Pulmonary valve replacement after repair of tetralogy of Fallot: Evolving strategies

Ralph S. Mosca, MD

From the Division of Congenital Cardiac Surgery, Department of Cardiac Surgery, New York University, Langone Medical Center, New York, NY.

Disclosers: Author has nothing to disclose with regard to commercial support.

Received for publication Sept 2, 2015; accepted for publication Sept 2, 2015; available ahead of print Oct 13, 2015.

Address for reprints: Ralph S. Mosca, MD, Division of Congenital Cardiac Surgery, Department of Cardiac Surgery, NYU Langone Medical Center, New York, NY 10016 (E-mail: ralph.mosca@nyumc.org).

J Thorac Cardiovasc Surg 2016;151:623-5

0022-5223/\$36.00

Copyright © 2016 by The American Association for Thoracic Surgery

<http://dx.doi.org/10.1016/j.jtcvs.2015.09.008>

Surgical palliation of tetralogy of Fallot often involves pulmonary valvotomy, a transannular patch, or incision in the right ventricular (RV) infundibulum, all of which can contribute to long-term pulmonary valve (PV) regurgitation.^{1,2} Evidence is mounting that chronic RV volume overload sets into motion a cycle of compensatory mechanisms that may lead eventually to irreversible RV dilatation, biventricular dysfunction, and chronic dysrhythmias.^{3,4} As a consequence, a significant reduction in survival is noted approximately 25 years after repair.⁵

Extrapolating from the known pathophysiologic response of the left ventricle to chronic aortic insufficiency,^{6,7} observing the decline in RV function in patients who have congenital PV regurgitation,⁸ and laboratory animal models of pulmonary regurgitation,⁹ many authors have advocated for early PV implantation.¹⁰⁻¹³ Although PV replacement has not yet been shown to increase patient lifespan, agreement is growing that restoring PV competence may afford symptomatic improvement, as well as beneficial hemodynamic effects on the right ventricle.

The effect of these changes is reduction of RV end diastolic volume without a reduction in RV ejection fraction, and improvement of mass/volume ratio, as well as possible improvements in electrophysiologic parameters (QRS duration) and exercise tolerance.¹⁴⁻²⁰ The operative risks inherent in reoperation and replacement of the PV have proven to be acceptable.^{21,22} Ongoing concerns are the indications for and optimal timing of PV replacement, and what constitutes the optimal valve.

Several retrospective studies^{10-13,16} using cardiac magnetic resonance imaging have attempted to describe the fate of the right ventricle after PV replacement. As a result, many agree that the following are indications for PV replacement after repair of tetralogy of Fallot: chronic moderate-to-severe pulmonary regurgitation (regurgitant fraction >25%), with either symptoms or >2 of the following anatomic or hemodynamic abnormalities signifying RV or LV dysfunction (Table 1).

Magnetic resonance imaging: RV outflow tract sagittal view; RV dilatation resulting from severe pulmonary insufficiency after tetralogy of Fallot repair.

Central Message

Pulmonary valve replacement after repair of tetralogy of Fallot may produce important functional and symptomatic improvements for patients.

See Articles page 687 and page 168 in the *Seminars* April issue.

See Editorial Commentary page 695.

Restoration of PV function using reparative strategies has been attempted since the recognition that native PV leaflet tissue can continue to grow after transannular patching and despite progressive regurgitation. Several authors have described methods of pulmonary valvuloplasty, referred to as PV restoration, recycling, or late repair, that use leaflet extension and valve resuspension, as well as ventricular and annular remodeling.²³⁻²⁶ The number of suitable candidates for these procedures is relatively small, estimated at approximately 15%, given the need for pliable valve tissue, integrity of the anterior leaflet, and absence of pulmonary stenosis.²⁷ Although short-term data seem promising, future studies are needed to determine the effectiveness of these strategies. A heightened awareness of the possibility of future repairs may guide current surgical therapy of primary repair of tetralogy of Fallot, with a goal of preserving as much PV leaflet tissue as possible.

The vast majority of patients will require valve implantation. The ideal PV substitute would be readily available, easy to implant, nonimmunogenic, durable, and would not require systemic anticoagulation. For use in children, growth potential would be an additional desirable feature. Currently, no such valve exists. Occasionally, a young child or adolescent requires early PV replacement as a result of rapid RV dilatation and/or reduction in RV function. In

TABLE 1. Parameters for PV replacement after repair TOF

Symptoms	RV dilatation/ dysfunction	Impaired left ventricular performance	Residual lesions
Exercise intolerance	$RVEDVi > 160 \text{ mL/m}^2$	$LVEDVi < 65 \text{ mL/m}^2$	RVOT obstruction
Heart failure	$RVESVi > 70 \text{ mL/m}^2$	—	ASD and/or VSD
Syncope	$RV EF < 45\%$	—	Mod + TR
Ventricular tachycardia	RVOT aneurysm	—	Mod + AI
—	—	—	QRS duration $> 140 \text{ ms}$

Presence of residual lesions, especially in association with ventricular dysfunction, may lead to earlier intervention, with concurrent pulmonary valve replacement. *RV*, Right ventricular; *RVEDVi*, indexed RV end diastolic volume; *LVEDVi*, indexed left ventricular end diastolic volume; *RVOT*, RV outflow tract; *RVESVi*, indexed RV end systolic volume; *ASD*, atrial septal defect; *VSD*, ventricular septal defect; *EF*, ejection fraction; *Mod*, moderate; *TR*, tricuspid valve regurgitation; *AI*, aortic valve insufficiency.

this situation, owing to PV annular dilation, often an adult-sized bioprosthesis can be inserted. If such insertion is not possible, a polytetrafluoroethylene valve can be constructed, or cryopreserved homografts or bovine jugular vein conduits can be used.²⁸⁻³⁰

In adolescent and adult patients, the most-common options for PV replacement, after they receive an RV outflow tract transannular patch, include cryopreserved homografts, bioprosthetic valves, and mechanical valves. Aortic or pulmonary homograft valves may be implanted in the native pulmonary outflow tract after a transannular patch. Most often, this implantation is more complicated than that of a stented bioprosthetic valve and has not been shown to be more durable.³¹

Stented bioprosthetic (xenograft) valves, most commonly porcine and bovine pericardial valves, are preferred by most surgeons. These valves are readily available in a range of sizes, easy to implant, function reliably, and do not require systemic anticoagulation. Despite several innovative anticalcification treatment processes, calcification remains the most common mechanism of valve failure. Freedom from reintervention after PV replacement is approximately 95% at 5 years after surgery, with young age at implantation and male gender being apparent risk factors for valve failure.³²

Increasingly, transcatheter valve replacements (Melody valve; Medtronic, Inc, Minneapolis, Minn; and SAPIEN valve; Edwards Lifesciences, Irvine, Calif) have been used to restore PV competence in RV-to-pulmonary-artery conduits, or after initial PV repair.³³ Experience with transcatheter valve implantation in the irregularly shaped RV outflow tract is early and varied.^{34,35} However, once an adult-sized, uniformly shaped bioprosthetic ring has been implanted, transcatheter PV replacement is feasible, with low risk and good short- to intermediate-term success. Additionally, repeat valve-in-valve implants have been reported.³⁶

Despite their durability, mechanical prostheses have been avoided as treatment for right-sided valvular pathology, given a reported 25% to 80% incidence of thromboembolic complications.^{37,38} The increased risk of dysfunction may be related to the lower pressure gradients and blood velocities seen on the right side of the heart, as well as lack of diastolic run-off (coronary flow) that is present in the aortic

position. Inherent in use of these prostheses is the need for robust systemic anticoagulation, which currently requires warfarin; however, future antiplatelet agents and direct thrombin inhibitors may provide attractive alternatives.³⁹

Nonetheless, a subpopulation of patients has been identified, in whom mechanical valves may prove beneficial. Predominantly, these patients are either older and have had multiple previous sternotomies, already have an indication for anticoagulation, or have a PV annulus size that prevents future transcatheter valve implantation. Patients with concurrent significant RV dysfunction or who suffer from congestive heart failure are poor candidates for mechanical PV replacement.^{40,41}

Implicit in obtaining the optimal PV replacement are proper patient selection and well planned surgical technique. The conduct of the operation will be dictated by past surgical history and residual lesions. Reoperative sternotomy with preparation for possible peripheral cannulation is essential. Replacement of the PV can be performed on the beating heart, without residual septal defects. Appropriate valve sizing, prosthesis angulation, and roofing of the repair are factors in achieving the best long-term result.^{42,43} Although often incorporated into the procedure, excision of the outflow tract scar and RV remodeling have yet to show benefits.⁴⁴

Preservation of the integrity of the RV infundibulum–PV complex provides the best long-term outcome after repair of tetralogy of Fallot. Thus, use of strategies to reduce the incidence of PV insufficiency and RV injury at the time of initial repair of tetralogy of Fallot is prudent.^{45,46} When some degree of PV insufficiency is inevitable, close observation for RV dilatation, cardiac dysrhythmias, and reduced RV function is warranted. As valve replacement options continue to improve, earlier intervention may be warranted. Currently, implantation of a bioprosthesis with a uniformly shaped ring provides the best intermediate-term result. Transcatheter implants will likely reduce the number of surgical interventions needed during the lifetime of patients who have tetralogy of Fallot.

References

1. Kirklin JK, Kirklin JW, Blackstone EH, Milano A, Pacifico AD. Effect of transannular patching on outcome after repair of tetralogy of Fallot. *Ann Thorac Surg*. 1989;48:783-91.

2. d'Udekem Y, Pasquet A, Lebreux L, Ovaert C, Mascart F, Robert A, et al. Does right ventricular outflow tract damage play a role in the genesis of late right ventricular dilatation after tetralogy of Fallot repair? *Ann Thorac Surg.* 2003;76:555-61.
3. Geva T. Indications and timing of pulmonary valve replacement after tetralogy of Fallot repair. *Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu.* 2006;9:11-22.
4. Murphy JG, Bersh BJ, Mair DD, Fuster V, McGoon MD, Ilstrup DM, et al. Long-term outcome in patients undergoing surgical repair of tetralogy of Fallot. *N Engl J Med.* 1993;329:593-9.
5. Nollert B, Fishclein T, Bouterwek S, Bohmer C, Klinner W, Reichart B. Long-term survival in patients with repair of tetralogy of Fallot: 36-year follow up of 490 survivors of the first year after surgical repair. *J Am Coll Cardiol.* 1997;30:1374-83.
6. Tornos MP, Olona M, Permanyer-Miralda G, Evangelista A, Candell J, Padilla F, et al. Heart failure after aortic valve replacement for aortic regurgitation: prospective 20-year study. *Am Heart J.* 1998;136:681-7.
7. Taniguchi K, Kawamaoto T, Kuki S, Masai T, Mitsuno M, Nakano S, et al. Left ventricular myocardial remodeling and contractile state in chronic aortic regurgitation. *Clin Cardiol.* 2000;23:608-14.
8. Shimazaki Y, Blackstone EH, Kirklin JW. The natural history of isolated congenital pulmonary valve incompetence: surgical implications. *Thorac Cardiovasc Surg.* 1984;32:257-9.
9. Kuehne T, Saeed M, Gleason K, Turner D, Teitel D, Higgins CB, et al. Effects of pulmonary insufficiency on biventricular function in the developing heart of growing swine. *Circulation.* 2003;108:2007-13.
10. Therrien J, Provost Y, Merchant N, Williams W, Colman J, Webb G. Optimal timing for pulmonary valve replacement in adults after tetralogy of Fallot repair. *Am J Cardiol.* 2005;95:779-82.
11. Oosterhof T, van Straten A, Vliegen HW, Meijboom FJ, van Dijk AP, Spijkerboer AM, et al. Preoperative thresholds for pulmonary valve replacement in patients with corrected tetralogy of Fallot using cardiovascular magnetic resonance. *Circulation.* 2007;116:545-51.
12. Geva T. Repaired tetralogy of Fallot: the roles of cardiovascular magnetic resonance in evaluating pathophysiology and for pulmonary valve replacement decision support. *J Cardiovasc Magn Reson.* 2011;13:9-32.
13. Frigola A, Giamberti A, Chessa M, Di Donato M, Abella R, Foresti S, et al. Right ventricular restoration during pulmonary valve implantation in adults with congenital heart disease. *Eur J Cardiothorac Surg.* 2006;29(Suppl 1):S279-85.
14. Pijuan-Domenech A, Pineda V, Castro MA, Sureda-Barbosa C, Ribera A, Cruz LM, et al. Pulmonary valve replacement diminishes the presence of restrictive physiology and reduces atrial volumes: a prospective study in tetralogy of Fallot patients. *Int J Cardiol.* 2014;177:261-5.
15. Adamson L, Vohra HA, Haw MP. Does pulmonary valve replacement post repair of tetralogy of Fallot improve right ventricular function? *Interact Cardiovasc Thorac Surg.* 2009;9:520-7.
16. Discigil B, Dearani JA, Puga FJ, Schaff HV, Hagler DJ, Warnes CA, et al. Late pulmonary valve replacement after repair of tetralogy of Fallot. *J Thorac Cardiovasc Surg.* 2001;121:344-51.
17. Herrild DM, Berul C, Cecchin F, Geva T, Gauvreau K, Pigula F, et al. Pulmonary valve replacement in tetralogy of Fallot: impact on survival and ventricular tachycardia. *Circulation.* 2009;119:445-51.
18. Scherptong RW, Hazehamp MG, Mulder BJ, Wijers O, Swenne CA, van der Wall EE, et al. Follow-up after pulmonary valve replacement in adults with tetralogy of Fallot: association between QRS duration and outcome. *J Am Coll Cardiol.* 2010;56:1486-92.
19. Eyskens B, Reybrouck T, Bogaert J, Dymarkowsky S, Daenen W, Dumoulin M, et al. Homograft insertion for pulmonary regurgitation after repair of tetralogy of Fallot improves cardiorespiratory exercise performance. *Am J Cardiol.* 2000;85:221-5.
20. Rotes AS, Johnson JN, Burkhardt HM, Eidem BW, Allison TG, Driscoll DJ. Cardiorespiratory response to exercise before and after pulmonary valve replacement in patients with repaired tetralogy of Fallot: a retrospective study and systematic review of the literature. *Congenit Heart Dis.* 2015;10:263-70.
21. Kanter KR, Budde JM, Parks WJ, Tam VK, Sharma S, Williams WH, et al. One hundred pulmonary valve replacements in children after relief of right ventricular outflow tract obstruction. *Ann Thorac Surg.* 2002;73:1801-6.
22. Babu-Narayan SV, Diller GP, Gheta RR, Bastin AJ, Karonis T, Li W, et al. Clinical outcomes of surgical pulmonary valve replacement after repair of tetralogy of Fallot and potential prognostic value of preoperative cardiopulmonary exercise testing. *Circulation.* 2014;129:18-27.
23. Papadopoulos N, Esmaili A, Ziere A, Bakhtiar F, Ozaslan F, Moritz A. Secondary repair of incompetent pulmonary valves. *Ann Thorac Surg.* 2009;87:1879-84.
24. Mainwaring R, Pirolli T, Punnett R, Hanley F. Later repair of native pulmonary valve in patients with pulmonary insufficiency after surgery for tetralogy of Fallot. *Ann Thorac Surg.* 2012;93:677-9.
25. Park CS, Lee C-H, Lee YO, Kim BG, Kim JT, Kim JY. Pulmonary valve repair late after right ventricular outflow tract reconstruction in children and adolescents. *Interact Cardiovasc Thorac Surg.* 2010;10:906-9.
26. Mavroudis CD, Frost J, Mavroudis C. Pulmonary valve preservation and restoration for repair of tetralogy of Fallot. *Cardiol Young.* 2014;24:1088-94.
27. Pretre R, Rosser B, Mueller C, Kretschmar O, Dave H. Recycling of the pulmonary valve: an elegant solution for secondary pulmonary regurgitation in patients with tetralogy of Fallot. *Ann Thorac Surg.* 2012;94:850-3.
28. Brown JW, Ruzmetov M, Vijay P, Rodefeld MD, Turrentine MW. Right ventricular outflow tract reconstruction with a polytetrafluoroethylene monocusp valve: a twelve-year experience. *J Thorac Cardiovasc Surg.* 2007;133:1336-43.
29. Fiore AC, Rodefeld M, Turrentine M, Vijay P, Reynolds T, Standeven J, et al. Pulmonary valve replacement: a comparison of three biological valves. *Ann Thorac Surg.* 2008;85:1712-8.
30. Chiappini B, Barrea C, Rubay J. Right ventricular outflow tract reconstruction with contera monocuspid transannular patch in tetralogy of Fallot. *Ann Thorac Surg.* 2007;83:185-7.
31. Bando K, Danielson GK, Schaff HV, Mair DD, Julsrud MD, Puga FJ. Outcome of pulmonary and aortic homografts for right ventricular outflow tract obstruction. *J Thorac Cardiovasc Surg.* 1995;109:509-18.
32. Zugairi R, Malik S, Jaquiss RD, Imamura M, Gossett J, Morrow WR. Risk factors for prosthesis failure in pulmonary valve replacement. *Ann Thorac Surg.* 2011;91:561-5.
33. Zahn EV, Hellenbrand WE, Lock JE, McElhinney DB. Implantation of the Melody transcatheter pulmonary valve in patients with a dysfunctional right ventricular outflow tract conduit: early results from the US clinical trial. *J Am Coll Cardiol.* 2009;54:1722-9.
34. Malekzadeh-Milani S, Ladouceur M, Cohen S, Iserin L, Boudjemline Y. Results of transcatheter pulmonary valvulation in native or patched right ventricular outflow tracts. *Arch of Cardiovasc Dis.* 2014;107:592-8.
35. Bienacka EK, Ruzyllo W, Demkow M, Kowalski M, Spiewak M, Piotrowski W, et al. Transcatheter pulmonary valve implantation in patients with right ventricular outflow tract dysfunction: early and mid-term results. *J Invasive Cardiol.* 2015;27:E82-9.
36. McElhinney DB, Hellenbrand WE, Zahn EM, Jones TK, Cheatham JP, Lock JE, et al. Short and medium-term outcomes after transcatheter pulmonary valve placement in the expanded multicenter US Melody valve trial. *Circulation.* 2010;122:507-16.
37. Ilbawi MN, Lockhardt CG, Idress FS, DeLeon SY, Muster AJ, Duffy CE, et al. Experience with St. Jude medical valve prosthesis in children: a word of caution regarding right-sided placement. *J Thorac Cardiovasc Surg.* 1987;93:73-9.
38. Nurozler F, Bradley SM. St. Jude medical valve in pulmonary position: anticoagulation and thrombosis. *Asian Cardiovasc Thorac Ann.* 2002;10:181-3.
39. Squizzato A, Dentali F, Steidl L, Ageno W. New direct thrombin inhibitors. *Intern Emerg Med.* 2009;18:617-25.
40. Stulak JM, Dearani JA, Burkhardt HM, Connolly HM, Warnes CA, Suri RM, et al. The increasing use of mechanical pulmonary valve replacement over a 40-year period. *Ann Thorac Surg.* 2010;90:2009-15.
41. Freling HG, van Slooten YJ, van Melle JP, Ebels T, Hoendermis ES, Berger RF, et al. Pulmonary valve replacement: twenty-six years of experience with mechanical valvar prostheses. *Ann Thorac Surg.* 2015;99:905-10.
42. Karamlou T, Ungerleider RM, Alsoufi B, Burch G, Silvergach M, Reller M, et al. Oversizing pulmonary homograft conduits does not significantly decrease allograft failure in children. *Eur J Cardiothorac Surg.* 2005;27:548-53.
43. Kogon BE, Rodby KA, Kirshbom PM, Kanter KR, Lyle T, McConnell M, et al. Adult congenital pulmonary valve replacement: a simple, effective, and reproducible technique. *Congenit Heart Dis.* 2007;2:314-8.
44. Geva T, Gauvreau K, Powell AJ, Cecchin F, Rhodes J, Geva J, et al. Randomized trial of pulmonary valve replacement with and without right ventricular remodeling surgery. *Circulation.* 2010;122(11 Suppl):S201-8.
45. Bacha E. Valve-sparing options in tetralogy of Fallot surgery. *Semin Thorac Cardiovasc Surg Pediatr Card Surg Annu.* 2012;15:24-6.
46. Vida VL, Guariento A, Castaldi B, Sambugaro M, Patalino MA, Milanese O, et al. Evolving strategies for preserving the pulmonary valve during early repair of tetralogy of Fallot: mid-term results. *J Thorac Cardiovasc Surg.* 2014;147:687-96.