Aortic Valve Sparing Surgery: The Use of the Coroneo Extra-Aortic Annuloplasty Ring

Review Article

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Summary:

Ideal prosthetic aortic valve should maintain excellent hemodynamic characteristics that are sustainable during varying hemodynamic conditions and demands, have minimal trans-aortic pressure gradients, should be durable in the long term, resist thrombus formation without the need for anticoagulation and be straightforward to implant. Unfortunately, the ideal prosthetic aortic valve does not yet exist. This review critically evaluates available-to-the-surgeon options.Critical evaluation of relevant literature sources available on PubMed with the emphasis on current situation and new trend in the aortic valve sparing procedures. Current prosthetic devices are associated with complications such as valve thrombosis and thromboembolic events, bleeding events associated with anticoagulation use and structural valve deterioration. Therefore native valve disease is replaced by prosthetic valve disease. Aortic valve sparing operations were developed to preserve the native aortic valve during surgery for aortic root aneurysm and ascending aortic aneurysm with associated aortic insufficiency, circumventing complications arising from prosthetic valve implantation by preserving the native aortic valve apparatus. There are two fundamental types of aortic valve sparing procedures: remodelling of the aortic root and reimplantation of the aortic valve. Evidence based medicine shows that reimplantation of the aortic valve is in long term associated with lower risk of developing aortic insufficiency. An alternative standardized approach that combines an external subvalvular aortic prosthetic ring annuloplasty with remodelling technique was presented. Implantation of an external aortic ring provides a reproducible technique for aortic valve repair with great preliminary results.

Introduction:

Aortic valve sparing operations were refined in order to preserve the native aortic valve during surgery for the aortic root aneurysm and surgery for the ascending aortic aneurysm with associated aortic insufficiency. The aortic root is an ensemble consisting of distinct entities: the aortic valve leaflets, the leaflet attachments, the sinuses of Valsava, the interleaflet trigones, the sinotubular junction and the annulus. [1-3] It is a remarkably complex and sophisticated structure. [1] Every single constituent of the aortic root has an optimal macroscopic, microscopic structure and anatomical architecture which contributes to the function of the aortic root: intermittent, unidirectional channeling of large volumes of fluid while maintaining laminar flow, minimal resistance, the least possible tissue stress and damage during varying hemodynamic conditions and demands. [4-7] This synchronized dynamic behavior of all aortic root components has shown to be of a great importance for a specific flow characteristic, left ventricle function and coronary perfusion. [8-10] When any of the aortic root components fail, it is the recognition of the complexity of the structure that has led to the development and advancements in sparing surgical procedures that respect the fundamental anatomical existence of the individual parts of the aortic root. [11-14]

Historical aspects surgical techniques:

Aortic root aneurysm etiology is primarily related to the dystrophic disease. Aortic valve repair is performed in only 1.7% of the cases, versus 69% for mitral valve repair. [15, 16] Over the past two decades, there has been a significant paradigm shift towards the aortic valve sparing procedures over prosthetic valve replacement in suitable candidates. [17] Operations that preserve a patient's native valvular anatomy bring numerous benefits for patients. The most prominent one is the avoidance of life- long anticoagulation. [18, 19] The introduction of the composite graft procedure by Bentall in 1966 has become a gold standard for the treatment of aortic root aneurism and aortic valve regurgitation. [20] Until recently, composite valve and graft replacement was the only standard surgical approach for the aortic root

aneurysm. [21] From the early 1990s, valve sparing procedures have become a feasible alternative, in hope that they will result in improved survival rate and fewer valve related complications. [18, 22] Two original procedures were initially described as the 'remodeling' technique proposed by Yacoub: reduction of the sinotubular junction diameter and creation there neo-sinuses of Valsalva with a scalloped Dacron tube graft sutured in the supravalvular position. [23] The second alternative was proposed by David and Feindel: the 'reimplantation' of the aortic valve within a straight tube, reducing both the annulus and the sinotubular junction diameter while abolishing the sinuses of Valsalva , thus impairing root dynamics. [24] Over the time, modified procedures emerged from the original Yacoub's and David's techniques such as Van Son, Hopkins, Hetzer procedures and others. [25-27] These methods focus on the aortic root reconstruction and the reduction of dilated aortic root diameters in order to restore proper valve function. [28, 29] Comparative analysis of early and late results of the aortic root reconstruction with aortic valve sparing prosedures and the composite mechanical valve conduit replacement introduced by Bentall et al. was carried out, showing that the aortic root reconstruction has a low early and late mortality, a high survival free of complications and little need for reoperation. During the late follow-up, the aortic root reconstruction with preservation of the aortic valve showed a lower incidence of bleeding, thromboembolic events and endocarditis. [30, 31] Numerous surgical variations have aimed to incorporate preservation of the aortic root dynamics with the treatment of dilated native annulus. [32, 33] This multiplicity of aortic valve repair and sparing procedures resulted in a lack of standardization, limiting adoption of such procedures. [34] Additionally, most failures with valve sparing techniques are due to residual cusp prolapse, either as a primary unrecognized lesion or secondary to an induced prolapse after root reconstruction. [35, 36] Aortic annuloplasty combined with re-suspension of cusp effective height are key steps for a reproducible aortic valve repair. Schäffers et al. proposed to address this issue with a dedicated caliper in order to restore cusp effective height up to 8-10 mm. [34, 37, 38] Certain controversy remains between external or internal annuloplasty rings. [39, 40] Even though subvalvular plane in the right coronary sinus is easier reached with internal ring, endovascular placement may interfere with cusp

mobility and increase the risk for hemolytic or thromboembolic events. Advantage of ring placed externally is the avoidance of these complications, as well as limiting placing tension on the device fixation stitches that is caused by the expanding aorta. [42]

Dynamic anatomy:

In vitro and in vivo studies have documented that cusp motion and flow patterns across the reconstructed aortic root are more physiologic after remodeling of the aortic root rather than the reimplantation of the aortic valve, as well as after procedures using a prosthetic conduit fashioned with neo- sinuses of Valsalva than without. [41-43] Dynamic anatomy reports showed that the three-dimensional a sigmoid shape of the aortic annulus could be divided into two tow-dimensional planes: one at the base of the aortic annulus also called the ventriculo-aortic junction, and the one at the sinotubular junction. [44, 45] Dilatation of both of these diameters is characteristic for lesion of the aortic root aneurysm. These advances in dynamic anatomic knowledge led to the development of different valve- sparing procedures for the treatment of the aortic root aneurysm.

Current situation:

Lansac et al. proposed a standardized approach for aortic valve repair addressing both the aorta and the valve, associating physiological reconstruction of the aortic root according to the remodeling technique with the re-suspension of cusp effective height and an expansible subvalvular ring annuloplasty using expansible aortic ring in order to achieve a complete and calibrated annuloplasty in diastole, while maintaining systolic expansibility of the aortic root (Extra-Aortic ^{TM} ,CORONEO, Inc., Montreal, QC,

Canada). [46, 47] This solved a problem in the treatment of aortic root aneurism and the lack of a geometric annuloplasty ring to facilitate reconstruction of the aortic root that restores physiological annular size and geometry during aortic valve repair. Cusp coaptation height was increased, reducing the stress on the cusps, thus protecting the repair. [37] A multi-centric study analyzed preliminary results of this new physiological approach to aortic valve repair with subvalvular aortic ring annuloplasty. In this multi-centric study, unselected patients with aortic root aneurysms were enrolled consecutively, regardless of their aortic insufficiency grade, presence of bicuspid valve or complex valvular lesion. The addition of a subvalvular aortic ring was systematically performed in all cases to reduce the diameter of the native aortic annular base in diastole. The choice of the aortic ring and the tube graft was standardized, based on the criterion of intra- operative measurement of a native aortic annular size with the Heagar dilators. The diameter of the prosthetic aortic ring was undersized by one size to restore a normal STJ/annular base ratio of 1.2. [48] A calibrated expansible aortic ring annuloplasty (Extra-Aortic ™ ,CORONEO, Inc., Montreal, QC, Canada) in different sizes was developed in order to facilitate technical standardization. From the result of this multi-centric analysis showed that the aortic function remained stable in most patients. Among the 126 survivors without reoperation, 115 patients had aortic insufficiency < grade 2 (91.3%) at the end of the follow up. Freedom of aortic regurgitation of grade II or more was 87.7% at 3 years (95%, Cl: 80.3-95.1%). [49]

Conclusion:

Aortic valve sparing operations that treat patients with aortic root aneurysm with or without aortic insufficiency and patients with ascending aortic aneurysm and aortic insufficiency are no longer experimental and unproved procedures. A successful aortic valve sparing or repair operation aims not only to correct the failing part of the aortic root, but also to restore the intra and inter component relationship of the aortic root elements to optimal dimensions and relations. The avoidance of

anticoagulation and prosthesis- related complications makes aortic valve repair a tempting procedure. [18, 19] Considering the growing rate of cusp repair reported in the literature, conservative aortic valve surgery seems to be developing into aortic valve repair surgery. [50-53] Expansible aortic ring (Extra-Aortic ™ ,CORONEO, Inc., Montreal, QC, Canada) was being implanted in an unselected population of patients with aortic root aneurysms enrolled in prospective multicentrice CAVIAAR trial (CAVIAAR, Conservative Aortic Valve surgery for aortic Insufficiency and Aneurysm of the Aortic Root)**.** A standardized management of dystrophic aortic roots towards a physiological approach to valve repair might improve long term durability of the results. However, the need remains for reliable long term data comparing valve replacement and valve repair procedures, thus limiting the widespread adoption of this procedure. An international multicentre registry of the aortic valve repair will play a key role to clarify and standardize the place of repair in the aortic valve surgery. AVIATOR (Aortic Valve insufficiency and ascending aorta aneurysm International Registry) is a prospective multicentre registry that shall provide us with the necessary answers in the future.

References:

1. Sievers HH, Hemmer W, Beyersdorf F, Moritz A, Moosdorf R, Lichtenberg, et al., The everyday used nomenclature of the aortic root components: the tower of Babel? Working Group for AorticValve Surgery of German Society of Thoracic and Cardiovascular Surgery. Eur J Cardiothorac Surg. 2012 Mar;41(3):478-82. doi: 10.1093/ejcts/ezr093. Epub 2011 Dec 1

2. Loukas M, Bilinsky E, Bilinsky S, Blaak C, Tubbs RS, Anderson RH. The anatomy of the aortic root.,Clin Anat. 2013 Sep 2. doi: 10.1002/ca.22295.

3. Frater RW, Anderson RH. How can we logically describe the components of the arterial valves?, J Heart Valve Dis. 2010 Jul;19(4):438-40

4. Misfeld M, Sievers HH. Heart valve macro- and microstructure, Philos Trans R Soc Lond B Biol Sci. 2007 Aug 29; 362(1484):1421-36

5. Yacoub MH, Cohn LH , Novel approaches to cardiac valve repair: from structure to function: Part II. Circulation. 2004 Mar 9; 109(9):1064-72

6. Yacoub MH, Kilner PJ, Birks EJ, Misfeld M. The aortic outflow and root: a tale of dynamism and crosstalk. Ann Thorac Surg. 1999 Sep;68(3 Suppl):S37-43.

7. Thubrikar M, Skinner JR, Aouad J, Finkelmeier BA, Nolan SP.Analysis of the design and dynamics of aortic bioprostheses in vivo. J Thorac Cardiovasc Surg. 1982 Aug;84(2):282-90.

8. Hose DR, Narracott AJ, Penrose JM, Baguley D, Jones IP, Lawford PV .Fundamental mechanics of aortic heart valve closure..J Biomech. 2006; 39 (5):958-67.

9. Bellhouse BJ, Bellhouse FH, Reid KG. Fluid mechanics of the aortic root with application to coronary flow. Nature. 1968 Sep 7; 219(5158):1059-61

10. Sturla F, Votta E, Stevanella M, Conti CA, Redaelli A. Impact of modeling fluid-structure interaction in the computational analysis faortic root biomechanics. Med Eng Phys. 2013 Dec; 35(12):1721-30. doi: 10.1016/j.medengphy.2013.07.015. Epub 2013 Sep 1.

11. Izumoto H. Aortic valve repair for aortic insufficiency in adults: a contemporary review and comparison with replacement techniques. Eur J Cardiothorac Surg. 2006 May;29(5):854; author reply 854-5. Epub 2006 Mar 7.

12. Gleason TG. Current perspective on aortic valve repair and valve-sparing aorticroot replacement. Semin Thorac Cardiovasc Surg. 2006 Summer; 18(2):154-64

13. Miller DC. Valve-sparing aortic root replacement: current state of the art and where are we headed? Ann Thorac Surg. 2007 Feb; 83(2):S736-9; discussion S785-90

14. Svensson LG, Deglurkar I, Ung J, Pettersson G, Gillinov AM, D'Agostino RS et al. Aortic valve repair and root preservation by remodeling,reimplantation, and tailoring: technical aspects and early outcome. J Card Surg. 2007 Nov-Dec; 22(6):473-9.

15. Iung B, Baron G, Butchart EG, Delahaye F, Gohlke-Bärwolf C, Levang OW, et al. A prospective survey of patients with valvular heart disease in Europe: The Euro Heart Survey on Valvular Heart Disease. Eur Heart J. 2003 Jul; 24(13):1231-43

16. Gammie JS, Sheng S, Griffith BP, Peterson ED, Rankin JS, O'Brien SM, et al. Trends in mitral valve surgery in the United States: results from the Society of Thoracic Surgeons Adult Cardiac Surgery Database. Ann Thorac Surg. 2009 May;87(5):1431-7; discussion 1437-9. doi: 10.1016/j.athoracsur.2009.01.064.

17. Rankin JS, Gaca JG. Techniques of aortic valve repair. Innovations (Phila). 2011 Nov;6(6):348-54. doi: 10.1097/IMI.0b013e31824641d7

18. Tian D, Rahnavardi M, Yan TD. Aortic valve sparing operations in aortic root aneurysms: remodeling or reimplantation? Ann Cardiothorac Surg. 2013 Jan;2(1):44-52. doi: 10.3978/j.issn.2225-319X.2013.01.14

19. Aicher D, Fries R, Rodionycheva S, Schmidt K, Langer F, Schäfers HJ. Aortic valve repair leads to a low incidence of valve-related complications. Eur J Cardiothorac Surg. 2010 Jan; 37(1):127-32. doi: 10.1016/j.ejcts.2009.06.021. Epub 2009 Jul 29

20. Bentall H, De Bonno A., A technique for complete replacement of the ascending aorta. Thorax 1968, 23:338-9

21. Iung B, Baron G, Butchart EG, Delahaye F, Gohlke-Bärwolf C, Levang OW, et al. A prospective survey of patients with valvular heart disease in Europe: The Euro HeartSurvey on Valvular Heart Disease. Eur Heart J. 2003 Jul;24(13):1231-43.

22. Lansac E, Di Centa I, Bonnet N, Leprince P, Rama A, Acar C, et al. Aortic prosthetic ring annuloplasty: a useful adjunct to a standardized aortic valve-sparing procedure? Eur J Cardiothorac Surg. 2006 Apr; 29(4):537-44. Epub 2006 Feb 2423

23. Yacoub M, Fagan A, Stassano P, Radley-Smith R. Result of valve conserving operations for aortic regurgitation [abstract]. Circulation 1983; 68 (Sup-pl.): III 321

24. David TE, Feindel CM. An aortic valve-sparing operation for patients with aortic incompetence and aneurysm of the ascending aorta. J Thorac Cardiovasc Surg. 1992 Apr; 103(4):617-21; discussion 622

25. Van Son JA, Battellini R, Mierzwa M, Walther T, Autschbach R, Mohr FW. Aortic root reconstruction with preservation of native aortic valve and sinuses in aortic root dilatation with aortic regurgitation. J Thorac Cardiovasc Surg. 1999 Jun;117(6):1151-6.

26. Hopkins RA. Aortic valve leaflet sparing and salvage surgery: evolution of techniques for aortic root reconstruction.. Eur J Cardiothorac Surg. 2003 Dec;24(6):886-97.

27. Hetzer R, Komoda S, Komoda T. Remodeling of aortic root by annular reconstruction and plication of sinuses of Valsalva. J Card Surg. 2008 Jan-Feb;23(1):49-51. doi: 10.1111/j.1540-8191.2007.00505.x.

28. Yacoub MH, Gehle P, Chandrasekaran V, Birks EJ, Child A, Radley-Smith R. Late results of a valve-preserving operation in patients with aneurysms of the ascending aorta and root. J Thorac Cardiovasc Surg. 1998 May;115(5):1080-90.

29. David TE, Armstrong S, Maganti M, Colman J, Bradley TJ. Long-term results of aortic valve-sparing operations in patients with Marfan syndrome. J Thorac Cardiovasc Surg. 2009 Oct;138(4):859-64; discussion 863-4. doi: 10.1016/j.jtcvs.2009.06.014. Epub 2009 Aug 3.

30. Dias RR, Mejia OA, Fiorelli AI, Pomerantzeff PM, Dias AR, Mady C, et al.
Analysis of aortic root surgery with composite mechanical aortic valve conduit andvalve-sparing reconstruction. Rev Bras Cir Cardiovasc. 2010 Oct-Dec;25(4):491-9.

31. Fattouch K, Murana G, Castrovinci S, Nasso G, Mossuto C, Corrado E, et al. Outcomes of aortic valve repair according to valve morphology and surgical techniques. Interact Cardiovasc Thorac Surg. 2012 Oct;15(4):644-50. Epub 2012 Jul 3.

32. Svensson LG, Cooper M, Batizy LH, Nowicki ER.
Simplified david reimplantation with reduction of anular size and creation of artificial sinuses. Ann Thorac Surg. 2010 May;89(5):1443-7. doi: 10.1016/j.athoracsur.2010.01.058.

33. Bakhtiary F, Monsefi N, Trendafilow M, Wittlinger T, Doss M, Moritz A. Modification of the David procedure for reconstruction of incompetent bicuspid aorticvalves. Ann Thorac Surg. 2009 Dec;88(6):2047-9. doi: 10.1016/j.athoracsur.2009.02.100.

34. Iung B, Baron G, Butchart EG, Delahaye F, Gohlke-Bärwolf C, Levang OW, et al. A prospective survey of patients with valvular heart disease in Europe: The Euro HeartSurvey on Valvular Heart Disease. Eur Heart J. 2003 Jul;24(13):1231-43.

35. Kunihara T, Aicher D, Rodionycheva S, Groesdonk HV, Langer F, Sata F, et al. Preoperative aortic root geometry and postoperative cusp configuration primarily determine long-term outcome after valve-preserving aortic root repair. J Thorac Cardiovasc Surg. 2012 Jun;143(6):1389-95. doi: 10.1016/j.jtcvs.2011.07.036. Epub 2011 Sep 8.

36. le Polain de Waroux JB, Pouleur AC, Robert A, Pasquet A, Gerber BL, Noirhomme P, et al. Mechanisms of recurrent aortic regurgitation after aortic valve repair: predictive value of intraoperative transesophageal echocardiography. JACC Cardiovasc Imaging. 2009 Aug;2(8):931-9. doi: 10.1016/j.jcmg.2009.04.013.

37. Bierbach BO, Aicher D, Issa OA, Bomberg H, Gräber S, Glombitza P, et al. Aortic root and cusp configuration determine aortic valve function. Eur J Cardiothorac Surg. 2010 Oct;38(4):400-6. doi: 10.1016/j.ejcts.2010.01.060. Epub 2010 Mar 12.

38. Schäfers HJ, Bierbach B, Aicher D. A new approach to the assessment of aortic cusp geometry. J Thorac Cardiovasc Surg. 2006 Aug;132(2):436-8.

39. Schäfers HJ. Aortic annuloplasty: a new aspect of aortic valve repair. Eur J Cardiothorac Surg. 2012 May;41(5):1124-5. doi: 10.1093/ejcts/ezr284. Epub 2012 Jan 26.

40. de Kerchove L, Vismara R, Mangini A, Fiore GB, Price J, Noirhomme P, et al. In vitro comparison of three techniques for ventriculo-aortic junction annuloplasty. Eur J Cardiothorac Surg. 2012 May;41(5):1117-23; discussion 1123-4. doi: 10.1093/ejcts/ezr237. Epub 2012 Jan 6.

41. Fries R, Graeter T, Aicher D, Reul H, Schmitz C, Böhm M, et al. In vitro comparison of aortic valve movement after valve-preserving aortic replacement. J Thorac Cardiovasc Surg. 2006 Jul;132(1):32-7.

42. Soncini M, Votta E, Zinicchino S, Burrone V, Mangini A, Lemma M, et al. Aortic root performance after valve sparing procedure: a comparative finite element analysis. Med Eng Phys. 2009 Mar;31(2):234-43. doi: 10.1016/j.medengphy.2008.07.009. Epub 2008 Sep 10.

43. Hanke T, Charitos EI, Stierle U, Robinson D, Gorski A, Sievers HH, et al. Factors associated with the development of aortic valve regurgitation over time after twodifferent techniques of valve-sparing aortic root surgery. J Thorac Cardiovasc Surg. 2009 Feb;137(2):314-9. doi: 10.1016/j.jtcvs.2008.08.006. Epub 2008 Dec 19.

44. Anderson RH, Devine WA, Ho SY, Smith A, McKay R. The myth of the aortic annulus: the anatomy of the subaortic outflow tract. Ann Thorac Surg. 1991 Sep;52(3):640-6.

45. Lansac E, Lim HS, Shomura Y, Lim KH, Rice NT, Goetz W, et al. A four-dimensional study of the aortic root dynamics. Eur J Cardiothorac Surg. 2002 Oct;22(4):497-503

46. Lansac E, Di Centa I, Vojacek J, Nijs J, Hlubocky J, Mecozzi G, et al. Valve sparing root replacement: the remodeling technique with external ring annuloplasty. Ann Cardiothorac Surg. 2013 Jan;2(1):117-23. doi: 10.3978/j.issn.2225-319X.2013.01.15.

47. Lansac E, Di Centa I, Raoux F, Bulman-Fleming N, Ranga A, Abed A, et al. An expansible aortic ring for a physiological approach to conservative aortic valve surgery. J Thorac Cardiovasc Surg. 2009 Sep;138(3):718-24. doi: 10.1016/j.jtcvs.2009.05.024.

48. Lansac E, Di Centa I, Raoux F, Al Attar N, Acar C, Joudinaud T, et al. A lesional classification to standardize surgical management of aortic insufficiency towards valve repair. Eur J Cardiothorac Surg. 2008 May;33(5):872-8; discussion 878-80. doi: 10.1016/j.ejcts.2007.12.033. Epub 2008 Feb 6

49. Lansac E, Di Centa I, Sleilaty G, Bouchot O, Arnaud Crozat E, Blin D, et al. An aortic ring to standardise aortic valve repair: preliminary results of a prospective multicentric cohort of 144 patients. Eur J Cardiothorac Surg. 2010 Aug;38(2):147-54. doi: 10.1016/j.ejcts.2010.01.041. Epub 2010 Mar 7.

50. de Kerchove L, Boodhwani M, Glineur D, Poncelet A, Verhelst R, Astarci P, et al. Effects of preoperative aortic insufficiency on outcome after aortic valve-sparing surgery. Circulation. 2009 Sep 15;120(11 Suppl):S120-6. doi: 10.1161/CIRCULATIONAHA.108.841445.

51. David TE, Armstrong S. Aortic cusp repair with Gore-Tex sutures during aortic valve-sparing operations. J Thorac Cardiovasc Surg. 2010 May;139(5):1340-2. doi: 10.1016/j.jtcvs.2009.06.010. Epub 2009 Jul 17.

52. Aicher D, Langer F, Adam O, Tscholl D, Lausberg H, Schäfers HJ. Cusp repair in aortic valve reconstruction: does the technique affect stability?. J Thorac Cardiovasc Surg. 2007 Dec;134(6):1533-8; discussion 1538-9. Epub 2007 Oct 26.

53. Schäfers HJ, Langer F, Glombitza P, Kunihara T, Fries R, Aicher D. Aortic valve reconstruction in myxomatous degeneration of aortic valves: are fenestrations a risk factor for repair failure? J Thorac Cardiovasc Surg. 2010 Mar;139(3):660-4. doi: 10.1016/j.jtcvs.2009.06.025. Epub 2009 Aug 18.

