of the aneurysm (9).

**Transverse aortic arch stenting.** Recoarctation is more commonly observed in patients with transverse arch hypoplasia (18). In many of these patients, the repair at the coarctation site itself is satisfactory, and the level of the obstruction is in the transverse arch. The increasing use of extended arch repair in neonates and infants with coarctation may reduce the incidence of this problem, but currently there are many patients in whom the transverse arch is the site of the obstruction (19).

Hamdan et al. (8) implanted stents in three patients with transverse arch hypoplasia and obtained good results with a drop in the gradient. In one of these patients the stent partially crossed the origin of the carotid artery. They elected to use warfarin for six months to prevent cerebral embolism from the stent. The rationale for this is not clear, though intuitively there is concern when stenting is done across such an important vessel. Portions of stent not opposed to the vessel wall or crossing side branches do not become endothelialized. Thus, if the stent struts were postulated to be possible sources of emboli, then long-term warfarin would be needed. Fortunately, in large vessels this seems to be uncommon, and others have not reported...
problems (9,14). If positioning of the stent without displacement is difficult in the descending aorta, then it is even more difficult in the transverse arch. The use of shorter stents, delivered with the balloon in balloon catheter (BIB, NuMed, Nicholville, New York) may improve the ability to stent the transverse arch accurately and safely without compromising the arch vessels. A marker catheter in the left carotid artery passed via a right brachial or transeptal approach is also helpful (20). Though there would be less concern about stenting across the origin of the subclavian artery, it also seems sensible to avoid this if possible.

**Threshold for stent implantation.** Hamdan et al. (8) included patients with coarctation or recoarctation based on conventional criteria including an upper to lower limb blood pressure gradient of >20 mm Hg and/or evidence of coarctation on imaging. Lower gradients are generally considered to be satisfactory end points for treatment and nonintervention. This threshold for intervention has evolved in response to the perceived risk-benefit ratio of surgery for lower gradients and the difficulty of improving lower gradients by balloon dilation due to inability to overcome the elastic recoil of the milder lesions or the need to use excessively large balloons with the attendant risk of aneurysm formation. Patients with “mild coarctation,” however, may have raised upper body segment blood pressures and may need long-term antihypertensive treatment or face the consequences of a sustained, albeit mild, elevation in blood pressure. Additionally, during exercise the blood pressure response will be more pronounced (21,22). The success of the technique in more severe coarctations may therefore lead to a lowering of the threshold for intervention (10). The definition of successful treatment of aortic coarctation by any means may need to be revised in the light of what is currently achievable with stent implantation.

**Infants and small children.** The smallest child in the series by Hamdan et al. (8) was four years and weighed 18 kg. The indications in this child and the other young children were not given. In two patients the stents were redilated after patient growth without difficulty. In the other larger series, several small children, including two infants, underwent stent implantation, with the majority having had previous surgical and or balloon dilation interventions (9,12). Stent implantation was also described in a neonate who had the stent resected and an end-to-end anastomosis performed seven months later (23). There are two major concerns with stenting the aorta in infants and small children. The sheath size required for stent implantation exceeds that of balloon catheters, and femoral artery occlusions have been reported (9). For this reason carotid artery access has been used by some investigators (11). In these children, the stent diameter would not be adequate for the aorta’s diameter when the child became an adult, and growth would unmask a stenotic segment. While the Palmaz stent is further dilatable during growth—as has been demonstrated in experimental coarctations (though aortic rupture has also been described in one model)—the ultimate diameter of the aorta in a particular child is unknown (24,25). Thus, implantation of a P308 stent will only allow for dilation to 18 mm, which might not be enough in some adults. In view of these concerns, stent implantation in infants or small children should only be performed in exceptional circumstances.

**Conclusions.** The study by Hamdan et al. (8) adds to the literature on the subject and confirms that the early and intermediate–term results of stent implantation in aortic coarctation are good. Questions remain regarding the technicalities of implantation (balloon size, stent length and diameter, inflation pressure, underdilation with elective redilation, edge flaring, etc.), the need for caution when implanting stents close to the arch vessels in arch hypoplasia and the indications for this procedure in patients with mild coarctation. More importantly, there is little data on the incidence of late aneurysm formation and its progression and the effects (if any) of a rigid segment of aortic wall on blood pressure control over the long term. In the absence of randomized trials, an international registry collecting prospective data on all catheter interventions for coarctation may be able to address some of these issues.

Despite these uncertainties, there are still some situations where primary stent implantation would seem to be superior to balloon dilation in adults. In transverse arch hypoplasia there is no localized obstruction suitable for balloon dilation, and thus elastic recoil is invariable. Similarly, in mild recoarctation, excessively large balloons would be required to overcome the elastic recoil, and they are more likely to cause extensive medial tears to be effective. In these situations, if treatment is indicated, then stent implantation would be the preferred option. At present, in the absence of randomized trials, it is premature to conclude that stent implantation is superior to balloon dilation in moderate to severe coarctation and recoarctation. Nevertheless, in view of the favorable short- and intermediate–term results, stent implantation is rapidly becoming the preferred treatment for older children and adults in many units. Long-term results are now awaited.

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**References**


5. Shaddy RE, Boucek MM, Sturtevant JE, et al. Comparison of