Ductal stenting in neonates with either duct-dependent pulmonary or systemic circulation has become a good alternative for the initial palliation of complex congenital heart disease. Changes of stent and catheter technology (low profile, flexible, premounted stents with good scaffolding), better patient selection and preparation, optimal interventional access and covering the complete length of the duct have significantly improved results.

It has long been realized that patients with a duct-dependent pulmonary or systemic circulation would benefit if duct patency could be maintained reliably for several months [1,2]. Conventional palliative treatment in neonates with a duct-dependent circulation currently consists of treatment with prostaglandin E1 for some days, followed by the surgical creation of an aortopulmonary shunt or surgical reconstruction of the aortic arch.

Such surgery in neonates, and even more so in premature or dysmature infants, can involve major complications, such as chylothorax, phrenic and vagal nerve palsy, early or late shunt occlusion or stenosis, distortion and differential growth of the pulmonary arteries or aorta, as well as surgical adhesions. These complications may add to the complexity of subsequent surgeries and compromise final outcome [3–6].

Previous attempts to stent the neonatal duct with early-generation, rigid, bare stents using relatively bulky, stiff wires, balloons and sheaths, frequently resulted in complications, such as worsening cyanosis or shock, bleeding, vessel rupture, duct spasm, tissue prolapse or acute thrombosis [7–10]. In addition, incomplete covering of the duct frequently resulted in ductal constriction, with inadequate pulmonary or systemic flow within hours or days following stent implantation.

By learning from these failures, using new techniques, applying a better patient selection and preparation, improved interventional access and covering the complete length of the duct with current low profile, flexible, premounted stents (with good scaffolding), the results of ductal stenting have been improved significantly [11–17]. This review discusses the stenting of different types of ducts:

- Duct-dependent pulmonary circulation
  - The short straight duct as in pulmonary atresia with intact septum
  - The long and tortuous duct as in pulmonary atresia with ventricular septal defect
  - The duct to a single lung

- Duct-dependent systemic circulation

General principles
Cardiac catheterization

Procedures should be performed under general anesthesia [12,13] or under conscious sedation [11,14,15,17,18]. Access is mostly obtained through a 5–6-Fr venous sheath and/or a 4-Fr (long) arterial sheath. Prophylactic antibiotic treatment (cefazolin in most patients) is usually recommended. Attention to hemostasis during catheter and wire manipulation is extremely important in neonates.

Angiography for ductal morphology

As with any complex interventional procedure in neonates, biplane fluoroscopy is recommended. Angiography is typically performed in the lateral projection or lateral-cranial (left anterior oblique 30° and cranial 20–30°).
However, in newborns with duct-dependent systemic blood flow, 30° right anterior oblique demonstrates the ductal anatomy very well, especially its junction with the distal aortic arch. Contrast injections are usually performed through a transvenously placed right coronary guiding catheter [12], arterially placed multipurpose catheter [14], the 4-Fr arterial sheath or Berman angiographic catheter within the duct (or with balloon occlusion of the descending aorta below the duct) [18]. Useful landmarks during the catheterization for the aortic end of the duct are the arterially advanced multipurpose catheter [11,14], or an esophageal thermometer or gastric probe.

**Management of prostaglandin infusion**

**Duct-dependent pulmonary circulation**

The management of prostaglandin infusion depends on the morphology of the duct. In patients with pulmonary atresia with intact ventricular septum, the duct is short and straight, and ductal constriction is required in order to grip the stent at deployment. Ideally the patient should arrive in the catheterization laboratory with the smallest acceptable patent duct. If the duct has not constricted since birth (typically in patients with fetal or early neonatal diagnosis where prostaglandin was started early), some constriction should be allowed by stopping the prostaglandin infusion for several hours or days and restarting when some constriction has occurred. In patients presenting after ductal constriction with cyanosis, prostaglandin can be stopped at the beginning of the procedure or after the duct has been crossed with the guiding wire. In patients with pulmonary atresia and ventricular septum defect, no ductal constriction is required as this duct is long and tortuous.

A route for reinitiation or increase of the dose of prostaglandin during the procedure should always be available; in case of acute constriction, local application of a small dose of prostaglandin (taken from the infusion) can be performed. Enhanced constriction during the procedure can be obtained by administering intravenous ibuprofen (10-mg/kg bolus).

**Duct-dependent systemic circulation**

Since self-expandable and balloon-expandable stents are available for stenting ducts with a diameter ranging between 5 and 10 mm, the infusion can be stopped immediately before the catheterization in most patients, or even after the stent has been implanted.

**Ductal morphology**

The morphology of the arterial duct predicts the technical difficulty of stenting and the risk of restenosis and necessity for reintervention [14,19,20]. In the normal heart with a left-sided aortic arch (also usually in left-sided obstructive lesions), the arterial duct connects the left pulmonary artery to the descending aorta just distal to the origin of the left subclavian artery and has a short, straight course (as seen on the lateral projection). Such duct is also typically observed in patients who develop pulmonary stenosis or atresia late in fetal life (FIGURE 1).

The arterial duct in neonates with severe right heart obstructive lesions early in fetal life has a very different anatomy: the duct in these patients is longer, considerably more tortuous in different planes (typically cumulated angulation of 270–360° in frontal plane and 360° in lateral plane) and mostly has a vertical origin from the aortic arch (FIGURE 2) [15,20]. The pulmonary trunk and pulmonary trifurcation may have a variable size; if small to hypoplastic, ductal tissue in the wall of the pulmonary arteries can account for early or late stenosis of a branch pulmonary artery (primarily left) [21].

The duct can be left-sided, right-sided or bilateral. When ipsilateral to the arch, the duct connects at the inner curve of the arch just distal to the ipsilateral subclavian artery; when the duct is contralateral to the arch it originates from the innominate or subclavian artery. The pulmonary arteries can be confluent or nonconfluent.

In patients with hypoplastic left heart syndrome (HLHS), the morphology of the duct can be classified into three categories depending on the orientation from the vertical plane, as described by Boucek et al. [18]. Type 1 ductal anatomy has a leftward loop at a mean orientation of 18° from the vertical plane. Type 2 ductal anatomy is mesoverted, with a mean orientation of 7.1° from the vertical plane and type 3 ductal anatomy has a rightward axis, with a mean of -4° rightward. Type 1 ductal anatomy is observed in more than two-thirds of the patients with HLHS [18].

**Choice of stent: length, diameter & type**

When choosing a stent, important features are stent length, diameter and design. The most distal parts of the duct appear to have a remarkable power to constrict, even when only a few millimeters are left unsupported [19,22]. Therefore, great care must be taken to cover the duct completely from the aortic end to have a remarkable power to constrict, even when only a few millimeters are left unsupported [19,22]. Therefore, great care must be taken to cover the duct completely from the aortic end....
Stenting the neonatal arterial duct

Figure 2. Aortagram of patient with pulmonary atresia–ventricular septal defect. The duct is long and tortuous, covering in the different planes 270 + 360° of angulation. Note the vertical take-off from the aorta.

until well within the pulmonary trunk, without covering the orifice of the pulmonary arteries. Ideally the complete duct should be covered by a single stent. In cases of incomplete stenting or significant prolapse of tissue through the stent cells, an additional stent should be implanted to cover and open the whole duct. The chosen stent length is thus slightly longer than the length of the duct. Determining stent length is usually relatively easy in cases with short, straight ducts, but it may be a challenge in patients with long and tortuous ducts. In a tortuous vertical duct in which the length is not exactly predictable, particularly when the advanced guiding wire will change the ductal shape, ductal stenting should be started at the pulmonary end to be sure that this part of the duct is at least covered. It is often preferable to implant two short stents in telescope technique than to confront problems when advancing a too long stent.

In patients with duct-dependent systemic circulation, crossing the isthmus is an important issue. The location of the distal end of such stent, either proximal at the ductal ampulla, or more distal in the descending aorta, may result in either the potential for late coarctation following prostaglandin discontinuation, or insufficient retrograde aortic perfusion by isthmic filling and narrowing, resulting in brain and myocardial hypoperfusion.

Stent diameter will depend on the indication for ductal stenting (duct-dependent pulmonary flow: bilateral vs single lung or duct-dependent systemic flow), the ductal length and anatomy, and, of course, the weight of the baby. The stent design and material determine the cross-sectional area, strut thickness and radial force. Larger metallic cross-sectional areas, thicker struts and smaller cell areas result in good scaffolding with limited tissue prolapse, which is important when used in the arterial duct. However, these properties reduce the flexibility and conformability of the stent. Radial force is no issue for use in the arterial duct. Side-branchnaccessibility is usually not required, but might be beneficial if additional stenting is considered in case of a significant aortic coarctation or a stenotic pulmonary artery bifurcation.

Stent implantation

Duct-dependent pulmonary circulation

The short straight duct

Flexible coronary stents, premounted on low-profile balloons are used (i.e., Multi-link Vision™, Tetra/Penta/Zeta stents [Guidant, CA, USA], Liberte™ [Boston Scientific, MA, USA], Driver™ [Medtronic, MN, USA]). These stents can be implanted through a 5-Fr (transvenous) guiding catheter or 4-Fr (transarterial) sheath. When positioning the stent, care should be taken to have minimal protrusion in the aorta. The superior aortic end of the stent is therefore aligned with the cranial aorto–ductal junction. Some protrusion into the aorta is acceptable, as long as the other side of the aortic wall is not touched, as this might lead to a fixed obstruction with coarctation. Excessive protrusion can complicate future stent reentry for redilation (if necessary). The stent should protrude slightly into the pulmonary trunk. Typically an 18-mm stent will be used in a mature neonate.

A stented duct is comparable with a central shunt where all the restriction lies within the shunt itself. Surgical experience has taught us that in neonates such shunts should be made of conduits between 3 and 4 mm. In practice, the duct is stented to a diameter of 3.5–4 mm for a normal-term baby [12,13]. In babies weighing less than 2.5 kg, the stent diameter should not exceed 3 mm, especially if the ductal length is less than 10 mm.

The final stent lumen will however not only depend on the stent diameter at implantation, but will also decrease within hours to days due to contraction of the vessel and tissue prolapse through the stent struts, and will further decrease within weeks to months due to endothelial hyperplasia or peal formation. Patients with a stent diameter of 4.0 mm will often initially require antifailure treatment due to increased pulmonary blood flow.

Long tortuous duct, vertical duct

When these types of ducts are accessed from the femoral artery, it is often difficult (and sometimes impossible) to obtain a stable wire position for ductal stenting. It may be possible to access the aorta anterograde from the femoral vein through the heart, but this route makes catheter control more difficult and may cause hemodynamic instability in small neonates by keeping the atroventricular and semilunar valves open. A so-called ‘coaxial catheter system’ may allow access to the duct: a 2.9-Fr Progreat™ microcatheter system (Terumo®, Haasrode, Belgium), which contains a 0.021-inch wire, is placed in a 4-Fr
Judkins right coronary catheter, through a cut-off 6-Fr guiding catheter (right coronary or mammary), with a short 6-Fr sheath over the cut-off end (hemostatic valve, also allowing contrast injections). The guiding catheter (with the right coronary catheter at its tip) is placed at the origin of the duct to ensure maximal stability. The duct is then gently probed by the soft 0.021-inch wire; as the wire is advanced more distally into the duct, the microcatheter is also advanced as distal as possible, followed somewhat by the right coronary catheter (if possible). Care should be taken not to induce vessel trauma or ductal spasm when trying to advance a stiff catheter into the tortuous duct. The floppy 0.021-inch wire is then exchanged for a 0.014-inch coronary wire (not too stiff), the coronary catheter removed and the stent implanted through the 6-Fr guiding sheath.

Access via the axillary artery may be the preferred route in selected patients [15,23]. Depending on the position of the duct at the inner curve of the aortic arch in relation to the subclavian arteries, the ipsi- or contralateral subclavian is used. Direct puncture of the axillary artery is preferred for placing a ‘long’ 4-Fr sheath within the subclavian artery; the sheath is advanced to the origin of the duct. Contrast medium can be administered easily by small hand injections during stent positioning.

In patients with a long, tortuous duct, flexible stents with more conformability to follow the curves are theoretically a better choice; however, stents with a larger cell area allow significant tissue prolapse, with the risk of a restrictive cobble stone appearance within hours. Such stents should therefore be inflated to a slightly larger diameter. Patients with this type of duct frequently have a hypoplastic pulmonary trunk and a small trifurcation, with ductal tissue extending into the pulmonary arteries; this will result in stenosis early after discontinuation of prostaglandin. These patients were classically treated with bilateral shunts, or a single shunt after plasty of the bifurcation on bypass. If stenting is chosen, the stent should preferably be advanced into the stenotic pulmonary artery, allowing perfusion of the other lung through the stent struts, or alternatively have a stented duct to one lung and a surgical shunt to the other lung.

Despite all these techniques, some of these complex, severely tortuous ducts remain very challenging and cannot be stented safely. This subgroup might remain the domain of surgical shunting.

The duct to a single lung

The term ‘discontinuous pulmonary arteries’, ‘isolated’ or ‘excluded’ pulmonary artery identifies a rare cardiovascular malformation in which one pulmonary artery is not connected to the main pulmonary artery but arises from an arterial duct. Isolated right pulmonary artery is found mostly in a normal heart (Figure 3), whereas an isolated left pulmonary artery is commonly associated with a right-sided aortic arch or with tetralogy of Fallot, in particular with pulmonary atresia and duct-dependent pulmonary circulation.

Neonatal surgical repair frequently leads to uneven distribution of the pulmonary blood [3], significant distortion [24], and residual or recurrent stenosis due to any residual ductal tissue [24,25]. Ductal stenting is therefore an attractive alternative to a surgical shunt. In addition, stent angioplasty enables the adaptation of shunt size to pulmonary artery growth by serial stent dilations, whereby corrective surgery can be postponed until the patient is older. Stent diameter in a duct to a single lung should, however, not be oversized: 3 mm is generally recommended, depending on the ductal length and weight of the baby. Larger stents can cause unilateral pulmonary overflow with the possibility of pulmonary hypertension and can even cause significant steal from the systemic circulation inducing low cardiac output [26].

Duct-dependent systemic circulation

Balloon-expandable versus self-expandable stents

Balloon- [27] or self-expandable [28] stents can be used for this indication. Balloon-expandable stents are more difficult to advance over the wire, and retrieval of the deflated balloon can cause stent slipping in an uncorrected duct. The self-expandable stents can conform to the anatomy of the arterial duct; by contrast, balloon-expandable stents are rigid and force the ductal anatomy to conform to the stent, thereby narrowing the orifice of the isthmus and impeding retrograde aortic arch flow. The balloon-expandable stent briefly interrupts systemic and myocardial perfusion during placement, which can be critical in infants with marginal ventricular function. Self-expandable stents (SinusRepo TM nitinol stents [OptiMed, Karlsruhe, Germany], Zilver stent [COOK, Denmark]) are therefore preferred for ductal stenting, especially in large ducts without any constriction. Such stents can currently be advanced through a short 5-Fr venous sheath over a 0.014-inch guiding wire, but these
modern self-expandable stents are not available worldwide. Most self-expandable stents need a 6- or even 7-Fr sheath for delivering stents, with minimum lengths of 20 mm and widths between 6 and 10 mm [18,27]. An advantage of the Sinus-Repo design is its ‘anti-jump’ mechanism, which allows stent retrieval after almost 80% of stent expansion and facilitates repositioning if necessary. The diameter of the utilized stents is chosen to be at least 1–2 mm above the minimal ductal diameter and even larger than the diameter of the descending aorta. This last recommendation is of particular importance when stenting the duct of newborns with interrupted aortic arch.

This results in the implantation of stents with a diameter of 7 mm in most cases, particularly in newborns with a birth weight of less than 2.5 kg and even in premature less than 1.5 kg. In patients where the ductal diameter measures 8–9 mm without any constriction, a 9- or 10-mm self-expandable stent should be implanted (also in patients with ductal aeurysms).

Premounted Genesis™ stents (Cordis) should be used when urgent stenting of a prostaglandin-resistant constricted duct in neonatal shock is performed, or if some ductal constriction is observed either at the pulmonary or aortic end (FIGURE 4). In an asymmetrically constricted or very short duct, a self-expandable stent may slip to the descending aorta or pulmonary trunk due to the still active working of the nitinol material after release. Premounted Genesis stents are available in different lengths of 12, 15, 18, 19 and 20 mm, they are premounted on 7-, 8- or 9–10-mm balloons, and can be advanced through a short 6–7 Fr venous sheath over a 0.035-inch guiding wire (FIGURE 4). Advancing through a long sheath is not necessary because of the tightly fixed stent.

Orientation of the arterial duct
The length of the duct, number of stents required for complete coverage, and technical and procedural complications are significantly related to the orientation of the arterial duct [18]. As described by Boucek et al., the majority of the ducts take a leftward orientation (type 1: 65%) with an average length of 17.4 mm [18]. The second most common ductal anatomy is a direct front-to-back orientation (type 2: 27.5%). These ducts are shorter, averaging 15.3 mm. The ducts that take a rightward course are uncommon (type 3: 7.5%) and are short (mean: 10.9 mm). The diameters of the ducts in the three categories are usually similar, with a mean of 6.6 mm. Ducts with a front-to-back and rightward orientation may pose additional difficulty in manipulating the catheter from the right ventricle to the pulmonary artery. Placement of the stent delivery system across the right ventricle in these patients may cause tension on the tricuspid valve and right ventricle, resulting in transient bradycardia and hypotension. Such rightward morphological duct stenting can also be performed from the aortic side using modern self-expandable stents through a 5-Fr sheath.

Restrictive aortic isthmus
Retrograde aortic arch perfusion through the isthmus can be problematic after stent implantation.

The obstruction can occur immediately at stent implantation as a result of stretching the orifice in one direction, thereby narrowing it in the perpendicular direction; this is more likely to happen with a rigid, balloon-expandable stent. Stent placement is precisely by positioning a multipurpose catheter within the isthmus of the aortic arch. The multipurpose catheter delineates the duct–aortic junction, and small amounts of contrast medium can be given by hand injection during stent placement to avoid overstenting of the duct causing distortion of the isthmus. In addition, access to the isthmus is preserved by the multipurpose catheter guiding. The obstruction can also occur a few hours after ductal constriction, or later as a result of tissue ingrowth or peel formation around the stent struts. The present echocardiographic evaluation may identify patients at risk: a very narrow or hypoplastic aortic arch appears to predispose for this complication. Patients with severe stenosis of the aortic isthmus may require either simultaneous stenting of the isthmus, or creation of a ‘reversed shunt’ between the pulmonary trunk and the aortic arch at the time of the sternotomy for bilateral banding [14,17,27,28,29].

Timing of ductal stenting
Duct-dependent pulmonary circulation
After radiofrequency valvotomy or balloon dilation of critical pulmonary valve stenosis has been performed, the decision needs to be made whether to proceed with ductal stenting. Technically, it is easy to stent the duct at the same procedure.
while the arteriovenous guide circuit is established. If the right ventricle is of normal size with a normal z-score of the tricuspid valve (<−2) there is usually no need to stent the duct. If the right ventricle is moderately or severely hypoplastic, the tricuspid valve has a z-score of less than −2, the tricuspid valve is stenotic or when significant residual subvalvar stenosis persists, additional blood flow to the lungs may be required for weeks or months. The duct may then be stented at the same procedure [13]. In case of doubt, we would proceed to carry out ductal stenting, avoiding the costs and risks of maintaining the baby on a prostaglandin infusion for days or weeks (waiting for the right ventricular stroke volume to increase), and avoiding the cost and burden of a second procedure. In other centers, patients with borderline right ventricles would be continued on prostaglandin infusion until an acceptable saturation (>80%) can be maintained without ductal flow [13]. In newborns with pulmonary atresia and ventricular septal defect, ductal stenting should be considered whenever a shunt is indicated, preferably after a postnatal adaptation time of 3–5 days.

**Duct-dependent systemic circulation**

Early in the experience of hybrid procedures, ductal stenting was performed mostly in advance of surgical bilateral banding. However, most centers now recommend that ductal stenting is undertaken after banding due to the (theoretical) risk of stent dislocation during intraoperative manipulation [11,14,18]. In the setting of a surgical–interventional hybrid procedure, the stent can be deployed through a direct arteriotomy of the pulmonary trunk through the sternotomy [27,30]. The restriction of the atrial septum is addressed after the bilateral banding and stenting of the duct [27].

In newborns and infants with low cardiac output caused by duct constriction despite continuous prostaglandin infusion, urgent percutaneous duct stenting utilizing premounted balloon-expandable stents is an effective high-urgency therapy.

**Anticoagulation – antiaggregation**

The role of anticoagulant and antiplatelet drugs remains unclear. During the procedure, standard intravenous heparin should be administered. Heparin is not routinely administered at the end of the procedure, but acetylsalicylic acid 1–3 mg/kg/day is often given for as long as stent patency is required [12,18,23,29], although this is certainly not evidence based. The efficacy and safety of clopidogrel 0.2 mg/kg/day in this setting still needs to be determined [23].

**Neointimal proliferation**

Duct patency after stenting is limited by in-stent restenosis, which occurs due to neointimal proliferation and/or neointimal formation. The ideal stent for this procedure still needs to be defined. Stent design determines (non)metal surface area, radial force, flexibility, conformability, scaffolding and prevention of tissue prolapse. Drug-eluting stents or covered stents have been proposed as a means of preventing instent restenosis in adults. Covered stents are slightly more bulky and require larger introducer sheaths (currently +1–2 Fr sizes) and can obviously not be used in the duct-dependent systemic circulation. The drug-eluting coatings contain agents that inhibit thrombus formation (e.g., heparin), inflammation (e.g., dexamethasone) and cellular proliferation (e.g., sirolimus or paclitaxel). The efficacy and safety of ductal stenting with such coated stents in newborn babies still needs to be established; significant liberation of immune suppressive drugs in the systemic circulation can be anticipated and has been documented.

In-stent stenosis can be managed by redilating or preferably by restenting the duct, thereby also accounting for patient growth.

**Discussion**

**Duct-dependent pulmonary circulation**

Ductal stenting obviously needs to be compared with the standard surgical shunt. The interventional approach performed, with the goal to be a minimally invasive alternative to a surgical shunt, cannot yet be proposed as ‘a must approach’. In experienced hands, ductal stenting appears to be feasible in approximately 80–90% of cases, the most challenging ducts being the long tortuous ones in pulmonary atresia and ventricular septal defect (VSD). In addition, such a minimally invasive alternative may only be possible by using the best currently available material and by choosing a variable arterial/venous access depending on the ductal morphology and origin. Only then is this approach less invasive than primary surgery and offers the possibility to adapt to the clinical needs of the individual patient. Compared with long term prostaglandin infusions, early ductal stenting shortens hospitalization significantly and reduces treatment costs. The lumen of a stented duct appears to narrow faster than a surgical shunt, necessitating redilation and restenting. This, however, allows titration of pulmonary flow to patient size and growth. Such redilation restenting must obviously be considered when assessing the cost-effectiveness of each strategy.

The stented arterial duct fulfils its function as a surrogate for an aortopulmonary shunt, augmenting the pulmonary blood flow until a definitive surgical procedure can be performed or until the ductal flow becomes redundant. During follow-up, no distortion of the pulmonary arteries has been observed and technical problems due to the stent are not encountered at subsequent surgeries, as the stent can easily be occluded by simple external compression (surgeons be aware: no recoil!).

**Duct-dependent systemic circulation**

Neonates with heart defects suitable for univentricular repair can benefit from this hybrid transcatheter-surgical palliation, having the Norwood type of aortic reconstruction carried out beyond the neonatal period at the same time of the bidirectional superior caval anastomosis [11]. Particularly in patients presenting with neonatal cardiogenic shock or other high-risk factors, percutaneous ductal stenting as part of a hybrid approach can significantly improve early survival [11,17,18,31–34]. In addition, patients with variants of the hypoplastic left heart complex, in whom the immediate postnatal decision regarding a uni- or biventricular...
approach is ambiguous, or who carry a high risk when biventricular repair is performed in the neonatal period, may have a major benefit from primary hybrid transcatheter-surgical palliation, postponing definitive decisions and surgery until later [14,17].

As experience has been increasing worldwide, the technique and material used for ductal stenting in this specific patient population have been adapted. Since the use of self-expandable Sinus-Repo nitinol stents and balloon-expandable Genesis stents, the results have improved significantly. Self-expandable stents are probably the stent of choice in most patients as they can conform to the anatomy of the arterial duct without significant obstruction of the istmus. By contrast, balloon-expandable stents are more rigid and force the ductal anatomy to conform to the stent. Such stents should, therefore, be reserved for patients in shock responsive to prostaglandin infusion, and in patients with an asymmetrically constricted or a very short duct, in which case a self-expandable stent may slip to the descending aorta or pulmonary trunk due to the still active working of the nitinol material after release.

Expert commentary
The worldwide experience of ductal stenting in patients with either duct-dependent pulmonary or systemic circulation has significantly increased over the past few years. This can largely be attributed to the improvement of stent and catheter technology (low profile, flexible, premounted stents with good scaffolding), but also to improve patient selection and preparation, optimization of interventional access and covering the complete length of the duct. In an ideal world, stents should be specifically designed for use in the neonatal arterial duct, meeting all the requirements necessary for ductal stenting. Realistically, however, the number of patients treated each year will remain small, necessitating the use of stents originally designed for other purposes. A downside of this technique is that surgeons might gradually lose their expertise in creating a neonatal shunt, theoretically increasing the surgical risk in the rare patient who will still need a surgical shunt.

Five-year view
Ductal stenting has come to stay. In well-selected patients, the interventional results are comparable to surgery and morbidity and costs are probably lower. However, currently, this procedure is still performed in only a few centers. More widespread use is remains limited, probably due to previously reported poor results, the lack of comparison studies and larger long-term outcome studies, the veto of surgeons in many teams and the complexity of some interventions that need to be embedded in a treatment strategy supported by the whole team. As surgeons and interventional cardiologists become more partners than competitors in the treatment of congenital heart disease, the obstruction within centers will slowly fade away. Due to the limited number of patients, specific stents for this indication will not be made. The interventionalist, therefore, needs to accept the compromise by using stents designed for other (coronary or renal) applications, keeping some key issues in mind when selecting a stent (size of the delivery sheath, stent flexibility and adequate scaffolding).

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Key issues
- Ductal stenting has evolved from dangerous and unpredictable to a safe and well-controlled procedure in selected patients.
- The short and straight duct, as observed in patients with pulmonary atresia with intact ventricular septum (PA/IVS) and hypoplastic left heart syndrome, are at the "easy" end of the therapeutic spectrum; the long and tortuous duct can be very difficult and even impossible to stent with current technology.
- Adequate patient selection and preparation (prostaglandin management) and individualized vessel access are essential for success.
- The duct needs to be stented over its complete length.
- Stents designed for other applications are used for ductal stenting.
- Stent selection depends on the indication for stenting (pulmonary vs systemic flow), patient weight, ductal morphology, size of delivery sheath, stent flexibility and adequate scaffolding.

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Papers of special note have been highlighted as:
• of interest

1 Blalock A, Taussig H. The surgical treatment of malformations of the heart in which there is pulmonary stenosis or pulmonary atresia. JAMA 128, 189–202 (1945).


• Concluded that, for the majority of patients ductal stenting cannot be recommended due to the procedural risk and short duration of palliation. Comparing this article with the current mostly positive reports on ductal stenting, the evolution of the technique over the last decade can be appreciated.


• Neointimal proliferation and stenosis formation is a major limitation eventually reducing the ductal flow.


• Reports an almost 8-year experience of combined percutaneous ductal stenting and surgical bilateral pulmonary artery banding in 58 neonates with hypoplastic left heart syndrome/complex.


• Concludes that ductal anatomy has a significant impact on the success of ductal stenting and complications during the procedure.


• Highlights the difference in morphology of the duct in pulmonary atresia and left heart obstructive lesions.


• Examined 41 specimens with pulmonary atresia and confluent pulmonary arteries histologically and demonstrated that ductal tissue in a pulmonary artery and pulmonary artery stenosis frequently coexisted.


• Stent oversizing should be avoided especially when stenting the duct to a single lung.


• Report on the evolution of a hybrid strategy in 34 patients for the management of hypoplastic left heart syndrome, highlighting the significant learning curve. Indicates that ductal stenting through a sheath directly in the main pulmonary artery is preferable to a traditional percutaneous, intracardiac course (no hemodynamic instability).


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