Cardiology in the Young (2014), **24**, 1117–1120
doi:10.1017/S1047951114002030

Original Article

Transcatheter management of neonatal aortic stenosis*

Gary E. Stapleton

Johns Hopkins All Children's Heart Institute, All Children's Hospital, Saint Petersburg, Florida, United States of America

Abstract Neonatal aortic valvar stenosis can be challenging to treat because of the varied morphology of the valve, the association with hypoplasia of other left heart structures, and the presence of left ventricular systolic dysfunction or endomyocardial fibroelastosis. Balloon valvuloplasty and surgical valvotomy have been well described in the literature for the treatment of neonatal aortic stenosis. Transcatheter therapy for neonatal aortic stenosis is the preferred method at many centres; however, some centres prefer a surgical approach. Balloon valvuloplasty for neonatal aortic stenosis is reviewed in this manuscript, including the history of the procedure, technical aspects, and acute and long-term outcomes.

Keywords: Cardiac catheterisation; balloon valvuloplasty; aortic stenosis; neonate

Received: 14 September 2014; Accepted: 14 September 2014

Balloon aortic valvuloplasty, which was first described in 1984, is the preferred treatment for aortic valvar stenosis at many centres. Neonatal aortic valve stenosis can be challenging to treat owing to different morphology of the valve in neonates, hypoplasia of the aortic anulus, association with abnormalities of other left heart structures, and the presence of left ventricular systolic dysfunction or endomyocardial fibroelastosis. Balloon valvuloplasty and surgical valvotomy have been well described in the literature for the treatment of neonatal aortic stenosis. To date, there have been no randomised studies that compare surgery with balloon valvuloplasty for procedural success, morbidity and mortality, or the need for reintervention, with most reports coming from single centres evaluating their own experience with one or both treatment modalities. Transcatheter therapy for neonatal aortic stenosis is the preferred method at many centres; however, some centres prefer a surgical approach. Balloon valvuloplasty for neonatal aortic stenosis is reviewed here, including the history of the procedure, technical aspects, and acute and long-term outcomes.

Early history

Balloon aortic valvuloplasty was first described in 1984 in a series of 23 patients who were 2–17 years of age at the time of their procedure.[1] The catheters were 9-Fr with a balloon length of 40 mm, and therefore not indicated for use in neonates or infants. Over the next several years, as lower profile balloons became available, the procedure was subsequently reported in neonates. Surgical valvotomy had been desribed earlier, but generally involved rigid valve dilation, and transcatheter balloon aortic valvuloplasty was sought as a less invasive alternative. Kasten-Sportes et al,[2] reported their series using a transfemoral approach where they used the antegrade approach to the aortic valve by advancing the valvuloplasty balloon across a patent foramen ovale if present. Otherwise, they would access the aortic valve

*Presented at All Children's Hospital Johns Hopkins Medicine 14th International Symposium on Congenital Heart Disease, Saint Petersburg, Florida, 15–18 February 2014, Special Focus: Diseases of the Cardiac Valves from the Fetus to the Adult, Co-Sponsor: The American Association for Thoracic Surgery (AATS).

Correspondence to: Dr G. E Stapleton, MD, Johns Hopkins All Children's Heart Institute, All Children's Hospital, Outpatient Care Center, 2nd Floor, 601 5th Street South, St. Petersburg, FL 33701, United States of America. Tel: +727 767 3333; Fax: +727 767 8990; E-mail: gtaple1@jhmi.edu

through a retrograde femoral arterial approach. They reported a 50% incidence of temporary femoral artery occlusion. Subsequent series reported using surgical carotid artery cutdown approach[3] and the umbilical artery.[4] These initial series demonstrated that balloon aortic valvuloplasty was feasible and resulted in acute gradient reduction with improved left ventricular systolic function. There was, however, a high rate of mortality in the early era of this procedure.

Technical aspects

Vascular access is often obtained in the femoral vessels and the valve can be approached retrograde through the femoral artery, or antegrade through the femoral vein. Many centres prefer crossing the valve retrograde through the femoral artery. The majority of balloons used for valvuloplasty go through a 3- or 4-Fr vascular sheath, which is generally well tolerated in term gestation neonates. If there is an atrial septal communication, the valve can also be crossed antegrade through a femoral venous sheath, and other centres prefer this approach. Some operators believe this may result in more stable balloon position during inflation, which may decrease the risk for avulsing an aortic valve leaflet, resulting in significant aortic insufficiency. However, navigating the balloon through a smaller left ventricular cavity can be challenging and may result in compromised cardiac output in a patient with left ventricular systolic dysfunction. It is also imperative to be sure that the valvuloplasty balloon is free from the mitral valve chordal apparatus before inflation. Surgical cutdown can also be performed to access the carotid artery. This gives a fairly straight course to the aortic valve and can potentially minimise the time required to cross the valve with a guidewire that is particularly important in patients with critical aortic stenosis and left ventricular dysfunction. It also minimises the risk of vascular access complications, particularly in smaller or premature neonates. It has been reported that the rate of femoral arterial access complications is much higher in patients < 2.5 kg (6%) compared with those who weigh 2.5–3.5 kg (0.9%).[5] There is evidence that this does not appear to affect long-term patency of the right carotid artery.[6] Balloon aortic valvulopasty in neonates has also been performed at the bedside with carotid artery access and transoesophageal echocardiographic guidance without fluoroscopy.[7]

When choosing the diameter of the valvuloplasty balloon, we typically start with a balloon to the annulus ration of 0.8–0.9. The balloon diameter can be increased by 1 mm, or a higher pressure balloon can be used, if there is a significant gradient. While it is not clear that larger diameter balloons cause higher grade aortic insufficiency, most operators will keep the final balloon to annulus ratio at 0.9–1.0, particularly in neonates. One study showed that balloon size does not correlate with the degree of aortic insufficiency immediately following the procedure or at 6-week and 1-year follow-up.[8] The authors used a balloon to annulus range of 0.7–1.6; however, the average was 0.9 and no long-term follow-up was reported.

Rapid right ventricular pacing may also be used during balloon inflation. This is done to decrease the left ventricular stroke volume and improve balloon stability, which may reduce the risk of trauma to the aortic valve leaflets and decrease the number of inflations to achieve the desired result. We initiate pacing at a rate of 160–180 beats/minute and increase by 10–20 beats/minute until the systolic blood pressure decreases by 50% or the mean arterial pressure decreases by 25%. This has been shown to improve gradient reduction and decrease the incidence of higher grade aortic valve insufficiency.[9]

Outcomes

The goal of balloon aortic valvuloplasty is to effectively reduce the degree of stenosis as much as possible without creating significant aortic valve insufficiency. This is particularly challenging in neonates owing to several factors. Other left heart structures including the mitral valve, left ventricle, aortic arch, and the aortic valve annulus itself are often hypoplastic. Many neonates have critical aortic stenosis and are acutely ill with left ventricular dysfunction, and are brought to the catheterisation laboratory on inotropic suport and prostaglandin infusion. The valve morphology in neonates may also be different than in older patients with aortic stenosis. The most common valve morphology in all patients with aortic stenosis is the functional bicuspid valve, which is the least common valve type to require reintervention or surgical valve replacement. Neonates have a higher incidence of a functionally unicuspid valve than older patients, and this valve type may be associated with a higher need for repeat balloon valvuloplasty. Neonates also have a higher incidence of dysplastic valves that do not often respond favourably to balloon aortic valvuloplasty and commonly require surgical intervention. Valve morphology was not been shown to be associated with increase risk of significant aortic valve insufficiency following balloon aortic valvuloplasty.[10]

In-hospital mortality following balloon aortic valvuloplasty has decreased significantly since the procedure was described in neonates. Early series for both surgical and balloon valvuloplasty reported early mortality of up to 59%.[11] As the procedure evolved and patient selection criteria improved, the mortality rates decreased to 11–13%, with a 10–20% surgical mortality in this era.[12] More recent series have reported an early mortality rate of 6–8% with acute

procedural mortality of 2%.[13] The presence of endomyocardial fibroelastosis is an independent predictor of time-related mortality.[14] Long-term survival following neonatal aortic valvuloplasty is reasonably high with a reported 10-year survival of 87% in patients who survived the early period.[15] Other adverse events associated with the procedure include stroke, occlusion at the arterial access site, and acute severe aortic insufficieny requiring urgent surgical valve repair or replacement. The mechanism of severe aortic insufficieny may be owing to leaflet avulsion, cusp prolapse, or disruption of the annulus.

The need for reintervention following balloon aortic valvuloplasty is high, with neonates having a higher rate of reintervention than those who undergo the procedure after 1 month of age. Over two-thirds of neonates undergoing balloon aortic valvuloplasty require either repeat balloon valvuloplasty or surgical repair or replacement of the aortic valve at 10 years after the procedure.[15,16] Risk factors that are associated with the need for earlier reintervention include higher residual gradient after balloon aortic valvuloplasty, left ventricular dysfunction before the procedure, and the presence of left ventricular endomyocardial fibroelastosis. Repeat balloon aortic valvulopasty is performed in over half of these patients within 10 years of their initial procedure owing to recurrent stenosis, with many of these occuring within the first year of life. It is likely that rapid somatic growth that occurs in infancy contributes to a high rate of recurrence during the first year. Decreased left ventricular systolic function before valvuloplasty[13] and an increased residual gradient immediately after the procedure are associated with an increase risk of reintervention. The Boston Children's Hospital group reported that a residual gradient < 35 mm mercury post valvuloplasty was asssociated with a longer freedom from reintervention and aortic valve replacement.[16] Repeat balloon valvuloplasty can be performed safely, results in significant gradient reduction, and can delay the need for eventual surgical intervention. The degree of aortic insufficiency is often increased following repeat balloon valvuloplasty; however, this has not been shown to increase the risk of surgical subsequent intervention.[17] Surgical reintervention following neonatal balloon aortic valvuloplasty is also common with predictors of shorter freedom from reintervention, including increased post valvuloplasty gradient, increased aortic regurgitation, and the presence of other left heart obstructive lesions. The aortic valve can be replaced surgically with the Ross operation, aortic homograft, or mechanical valve in patients with a large enough aortic annulus. The reported freedom from aortic valve replacement is 87, 75, and 59% at 1, 5, and 10 years, respectively.[18]

The majority of neonates have either no or mild aortic insufficiency immediately after balloon aortic valvuloplasty, with a 2% incidence of severe insufficiency in more recent series.[13,16] However, aortic insufficiency is generally progressive during long-term follow-up and progression to moderate-to-severe insufficiency occurs in over one-third of the patients by 10 years after balloon valvuloplasty.

Although many of these patients have associated hypoplasia of other left heart structures at the time of diagnosis, successful balloon aortic valvuloplasty has been shown to result in the growth of the aortic valve annulus. The majority of patients with aortic valve annulus z-score < 1 have normalisation of their annulus size within 1–2 years. Patients with low left ventricular end-diastolic diameter z-scores also showed normalisation of their left ventricular dimensions during this time. The mitral valve annulus z-scores generally remain low.[15]

Comparison with surgery

There have been no prospective randomised studies comparing balloon aortic valvuloplasty with surgical valvotomy to date. There are numerous retrospective studies comparing outcomes between these two treatment modalities; however, the majority of these are from single centres with a clear bias in which procedure they favour. In 2001, McCrindle et al, [11] published the outcomes from 18 centres who were evaluated by the Congenital Heart Surgeons Society. There were 110 neonates in this series, 82 of whom underwent balloon aortic valvuloplasty. The procedural risks, including early mortality, and the rate of reintervention were similar in both the surgical and balloon valvuloplasty groups. They did find that neonates who underwent balloon aortic valvuloplasty had a lower immediate post-procedural gradient, higher degree of aortic valve insufficiency, and a shorter duration of hospitalisation compared with the surgical group. Since this publication, there have been significant improvements in both surgical and transcatheter techniques. Prior surgical series reported patients who had undergone rigid aortic valve dilation in the operating room, including earlier series using a transapical approach. Since then, more refined surgical techniques have been described including resection of nodular dysplasia, thinning of the aortic valve leaflets, and creation of neocommisures. Catheter technology has also improved during this time as well with the development of lower profile balloons, soft tip guidewires for crossing the aortic valve, and the introduction of rapid right ventricular pacing. Recently, Siddiqui et al,[19] published a comparison of surgical valvotomy with balloon valvuloplasty from three centres in Australia.

They reported 129 patients, 67 of which were neonates. Of the total number of patients, 86 in their series underwent surgical valvotomy. They reported that patients who underwent balloon aortic valvuloplasty had a higher rate of reintervention than the surgical valvotomy group. The median time to reintervention for the balloon valvuloplasty group was 11 months compared with 5 years for the surgical group. However, they also reported that the mean residual gradient post valvuloplasty was 40 mmHg, versus 30 for the surgical group, which has been shown to be a risk factor for earlier intervention. They also stated in their manuscript that they predict patients who undergo balloon aortic valvuloplasty will ultimately need surgical valve replacement owing to the "destructive nature" of the procedure. However, they did not show a significant difference in the need for surgical valve replacement between the two groups in their study. Interestingly, the reported incidence of surgical valve replacement 10 years after sugical commisurotomy was 57% in another recent publication, which is very similar to that reported following balloon aortic valvuloplasty.[20]

Conclusion

Balloon aortic valvuloplasty can be performed safely in neonates and results in significant reduction in the severity of stenosis. The need for reintervention and the eventual surgical valve repair or replacement is common because of recurrent stenosis, progressive valve insufficiency, or both. Factors that lead to increased risk of reintervention include hypoplasia of the aortic anulus, other left heart obstructive lesions, higher post-procedure gradient, left ventricular dysfunction, and the presence of a functionally unicuspid or dysplastic aortic valve. Whereas transcatheter management of neonatal aortic valve stenosis is preferred at many centres, some institutions prefer surgical valvotomy. Ongoing evaluation of outcomes and development of criteria for patient selection for balloon valvuloplasty is important to provide the best outcomes for these patients.

Acknowledgement

None.

Financial Support

This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

Conflicts of Interest

None.

References

1. Lababidi Z, Jiunn-Renn W, Walls JT. Percutaneous balloon aortic valvuloplasty: results in 23 patients. Am J Cardiol 1984; 53: 194–197.
2. Kasten-Sportes CH, Piechaud JF, Sidi D, et al. Percutaneous balloon valvuloplasty in neonates with critical aortic stenosis. J Am Coll Cardiol 1989; 13: 1101–1105.
3. Fischer DR, Ettedgui JA, Park SC, et al. Carotid artery approach for balloon dilation of aortic valve stenosis in the neonate: a preliminary report. J Am Coll Cardiol 1990; 15: 1633–1636.
4. Beekman RH, Rocchini AP, Andes A. Balloon valvuloplasty for critical aortic stenosis in the newborn: influence of new catheter technology. J Am Coll Cardiol 1991; 17: 1172–1176.
5. Kobayashi D, Sallaam S, Aggarwal S, et al. Catheterization-based intervention in low birth weight infants less than 2.5 kg with acute and long-term outcome. Catheter Cardiovasc Interv 2013; 82: 802–810.
6. Borghi A, Agnoletti G, Poggiani C. Surgical cutdown of the right carotid artery for aortic balloon valvuloplasty in infancy: midterm follow-up. Pediatr Cardiol 2001; 22: 194–197.
7. Weber HS, Mart CR, Kupferschmid J, et al. Transcarotid balloon valvuloplasty with continuous transesophageal echocardiographic guidance for neonatal critical aortic valve stenosis: an alternative to surgical palliation. Pediatr Cardiol 1998; 19: 212–217.
8. Hamidi-Manesh L, Tibby SM, Herman R, et al. Influence of balloon size on aortic regurgitation in neonates undergoing balloon aortic valvuloplasty – a retrospective study over and 11-year period. J Interv Cardiol 2013; 26: 200–207.
9. Wizke C, Don CW, Cubeddu RJ, et al. Impact for rapid ventricular pacing during percutaneous balloon aortic valvuloplasty in patients with critical aortic stenosis: should we be using it? Catheter Cardiovasc Interv 2010; 75: 444–452.
10. Maskatia SA, Justino H, Ing FF, et al. Aortic valve morphology is associated with outcomes following balloon valvuloplasty for congenital aortic stenosis. Catheter Cardiovasc Interv 2013; 81: 90–95.
11. McCrindle BW, Blackstone EH, Williams WG, et al. Are outcomes of surgical versus transcatheter balloon valvotomy equivalent in neonatal critical aortic stenosis? Circulation 2001; 104: I152–I158.
12. Egito ES, Moore P, O'Sullivan J, et al. Transvascular balloon dilation for neonatal critical aortic stenosis: early and midterm results. J Am Coll Cardiol 1997; 29: 442–447.
13. Petit CJ, Ing FF, Mattamal R, et al. Diminished left ventricular function is associated with poor mid-term outcomes in neonates after balloon aortic valvuloplasty. Catheter Cardiovasc Interv 2012; 80: 1190–1199.
14. Han RK, Gurofsky RC, Lee KJ, et al. Outcome and growth potential of left heart structures after neonatal intervention for aortic valve stenosis. J Am Coll Cardiol 2007; 50: 24–6-14.
15. McElhinney DB, Lock JE, Keane JF, et al. Left heart growth, function, and reintervention after balloon aortic valvuloplasty for neonatal aortic stenosis. Circulation 2005; 111: 451–458.
16. Brown DW, Dipilato AE, Chong EC, et al. Aortic valve reinterventions after balloon aortic valvuloplasty for congenital aortic stenosis. J Am Coll Cardiol 2010; 56: 1740–1749.
17. Petit CJ, Maskatia SA, Justino H, et al. Repeat balloon aortic valvuloplasty effectively delays surgical intervention in children with recurrent aortic stenosis. Catheter Cardiovasc Interv 2013; 82: 549–555.
18. Fratz S, Gildein HP, Balling G, et al. Aortic valvuloplasty in pediatric patients substantially postpones the need for aortic valve surgery. Circulation 2008; 117: 1201–1206.
19. Siddiqui J, Brizard CP, Galata JC, et al. Surgical valvotomy and repair for neonatal and infant congenital aortic stenosis achieves better results than inventional catheterization. J Am Coll Cardiol 2013; 62: 2134–2140.
20. Rehnstrom P, Malm T, Jogi P, et al. Outcome of surgical commissurotomy for aortic valve stenosis in early infancy. Ann Thorac Surg 2007; 84: 594–598.