Intravascular stenting for the treatment of coarctation of the aorta in adolescent and adult patients

Mise en place d’endoprothèse dans le traitement de la coarctation de l’aorte chez les adolescents et les adultes

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Received 9 June 2011; received in revised form 13 August 2011; accepted 17 August 2011
Available online 21 November 2011

Summary In the past 10 years, stent implantation has become a real alternative to surgery in the management of both native and recurrent coarctation of the aorta in adolescents and adults. The purpose of this report is to provide a detailed review of stent implantation techniques, including pre-procedure imaging, technical aspects and results. The success rate is usually high (around 90%), and the procedure results in an increase in the diameter of the coarcted segment, a decrease in the transisthmic systolic gradient and a better control of systemic hypertension. The most serious complication, rupture of the aorta, can be fatal, but is rare (< 2%). Aneurismal dilatation is another potential problem that occurs in around 5–9% of cases, and may be related to overstretching and pre-stent dilatation, so these should be avoided. It is necessary to point out that most of these aneurysms are small and conservatively managed. Restenosis is another complication that may result from neointimal proliferation, stent recoil and stent fracture. Balloon dilatation with a higher inflating pressure or repeat stent implantation is proposed herein. A comparison with surgery is also discussed, and a follow-up protocol is proposed to capture late complications. Owing to good initial and intermediate results, stent implantation is nowadays considered as a first-line therapy in most adolescents and adults with (re)coarctation of the aorta.

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Abbreviations: BIB, balloon-in-balloon; CI, confidence interval; CT, computed tomography; MRI, magnetic resonance imaging; OR, odds ratio; PTFE, polytetrafluoroethylene; RR, risk ratio.
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doi:10.1016/j.acvd.2011.08.005
Background

Although the optimal treatment of coarctation of the aorta remains arguable, with no real randomized controlled trials comparing a percutaneous approach to surgical repair, the endovascular treatment of both native and recurrent coarctation has gained a widespread acceptance since the mid 1990s, especially in adolescents and adults [1]. As has been observed with other balloon dilatation techniques, there has been a recent shift from balloon angioplasty alone to stent implantation. Balloon dilatation can injure the intima and part of the media, so although the vessel diameter is increased, fibrous scar tissue can form over a period of months [2,3] that may result in recoil, restenosis and aneurismal disease. Advantages of using a stent are the radial support to the vessel wall and the apposition of the torn vessel intima to the media with the possibility to perform redilatation (especially in young patients) with no need for oversizing to avoid major transmural tears [4–6].

The purpose of this report is to provide a detailed review of balloon-expandable stents for the transcatheter treatment of adolescents and adults with (re)coarctation, including pre-procedure imaging, technical aspects of the technique, results and complications. A comparison with surgery is also discussed, and a follow-up protocol is proposed.

Pre-procedure imaging

It is well established that Doppler echocardiography can be used to diagnose and estimate the severity of coarctation of the aorta. However, in adults, adequate imaging of the isthmic anatomy is not as good as in infancy. Difficulties can be encountered in patients in whom the distance between the ultrasound probe and the descending aorta is too large and in whom image resolution is too poor. Similarly, gradient measurements by continuous-wave Doppler may not be obtainable in all patients.

MRI is a good alternative, and a reliable non-invasive method to depict the aortic arch anatomy. Both spin- and gradient-echo sequences, especially in the oblique plane, can be used to demonstrate the arch anatomy and provide accurate measurements of the aorta [7]. Cine MRI can be used to depict lucent jets of high-velocity flow through the site of coarctation, with jet length correlating to the angiographic severity of coarctation [8,9]. Phase-contrast sequences make it possible to calculate the peak systolic velocity gradient (similarly to the echo Doppler technique using the Bernoulli formula) and blood-flow quantification. An increase in aortic blood flow at the level of the diaphragm, in comparison to that just below the coarctation site, reflects the amount of blood flow through the collateral vessels. Of particular importance to the interventionist is the choice of the balloon/stent. For this, various calculations have to be made: narrowest diameter at the coarctation site (coarcted segment); the isthmic diameter just above the transverse arch (proximal to the origin of the left subclavian artery) and the diameter of the thoracic aorta at the level of the diaphragm [10].

CT can also be used to calculate these aortic diameters, and is recommended in patients with claustrophobia, metallic clips or thoracic prostheses (that may cause artefacts on MRI) or pacemakers/defibrillators. Both MRI and CT techniques make it possible to obtain contrast-enhanced imaging and 3D reconstructions that are very useful for the cardiologist, providing images very similar to those from classic angiography. Similar information can also be obtained from cardiac catheterization, but this technique is mainly used for interventional procedures.

The stent implantation technique

Owing to the possibility of chest pain during inflation and patient movement [5,11], the procedure is usually performed under general anaesthesia. Patients are often given antibiotic prophylaxis and heparin 100 IU/kg body weight
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(maximum 5000 IU) [12], administered before the introduction of sheath. Heparin is neither reversed at the end of the procedure nor continued after the procedure.

The aorta is usually entered retrogradely, using a guidewire from the femoral artery. The aortic pressures are recorded in the thoracic aorta before crossing the narrowest segment with the angiographic catheter (classically a pigtail catheter). Sometimes, it may be useful to employ a straight catheter (e.g., a right Judkins catheter with hydrophilic guidewire; Terumo) to cross a very tight lesion. Once the coarctation has been crossed, the aortic pressure is recorded again, allowing the calculation of the peak-to-peak systolic gradient across the coarcted segment. This pressure gradient is essential, and when the peak-to-peak systolic gradient is >20 mmHg, this defines (re)coarctation of the aorta [5]. However, this pressure gradient can be less important due to general anaesthesia or the development of important collateral vessels. Aortography is then performed to demonstrate the anatomy of the aortic arch and coarctation, and to calculate the aortic dimensions reported above [12]. Angiography is usually performed in the left aortic oblique projection (30–60°) [3,12], in lateral and anteroposterior projections.

When the coarcted segment is nearly atretic, brachial arterial access is obtained for aortic arch angiograms and to cross the coarctation with a guidewire [4,11]. After imaging, if the patient fulfils the classic criteria, stent implantation can be used as an alternative to classic balloon angioplasty alone. Owing to the use of large introducing sheaths, vascular closure devices (e.g., Perclose AT; Abbott Vascular Devices) are placed before dilatation as pre-closing devices to avoid bleeding and achieve effective haemostasis after the procedure [4].

The choice of stent diameter and length is of major importance for this technique. The stent must cover the coarcted segment without protrusion into the left subclavian artery. Stent diameter is selected based on the diameter of the proximal aorta —mainly transverse or distal arch diameter— or 1–2 mm larger [4,5]. The stent diameter must not exceed the diameter of the descending aorta at the level of the diaphragm, in order to avoid aneurysm formation or rupture. Another approach is to use the average of the aortic isthmus (or transverse aortic arch) and the descending aorta at the level of diaphragm. The ratio of expanded stent diameter to that of coarcted segment is frequently around 2–3.5 and should be <3.5 [13].

In order to form a rigid track for stabilization of the balloon/stent during deployment, a Rosen (Cook, Bloomington, USA) or exchange Amplatz superstiff guidewire (Meditech) is used, with the tip placed above the coarcted segment in the ascending aorta or the right subclavian artery. Over that wire, the delivery sheath and its dilator are then advanced to the transverse aorta. A balloon-expandable stent is hand crimped down onto the balloon, which is a little bit longer than the stent. This can be performed by a piece of umbilical tape looped around the stent and the balloon and pulled at both ends to help tighten the stent onto the balloon. The dilator is then removed, and the balloon—stent complex is advanced within the sheath to the coarctation site and a little bit further. The sheath is then withdrawn, exposing the balloon—stent complex, which is correctly placed across the stenotic lesion. The position is usually checked by angiography through the sheath before inflation. For balloon-expandable stents, deployment is realized by inflation of the balloon catheter using one or two inflation devices with a 20 or 30 mL syringe (especially for larger balloons), and without exceeding the maximal pressure value recommended by the manufacturer [12]. Inflation lasts for a few seconds. Sometimes, right ventricular pacing (or rarely adenosine infusion) is employed to facilitate stent placement during inflation [14]. If a waist or any significant pressure gradient persists, further dilatation is usually performed using a higher-pressure balloon catheter [15].

The stent implantation procedure is classically considered successful if the residual gradient is <10 mmHg, with an improvement in diameter to >90% of the normal adjacent aortic arch vessel [15–18]. The success rate is >90% [14,16,18,19], generally with no residual gradient, whereas balloon dilatation alone usually results in persistent gradient. As proposed by Chessa et al. [12], it is recommended not to flare the ends of the stent with a balloon of a larger size to model it to the dilated post-stenotic segment because there is no clear evidence of any significant benefit, but a real risk of stent migration or aneurysm formation.

If the haemodynamic and angiographic results are correct, the sheath is removed, and closure of the femoral artery is realized with a vascular occluding system. The classic predilatation technique is no longer recommended because it can make it more difficult to obtain good contact with the stenotic segment, and direct stenting is now recommended to decrease the risk of embolization [19].

If the patient is on antihypertensive drug treatment, this is usually continued for 1–4 months, with restriction for competitive sport or strenuous exercise. If the patient is not taking any drug before the procedure, antihypertensive medication for 1 month to avoid barotraumatic lesions has been proposed [16], but this is not commonly used. In around 17% of cases, stents may need to overlap arch vessels [16]. This can be achieved without compromising distal perfusion due to the availability of open-cell design stents. In theory, these allow balloon angioplasty through the cell into adjacent arch branches. Such patients should receive long-term anti-platelet therapy.

Complications

The most serious complication of stenting is rupture of the aorta, which although rare, may lead to severe haemothorax with circulatory collapse and death [12,15,20]. This has been reported to occur in 1.6% of 565 procedures in a large multicentre study [16]. The risk factors for aortic wall complications (dissection and intimal tear) in this study included: performing pre-stent balloon angioplasty (odds ratio [OR] 4.18); location of the coarctation at the abdominal aorta compared to the isthmus (OR 5.74); and age >40 years (OR 2.95) [16]. Use of a covered stent at implantation has been proposed to reduce the risk of aortic wall complications. However, there is no evidence of better results in comparison with bare stents, but there is an increased risk of occlusion of side branches [16]. Despite this, direct availability of covered stents in the catheterization laboratory is a prerequisite for interventional treatment of coarctation [15].
Aneurysmal formation is another potential complication of stenting. However, definitions vary between minimal bulging with > 3–3 mm dyskinesis of the aortic wall [20,21]; > 10% expansion of the aorta outside the stent [13,22]; dilatation of the aorta at the dilatation site exceeding 120% [14] or 150% [17,21] of the diameter of the aorta at the level of the diaphragm. Thus, the real incidence of aneurysms is unknown, but is probably around 5–9% [13,14,17]. The vascular causes of aneurysm include: damage to the vessel wall by the balloon with overstretching; technical difficulties; and aortic cystic medial necrosis with decreased density of elastin in the arterial wall and increase collagen content as underlying anomalies. In fact, special precautions have to be taken to avoid manipulating the tip of the catheter or guidewire over the recently dilated aortic segment. In the experience of Mahadevan et al. [20], no predictive factors could be established for aneurysm formation, including age, initial systolic blood pressure, coarcted dimension, pre- or post-stenting gradient, native or recoarctation, or type of stent. Similar findings have been reported in a multicentre study by Forbes et al. [13]. In addition, no significant difference in the incidence of aortic wall injury could also be found according to the volume of cases (< 25 or > 25) or the centre [14]. However, a balloon-to-coarctation ratio > 3.5 at initial procedure and pre-stent angioplasty have both been associated with more aortic wall injury [13], and should therefore be avoided. It is necessary to point out that the majority of these aneurysms are small and conservatively managed. Only large aneurysms require the use of a covered stent or surgical resection.

Another potential complication is stent migration and embolization during the procedure. Most commonly, the stent slips down inside the thoracic aorta, frequently without clinical consequence, more rarely proximally [15]. The cause of stent migration can be related to: an oversized balloon (> 2 mm larger than the proximal aorta), an undersized balloon catheter, or balloon rupture [16]. The latter has been reported more frequently with the old P8 Palmaz stent [16]. Usually, the stent does not need to be repositioned, but if this is necessary, the stent can be mobilized within the aorta using a balloon catheter, and fully expanded at the most appropriate site. Rarely, the stent can become trapped in the aorta or femoral artery, in which case, it can be captured with a lasso and pulled back into a sheath [19]. In case of malposition, a second procedure is performed, which usually results in a successful outcome.

Restenosis is another possible issue after stent placement, but is less frequent than after balloon angioplasty alone, where it has been reported to occur in 13–31% of cases [3]. Restenosis has been reported after stenting in 2.7% of patients in a study of 578 patients [13], and in 12% in a large multicentre study in 302 patients, although in this study, if planned/staged repeat interventions were excluded, the restenosis rate was only 4% [14]. This is clearly the main reason for using stent instead of balloon angioplasty alone in the percutaneous treatment of coarctation. The re-coarctation may result from re-modelling of the coarcted segment and development of neointimal proliferation, stent fracture, stent recoil and growth [13,14]. Most authors have proposed re-dilation of the stent using a balloon catheter with a higher inflating pressure or repeat stent implantation in the case of stent fracture [12,13].

Cerebral vascular accident is rare (< 1%), and can be related to dissection with severe neurological injuries due to volume loss, peripheral embolism, balloon rupture and stent migration [16]. Another possible complication is paradoxical hypertension following the procedure, which is usually treated with oral β-blockers for several weeks. Lastly, problems related to femoral access and the use of a large sheath are possible, including loss of femoral pulse with risk of ischaemia and haematoma [15]. The risk of these can be reduced by the use of vascular closure devices.

### Choice of stent and balloon catheter

The choice of stent and balloon catheter depends on institutional approach and individual operator preference. Different types of balloon-expandable stents and balloon catheters can be used. Stents include the bare or covered Cheatham Platinum CP stents (NuMED; Hopkinton, NY, USA), Mega LD or Max LD (EV3; Plymouth, MN, USA), Palmaz (Johnson and Johnson; Cordis, Roden, The Netherlands), and Adventa V12 (Atrium; Mijdrecht, The Netherlands) (Table 1). Most of these are made from stainless steel, although the CP stent is made from an alloy of 90% platinum and 10% iridium [23]. Usually, the Palmaz XL, CP eight-zig or EV3 stents are employed for longer stenotic segments. Advantages of these stents are: a good expansibility and radial force, and lesser shortening than the Palmaz 8 series. The CP eight-zig stent is quite similar to the Palmaz XL, but has a better radio-opacity and rounded edges, which are probably less traumatic for the aortic wall [12].

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Dimensions of some of the available stents.</th>
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<tr>
<td>Stent</td>
<td>Stent expansion diameter (mm)</td>
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<tr>
<td>CP bare/covered stent</td>
<td>12–24</td>
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<tr>
<td>IntraStent™ Mega™ LD</td>
<td>9–18</td>
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<tr>
<td>IntraStent™ Max™ LD</td>
<td>16–25</td>
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<tr>
<td>Palmaz® XL</td>
<td>14–25</td>
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<tr>
<td>Adventa V12 (covered)</td>
<td>12–16 (up to 22)</td>
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a. NuMED, Hopkinton, NY, USA.

b. EV3, Plymouth, MN, USA.


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Figure 1. Adult native coarctation in an 18-year-old man. The coarctation diameter is 4.2 mm (A). Inflation of the inner BIB with a CP stent (8Z34) (NuMED) (B). Inflation of the outer balloon (diameter 14 mm, length 35 mm) (C). Control angiography (D). The coarctation diameter is now 13 mm with no persistent gradient. BIB: balloon-in-balloon.

(fracture, aneurysm or in-stent thrombus) and initially for patients at risk of complications due to complex anatomy (mainly tortuosity) or advanced age [4,24]. The most widely used is the CP covered stent, which uses a gold soldering process to avoid fracture and which is fitted with a covering of expanded polytetrafluoroethylene (PTFE) that can be stretched up to a diameter of 12–24 mm. Its implantation is similar to that of a bare stent, but requires 2–3 F larger sheaths than employed for the introduction of the sole balloon catheter. An alternative covered stent is the Advanta V12 stent (Atrium). The self-expandable covered stent (Valiant, Medtronic) (Fig. 2) can also be used to exclude an aneurysm. However, this stent requires a larger introducing sheath with lesser radial force than the other covered stents, so is not frequently employed.

Superiority of covered stents over bare stents in terms of efficacy, aortic diameter expansion and gradient reduction has not been proven, but there is a real risk of occlusion of side branches. However, covered stents are preferred in situations such as: subatretic coarctation, native coarctation associated with patent ductus arteriosus (Fig. 3), (re)coarctation combined with aneurysm (Fig. 4) and recurrent coarctation after PTFE patch [22,24].

Figure 2. A 38-year old patient with coarctation corrected at the age of 10 years by a 10-mm prosthetic tube and suffering from recurrent haemoptysis due to a small aneurysm at the inferior connection of the tube to the descending aorta (A). Aneurysm exclusion with a self-expandable stent (Valiant, Medtronic; diameter 38 mm, length 50 mm) (B). Full expansion of the previous stent is achieved by implantation of a Palmaz stent (diameter 25 mm; length 40 mm).
Figure 3. Native coarctation combined with a small arterial duct in a 15-year-old boy. The diameter of coarctation is 13 mm (A). Notice the left-to-right shunt through the arterial duct. Control angiography after implantation of covered CP stent (8Z28) over a BIB (diameter 20 mm, length 30 mm) (NuMED) (B). There is no persistent left-to-right shunt and no residual gradient is recorded. BIB: balloon-in-balloon.

Cardiovascular and haemodynamic results and changes

Stenting of a coarctation induces cardiovascular modifications. The commonly reported changes include an increase of coarcted diameter from 6.9 mm (1.3–15.5 mm) to 13.8 mm (5.5–23 mm), a decrease in pressure gradient from 26 to 2 mmHg, and a decrease in blood pressure, with reduction in antihypertensive drugs and no hypertension in two thirds of patients at long-term follow-up [14]. In addition, Babu-Narayan et al. [25] have shown, in an MRI study performed 10 months after stenting, a significant decrease in left and right ventricular mass, enhanced left ventricular function, and a reduction in the size and blood flow through collaterals. They also demonstrated an increase in ascending aorta distensibility [25] that may reduce the classic cardiovascular risks of coarctation, but with no data available at present for late outcomes.

It has been shown that, despite early surgical repair, young normotensive adults may have persistent abnormalities of the vascular reactivity, with increased resistance of vessels anatomically positioned above the coarctation [26]. This has emphasized the concept of peripheral vasculopathy in coarctation that could probably influence late systolic hypertension [26–28]. In fact, similar findings have also been reported following stenting [29,30]. Moreover, some have also suggested that a rigid segment of the aorta generated by a stent may lead to exercise-induced hypertension.
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[29]. In fact, such hypertension is found in about one third of normotensive patients following either surgery or stenting. However, De Caro et al. [31] could not find any difference between patients who underwent surgery or stenting. Lastly, both post-stenting and surgery patients have poorer left ventricular long-axis function than controls, as shown by tissue Doppler imaging, reflecting subendocardium impairment [32].

Comparison between stenting and surgery

In 2006, Carr published a comparison between angioplasty (stent, balloon dilatation or a combination; n = 633) and surgery (n = 213) in adult aortic coarctation patients, based on papers published during 1995–2005 [33]. Stenting alone had the lowest morbidity (mean 9%, range 0–20%), while morbidity was slightly higher in the surgical group (mean 11%, range 0–25%), mainly related to bleeding and recurrent laryngeal nerve injury. Balloon dilatation alone was associated with more complications than stenting (OR 2.4; 95% confidence interval [CI] ± 0.8; relative risk [RR] 2.1), including traumatic aneurysm formation and aortic dissection. Restenosis occurred in a mean of 11% (range 0–25%) in the stented group, but in only 2% (range 0–9%) in the surgical group [33]. Stenting cured hypertension (medication free) in a mean of 61% of patients, compared to 64% after surgery. These results are clearly in favour of surgery for coarctation in the adult population. However, no exhaustive protocol concerning hypertension or aortic imaging could be obtained in the follow-up of these surgical series.

It is difficult to make recommendations because stent technology has evolved over time, resulting in better stent designs. This, along with greater experience should combine to give better results with stents. Both surgical treatment and stenting lack fundamental prospective mid- and long-term follow-up data concerning hypertension and arch anatomy. Protocols for such studies should include repeated exercise studies, 24-hour ambulatory blood pressure monitoring and MRI/CT evaluations.

Since the publication by Carr [33], results of a large non-randomized surgical cohort have been published, including 404 patients with a follow-up of 27 years [34]. The rate of persistent hypertension in this series was 57%, but with only 13% of patients with significant residual gradient. The risk factors for hypertension included repair with prosthetic material, male sex, residual gradient and older age at follow-up.

In the future, it may be of interest to set up a multicentre prospective randomized clinical trial comparing stenting angioplasty and surgical repair to define the best form of treatment for coarctation of the aorta in adolescents and adults.

Late complications

Patients with coarctation of the aorta have a high risk of late cardiovascular morbidity and mortality, mainly related to persistent systemic hypertension. Other potential late complications include premature coronary artery disease, sudden cardiac death, heart failure, stroke, recoarctation, left ventricular outflow tract obstruction, major aneurysm, rupture, dissection, endarteritis and fistulae [1]. In the experience of Oliver et al. [35], with a cohort of 235 patients including those treated with surgery or balloon angioplasty/stenting and those with native coarctation, 16% experienced aortic wall complications during follow-up, including ascending aortic aneurysms (9%) and descending aortic aneurysms (4%). There was no difference among the three groups with respect to the development of aortic complications. However, in this population, 57% had associated bicuspid aortic valve. Multivariable analysis did not reveal any significant relationships between previous repair, type of repair, age at repair, residual Doppler gradient or systemic hypertension and the occurrence of aortic wall complications [35]. In fact, only aging (RR 1.4 per decade of age, 95% CI 1.1–1.8; p = 0.002) and presence of a bicuspid valve (RR 3.2, 95% CI 1.3–7.5; p = 0.00023) were significantly associated with aortic wall complications [35]. The increased risk in patients with a bicuspid aortic valve may result from factors such as thinner elastic lamellae of the aortic media with greater distance between lamellae and premature medial smooth cell apoptosis [35].

Follow-up protocol

Long-term evaluation of both stent and aortic wall integrity is essential to monitor potentially life-threatening complications. Although MRI is considered to be the gold standard following surgical repair [36], use of MRI following implantation of a stainless steel stent has been shown to be relatively ineffective due to magnetic susceptibility and metallic stent artefact with loss of signal. Thus, CT scanning is considered the optimal follow-up method to detect anatomical characteristics such as aneurysm formation, intrastent stenosis, dissection and stent fracture [12,22,37]. Usually, a contrast-enhanced aortic CT scan is performed 3–6 months following the procedure, or earlier if there is any significant procedural complication [22]. However, radiation burden should not be ignored, especially if CT is repeated. Therefore, Rosenthal and Bell [37] have proposed an alternative to CT using modern MRI sequences, especially in patients with platinum stents, to decrease the cumulative radiation burden. Finally, after coarctation stenting, the optimal frequency of imaging should be three to five yearly in the absence of intervening clinical, echocardiographic or radiological concerns [1,6,22].

Conclusions

To conclude, stent implantation is a good alternative to surgery for the treatment of coarctation of the aorta in adolescents and adults. It is associated with a low-residual gradient and a low rate of restenosis, both immediately and at follow-up. It is effective in controlling systemic hypertension and has a relatively low incidence of complications. All these results compare favourably with those of surgical repair, and justify the present use of primary stenting.
at a first-line therapy in most adolescent and adults with (re)coarctation of the aorta.

Disclosure of interest
The authors declare that they have no conflicts of interest concerning this article.

Acknowledgement
The author thanks S. Haulon for reviewing this article.

References
[34] Hager A, Kanz S, Kaemmerer H, Schreiber C, Hess J. Coarctation Long-term Assessment (COALA): significance of arterial hypertension in a cohort of 404 patients up to 27 years after the surgical repair of isolated coarctation of the aorta, even

