Surgical Management of Small Aortic Root

Ghavidel A. A. M.D.

Shahid Rajaee Heart Center

Abstract

A common goal of Heart valve replacement is to prevent or cure symptoms of heart failure and decrease the likelihood of heart failure-related death. Complete abolition of transvalvular gradients is not possible because of the obstructive effects of the prosthetic valve stents and sewing ring. Aortic valve replacement (AVR) in the patients with small aortic annulus is a challenging procedure and is not an uncommon surgical problem. Sever patient-prosthetic mismatch is a predictor of higher long-term mortality and congestive heart failure. For patients undergoing AVR who are at risk of sever mismatch, every effort should be made to use a larger prosthesis or to consider a prosthesis with a larger effective orifice area. Valve selection for the small aortic root is a multi-factorial process. These factors include patient age, lifestyle, pregnancy status, drug compliance, EOA of prosthetic valve, availability of prosthesis, experience & skill of surgeon.

Introduction

The overall goal of aortic valve replacement is to reduce the pressure and volume overload on the left ventricle (LV) thereby helping the remodeling process of the ventricle. However when the aortic root is small these goals may be difficult to achieve.[1,2,5]

At what stage we consider the aortic root to be small is a mater of controversy. Different definitions have been suggested, for instance a diameter of less than 21 mm has been used to describe absolute small valve size.[5] However, to be more precise, many authors have used the term prosthetic-patient mismatch (PPM) to define small aortic root. This term itself has many definitions:[1,3,4,5,9]

1. Peak gradient of more then 30 mmHg across the valve
2. Increased gradient during exercise
3. Prosthetic valve cross sectional area (CSA) less than patient's own valve CSA
4. Internal diameter of the prosthetic valve relative to body surface area (BSA) of less than 10 mm/m2
5. Indexed effective orifice area (iEOA) less than 90th percentile

The most popular and applied definition however, has been iEOA of less than 0.85. Use of different definitions in clinical research has resulted in different conclusions for the same question and has made comparison difficult.

Definition of effective orifice area (EOA)

This is usually measured using echocardiography techniques using continuity equation using the following formula:

$$EOA = (CSA_{LVOT}.TVI_{LVOT}) / TVI_{AO}$$

Where: EOA is effective orifice area in cm2 , CSA LVOT is the cross sectional area of the left ventricular outflow in cm2 determined by two-dimensional measurement of LVOT diameter, TVI LVOT is the velocity time integral of forward blood flow in cm derived from pulse-wave Doppler in the LVOT,and TVI AO is the velocity time integral across the aortic valve derived from software integration of transvalvular continuous wave Doppler.

EOA is divided to BSA (Body Surface Area in) to obtain indexed EOA (iEOA).

Prosthetic-patient mismatch affects LV function and therefore patient's original symptoms may not be alleviated. This has adverse effects on the patient's quality of life. For every 1.0 mmHg increase in trans-aortic gradient, the risk of LV dysfunction and heart failure will increase by 1.03 times.[2,3,6]

When the PPM is defined as iEOA of less than 0.8, this on its own is a factor for developing LV dysfunction and heart failure.[1,2] However this does not apply if the definition is changed to an iEOA of less than 0.85. One study has shown that by considering an iEOA of less than 0.75 in patients less than 60 years of age as PPM then there is a significant risk of heart failure in this age group but not in those older than 60 years who might not be as active.[40] When BSA is less than 1.7 m2, an EOA of less than 0.75 is not important, while the reverse is true for patients with BSA of more than 1.7 m2.[3,5,6,40]

PPM and effect on survival

The effect of PPM on survival is a mater of controversy. In 1997 Pibarot & his colleagues reviewed 72 patients after AVR. Using iEOA of less than 0.85 as PPM he did not find any significant difference in survival of patients with or without PPM. However he showed that patients with PPM were in higher NYHA classification.[2,6,7] In a meta-analysis of 1300 patients comparing patients with and without PPM, those with small aortic valve prosthesis had higher operative risk (1.0%). However there was no difference in mid- and long-term survival.[8,38] The conclusion appears to be; although PPM seems not to affect long-term mortality, it certainly increases morbidity of these patients.

Surgical options

There are two approaches to the problem of small aortic root during aortic valve replacement:

1. Choosing valve device of appropriate size
2. Aortic root enlargement

In reality none of the artificial valves available are ideal. All the stented biologic or prosthetic valves used today reduce the aortic EOA to some degree. [6,9]It seems that for patients with small aortic root the ideal choice is aortic homograft (or pulmonary autograft) implantation.[5,6] These have excellent hemodynamic performance and do not reduce the diameter of the aortic root significantly. However for those patients with severely calcified and non-compliant aortic root, and those younger than 20 years of age use of aortic homograft is contraindicated.[2,6,9] Aortic root of larger than 30 mm is also a relative contraindication.[9]

Methods of allograft implantation:

Subcoronary implantation is the most frequent method used, and approximately 57% of aortic allograft implantations are done using this method.[9] In this technique the valve is implanted using two rows of suture lines. The valve is first placed down using three stay sutures. The valve is then sutured to the annulus with either continuous or interrupted sutures. A second row of sutures secures the valve to the aortic wall. Some surgeons prefer to preserve the non-coronary sinus. The aortic allograft can also be implanted as a full root replacement or inclusion cylinder.[6,9,10] As the occurrence of patient-prosthetic mismatch is rare in total root replacements, and the implantation procedure dos not increase the operative risk ,the recommendation is made to consider this implantation technique if a small projected IEOA is expected [11]

One of the advantages of allograft is in the surgical management of aortic valve endocarditis with aortic root abscess formation. Using aortic allograft the infected areas can be resected and at the same time repaired. The operative results of allograft implantation in the aortic position is good (table 1), however one of the problems with these devices is gradual structural deterioration and especially the occurrence of aortic regurgitation. The re-operation rate at 20 years is reported to be 70%.[5,6,9,15]

Pulmonary autograft

Pulmonary autograft may be used in patients with small aortic root. This is especially useful for young patients who are yet to grow and are active and athletic. It is the only device that has been shown to grow with time. It has an excellent hemodynamics with a

Table 1: Long-term results of allograft implantation in aortic position.

Hospital mortality	4-7 %
5 year survival	84-91%
Freedom from Structural degeneration	80-94% at 5 yr. 19-32% at 20 yr.
Freedom from Re-operation	38-50% at 20 yr

transvalvular mean gradient of less than 3.0 mmHg. However the surgical procedure is more complex and it requires implantation of a homograft in the pulmonary circulation. In addition, the re-operation rate is also relatively high.[5,9.17]

The only absolute contraindication for use of pulmonary autograft is pulmonary regurgitation. The relative contraindications to this procedure include COPD, ESRD, Marfan syndrome and coronary artery anomalies. The hospital mortality and long term survival after this procedure usually is satisfactory. The other problem after this operation is with the homograft placed in the right side of the heart. According to published data the incidence of homograft incompetence and stenosis may reach 9.5% and 30% respectively (table 2).[5,15.16,18,20]

Table 2: *Early & late results of Ross operation (pulmonary autograft)*

Hospital mortality:	0 – 1.7%
Valve related late death:	1.7- 3 %
Early autograft dysfunction:	1.5%
Homograft insufficiency:	9.5%
Homograft stenosis:	24-30%
Trivial neo aortic insufficiency:	53%
Mild to moderate insufficiency:	3%
Redo AVR:	1.5%

Stentless bioprosthetic valves

Another option in dealing with small aortic root is using Stentless bioprostheses which are considered as the third generation valves.

These include: Edward lifescience prima plus, Aorthec free sewn, Medtronic freestyle and Cryolife O'Brien, which can be inserted both using subcoronary position or as a full root replacement. Valves such as Sorin Pericarbon, Biocor PSB/SJM and St. Jude Toronto SPV may be inserted only by subcoronary technique. [5,9,10,12,14]

The St.Jude Toronto SPV valve is prepared from the porcine aortic root combined with a polyester mesh. It is gluteraldehyde fixed at zero pressure. 85% of these valves are free of degeneration at 9 years.[9,10,15]

The second valve depicted in is the freestyle valve manufactured by the Medtronic Hall Company. Its advantage over the Toronto valve is that it can be inserted as a full root. In order to decrease the incidence of leaflet calcification this valve is treated with amino-oleic acid. The 9 year degeneration free rate of this valve is also 85%.[5,9,12,13]

Overally, stentless valves result in significant increase in survival compared to stented valves (5 times better).[5,10,14] One reason is a better hemodynamic profile of these devices. The mean gradient across these valves is less than 10 mmHg. Their EOA is such that even in small aortic root (19 mm) they function adequately without resorting to additional surgical procedures.

The full root technique results in significantly less aortic incompetence compared to subcoronary technique. In fact in total root replacement the EOA is also larger. Therefore in patients with small aortic root, it is logical to use the full root method. However this technique is more demanding than the subcoronary insertion. [10,11,13,14]

In patients with small aortic root and left ventricular dysfunction, using stentless valves despite increasing the operative time is more beneficial and results in improved LVEF.[5,10]

New generation mechanical valves :

The new generation mechanical valves like St. Jude

Table 3: Comparison of Geometric areas between Carbomedics & St.Jude aortic prosthetic valves.

Valve type/ size	19 mm	21 mm
St. Jude (Standard)	1.21 cm2	1.81 cm2
St. Jude (Regent type)	1.6 cm2	2.0 cm2
Carbomedics (Classic)	1.12 cm2	1.66 cm2
Carbomedics (Top Hat)	1.59 cm2	2.07 cm2

HP and Regent valves, or Carbomedics R-series and Top Hat allow insertion of a valve with a larger EOA despite same external diameter.

Geometric orifice area

Geometrical analysis has revealed that the orifice area of Carbomedics Top Hat aortic valve is approximately the same as St. Jude Regent valve. (Table 3).

On the other hand, the function of size 19 St. Jude HP valve is at least the same as the standard St. Jude size 21 valve, and in fact the former valve has better hemodynamics and peak transvalvular gradient. [22, 23, 26, 27, 30, 31] Therefore if one has to use a valve size less than 21 mm, it is prudent to use the new generation devices.

Table 4 compares the mean and peak gradients of standard St. Jude and HP valve. The mean gradient of HP valves is approximately 10mmHg lower.[24,25,35]

The clinical as well as hemodynamics results with the Regent valve have been excellent. The long term result with this valve is still awaited but the LV mass regression six months after insertion of this valve has been significant (from 169 g/m2 to 137.2 g/m2, P<0.001). Table 5 shows the hemodynamic characteristics of the St. Jude Regent valve.[21,28,29,30,35,38]

The Top Hat Carbomedics aortic valve sits in the supra-annular position. It is important to size this valve carefully such that the height of the sewing ring does not obstruct the coronary ostia. We should use the specific sizing set of Top Hat Carbomedics aortic valve to achieve proper prosthetic valve size.[32,35,38,42,46]

In a study of patients whose aortic root was meseaured as 19mm, it has been demonstrated that St. Jude Regent and Sorin bicarbon valves have better in vivo hemodynamics than other valves such as On-X 19mm, Carbomedics Top Hat 21 mm and ATS 18 mm. The other advantage of Sorin bicarbon valves was less regurgitant volume, while St. Jude Regent and ATS valves had the largest regurgitant volume. However, this difference does not have significant importance clinically.[21,22,24,25,26,28,29]

Table 4: Comparison of trans-valvular gradients at rest and exercise between Standard type & hemodynamic plus type of St. Jude Medical bioprosthetic heart valve.

	St. Jude 19 HP	St. Jude 21 SD
MG at rest (mmHg)	8	9.5
PG at rest (mmHg)	15.4	19.1
MG at stress (mmHg)	12.9	16.5
PG at stress (mmHg)	28	35.3

Techniques of Aortic Root Enlargement

There are two main approaches to aortic root enlargement procedures:

1. Anterior approach

Table 5: Hemodynamic & Geometric characteristics of Regent type St. Jude medical heart valve.

	19 mm	21mm	23 mm
Mean Gradient (mmHg)	13.8	7.4	5.4
EOA (cm2)	1.6	2	2.2

2. Posterior approach

Anterior approach

Rastan-Konno operation is the main anterior approach for enlarging the aortic root and relief of complex subaortic stenosis .In this procedure the aorta is opened longitudinally and the incision is continued to the RVOT. Next, the interventricular septum is incised from lateral to the right coronary ostium and continued if necessary to the anterior papillary muscle. The defect in the septum is repaired using a separate patch. The aortic annulus is then repaired and the valve of appropriate size inserted. A second patch is used to repair the RVOT.[5,9,65]

The Rastan-Konno operation is used in cases of complex subaortic stenosis. It is also used in patients with small aortic root or who are in need of re-operation. This procedure, however, has a higher mortality and morbidity compared to other techniques (8 to 34%). Although the 10 to 15 years survival after this operation is reported to be 93% and 85% respectively, we emphasize that this complex procedure should be considered as a last surgical option in patient who had only small aortic annulus size with normal subaortic portion.[65]

Ross-Konno procedure is an alternative technique used in young growing patients with complex subaortic stenosis who also have abnormal aortic valve and hence need valve replacement.[9] In this operation only one patch is used which is the anterior wall of the pulmonary autograft. The limitations of this procedure are same as the Ross operation.

Posterior approach

The Nick's method of aortic root enlargement was devised by Dr. Nick in 1977. In this technique the aortotomy is continued to the aortic annulus and crosses the middle of the non-coronary cusp. The other is the Manouguian method which is an alteration of the Nick's technique. In this procedure the aortotomy incision is extended through the commissure between the non- and the left coronary cusps. The defect created is enlarged using a patch and if necessary the incision can be extended up to 2 cm into the anterior mitral leaflet. Using these techniques the aortic diameter and circumference may be enlarged by up to 5 mm and 20mm respectively. Therefore a valve device of 2 size larger can be used and the gradient may be reduced to a maximum of 18 mmHg.[9,54,55,56,57,58]

It appears that posterior aortic root enlargement is a better option than inserting a size 19 standard prosthetic aortic valve. Although there is no difference in the hospital mortality rate but the 10 year survival is better in those whose aortic root is enlarged. [59,63] The disadvantage of the posterior technique is the occurrence of mitral regurgitation which occurs in as many as 14% of patients. However mitral valve replacement in this group of patients is rare.[59,60,61,62]

Lastly we would mention the left ventricular apico-abdominal aortic valved conduit placement. This operation may be performed only in patients with small aortic root with prosthetic valve malfunction who have undergone several operations but have no prosthetic valve regurgitation.[5,9]

Summary

In summary, in patients with small aortic root, the factors affecting our decision in choosing the type of procedure and device include; age, BSA, patient's life style, drugs compliance, pregnancy status and other illnesses. For the surgeon, his own abilities, type of device available and the device effective orifice area are important issues.[9,50]

Generally it is advised that the valve used should have an iEOA of at least 0.75 cm2/m2 and in fact the gold standard is an iEOA > or = to 0.85.[2,5,6,9,53,54]

The new generation prosthetic valves and stentless bioprostheses are adequate even when the aortic annulus is 19 mm in diameter. For patients with BSA of less than 1.6 m2 using size 19 St. Jude HP or Regent valve is quite acceptable, however they still can be used for those with BSA of less than 1.8 m2. [3, 6, 21, 32, 34, 37, 38] The 19 mm standard st.jude aortic valve is only appropriate for small patients, such as women with BSA of less than 1.47 m2 and men with BSA of less than 1.6 m2.[42,49,52]

When using stentless valves, it is advisable to use the total root replacement technique since it has better

long-term outcome with no added operative risk over the subcoronary technique.[9,10,11,14,15,48,64]

Lastly it seems that if the above techniques cannot be used, the surgeon has no option but to enlarge the aortic root in order to improve the hemodynamic status , relive the LVOT obstruction adequately and achieve the maximum LV mass regression in the future. [31,33,36,40,51,52,64] In this situation the posterior root enlargement techniques are both safer and easier to perform.

At the end it is apt to mention that in children and growing adults the Ross or Ross-Konno procedure are preferable to other options.

Acknowledgment

I would like to thank Dr Hossein Javadpour for editing this manuscript.

References

1. Penta de Peppo A, et al." Small functional size after mechanical aortic valve replacement: No risk in young to middle-age patients".Ann Thorac Surg 2005;79:1915-20.

2. Ruel M, et al."Late incidence & predictors of persistent or recurrent heart failure in patients with aortic prosthetic valves".J Thorac & Cardiovasc Surg 2004;127:149-56.

3. Rao V, et al." Prosthesis-patient mismatch affect survival after aortic valve replacement".Circulation 2000; 102:3-7.

4. Hanayama N, et al."Patient prosthesis mismatch is rare after aortic valve replacement: valve size may be irrelevant". Ann Thorac Surg 2002:73:1822-28.

5. Cohn L, Edmunds H," Cardiac surgery in the adult". Mc Graw Hill 2003 2th ed Chap 32 & 34.

6.Pibarot P, et al."Impact of prosthesis patient mismatch on hemodynamic & symptomatic status, morbidity and mortality after aortic valve replacement with a bioprosthetic heart valve". J Heart Valve Dis 1998;7:211-8.

7. Pibarot P, et al." Patient -prosthesis mismatch can be predicted at the time of operation". Ann Thorac Surg. 2001; 71: S265-268.

8. Pibarot P, et al." The effect of prosthesis-patient mismatch on aortic bioprosthesis valve hemodynamic performance and patient clinical status". Can J Cardiol. 1996; 12 :379-387.

9. Kouchoukos N, et al." Cardiac surgery". Churchill Livingston 2003 3th ed chap 12.

10. Matsue H, et al." Mid-term results of freestyle aortic stentless bioprosthetic valve:clinical impact of quantitative analysis of in-vivo flow velocity by MRI". J Heart Valve Dis 2005;14(5):630-6.

11. Ennker J, et al."Stentless bioprostheses in small aortic root: impact of p-p mismatch on survival & quality of life".J Heart Valve Dis 2005;14(4):523-30.

12. Bach DS, et al." Eight year results after aortic valve replacement with the freestyle stentless bioprosthesis". J Thorac Cardiovasc Surg 2004;127:1657-63.

13. Botzenhardt F, et al." Hemodynamic comparison of bioprostheses for complete supra-annular position in patients with small aortic annulus". J Am Coll Cardiol 2005;21:2054-60.

14. Jaffe WM, et al." Rest & exercise hemodynamic of 20 to 23 mm allograft,Medtronic intact (porcine), and St. Jude medical valves in the aortic position".J Thorac Cardiovasc Surg 1990;100:167-74.

15. Tineke P, et al."Human tissue valves in aortic position". Circulation 2001;103:1515-21.

16. Kouchoukos NT, et al." The Ross procedure: long-term clinical & echocardiographic follow-up". Ann Thorac Surg 2004:78:773-81.

17. Legarra JJ, et al." Behavior of the pulmonary autograft in systemic circulation after the Ross procedure". Heart Surg Forum 2001;4:128-34.

18. Hraska V, et al." Ross & Ross-Konno procedure in children & Adolescents:mid-term results". Eur J Cardiothorac Surg 2004;25:742-7.

19. Reddy VM, et al."Aortoventriculoplasty with the pulmonary autograft: the Ross-Konno procedure". J Thorac Cardiovasc Surg 1996;111:158-65.

20. Bradley S, et al." Early results of the Ross procedure in simple and complex left heart disease".Circulation 1999;100:162-9.

21. Shimabukuro T, et al."Hemodynamic evaluations of patients with small aortic annulus with St. Jude medical prosthetic heart valve". Jpn J Thorac Cardiovasc Surg 1998;46:1285-91.

22. Bottio T, et al."Small aortic annulus:the hemodynamic performance of 5 commecially available bileaflet mechanical valves". J Thorac Cardiovasc Surg 2004;128:457-62.

23. Sasaki Y, et al."Clinical & echocardiographic evaluation of the Medtronic-Hall 20A valve in the aortic position in patients with small aortic annulus". Kyobu Geka 1997;50:819-23.

24. Fiore AC, et al." Valve replacement in the small aortic annulus: prospective randomized trial of St.Jude with Medtronic Hall". Eur J Cardiothorac Surg 1997;11:485-91.

25. Badano L, et al." Doppler echocardiographic evaluation of thr new mechanical bileaflet Sorin Bicarbon valve prosthesis

Compared with St. Jude medical". G Ital Cardiol 1994;24:733-43.

26. Bech-Hanssen O, et al." Assessment of effective orifice area of prosthetic aortic valves with Doppler echocardiography: an in-vivo and in vitro study". J Thorac Cardiovasc Surg 2001;122:287-95.

27. Walter T, et al." Comparison of On-X and SJM HP Bileaflet aortic valves". J Heart Valve Dis 2000;9:403-7.

28. Belgi A, et al." Hemodynamic performance of mechanical aortic valves in narrow aortic annulus cases". Anadolu Kardiyol Derg 2005;5:30-3.

29. Noera G, et al." Hemodynamic evaluation of the Carbomedics R, St Jude medical HP and Sorin-Bicarbon valve in patients with small aortic annulus". Eur J Cardiothorac Surg 1997;11:473-5.

30. Carrel T, et al." Early on vivo experience with the hemodynamic Plus St. Jude medical heart valves in patients with narrowed aortic annulus". Ann Thorac Surg 1996;61:1418-22.

31. Albes JM, et al." Are mechanical valves with enhanced inner diameter advantageous in the smallsized aortic annulus?". Ann Thorac Surg 2003;76:1564-70.

32. Franzen SF, et al." Aortic valve replacement for aortic stenosis in patients with small aortic root". J Heart Valve Dis 1996;3:s284-8.

33. Gelsomino S, et al." Patient-prosthetic mismatch after small-size stentless aortic valve replacement". J Card Surg 2004;19:91-7.

34. Natsuaki M, et al."Influence of St. Jude Medical valve in patients with aortic stenosis & small aortic annulus on cardiac function and late survival results". Artif Organs 2002;26:840-6.

35. De Paulis R, et al." Hemodynamic performance of small diameter carbomedics and St.Jude valves". J Heart Valve Dis 1996;3:S339-43.

36. Gelsomino S, et al." Early in-vivo hemodynamic results after aortic valve replacement with the St.Jude medical Regent mechanical heart valve in patients with pure aortic stenosis". J Card Surg 2003;18:125-32.

37. Bach DS, et al." Hemodynamic and early performance of the St. Jude medical Regent aortic valve prosthesis". J Heart Valve Dis 2001;10:436-42.

38. Blackstone EH, et al." Prosthesis size and long term survival after aortic valve replacement". J Thorac Cardiovasc Surg 2003;126:783-96.

39. Kirsch ME, et al." Clinical And hemodynamic performance of the 19-mm Medtronic Mosaic bioprosthesis". J Heart Valvw Dis 2005;14:433-9.

40. Moon MR, et al." Prosthesis-patient mismatch after aortic valve replacement: Impact of age and body size on late survival". Ann Thorac Surg 2006;81:481-8.

41. Kadir I, et al." Comparison of exercise and dobutamin echocardiography in the hemodynamic assessment of small size mechanical aortic valve prostheses". Eur J Cardiovasc Surg 2002;21:692-7.

42. Izzat MB, et al."Comparison of hemodynamic performance of St. Jude medical and Carbomedics 21 mm aortic prostheses by means of dobutamine stress echocardiography". J Thorac Cardiovasc Surg 1996; 111:408-15.

43. Mohty-Echahidi D, et al." Impact of prosthesis-patient mismatch on long-term survival in patient with small St. Jude medical mechanical prostheses in the aortic position". Circulation 2006; 113:420-20.

44. Niinami H, et al." A comparison of the in vivo performance of the 19-mm St. Jude medical hemodynamic plus and 21-mm standard". Ann Thorac Surg. 2002; 74:1120-4.

45. Sawant D, et al." Nineteen-millimeter aortic St. Jude medical heart valve prosthesis: up to sixteen years' follow-up". Ann Thorac Surg. 1997; 63:964-70.

46. De Paulis R, et al." Hemodynamic performance of small diameter carbomedics and St. Jude valves". J Heart Valve Dis. 1996; S3:339-43.

47. De Paulis R, et al." Doppler echocardiographic evaluation of the Carbomedics valve in patients with small aortic annulus and valve prosthesis-body surface area mismatch" J Thorac Cardiovasc Surg. 1994; 108:57-62.

48. Ennker J, et al." Stentless bioprostheses in small aortic roots: impact of patients-prosthesis mismatch on survival and quality of life". J Heart Valve Dis. 2005 14: 523-30.

49. Oka K, et al." The 19mm St. Jude medical prosthesis aortic valve evaluated by long-term hemodynamic sequelae".J Cardiol. 1990;20: 917-28.

50. Petracek MR." Assessing options for the small aortic root". J Heart Valve Dis. 2002;S11: 50-5.

51. Roscitano A, et al." Indexed effective orifice area after mechanical aortic valve replacement does not affect left ventricular mass regression in elderly". Eur J Cardiothorac Surg. 2006; 29:139-43.

52. Lee JW, et al." Left ventricular muscle mass regression after aortic valve replacement". J Korean Med Sci. 1999; 14:511-9.

53. Milano AD, et al. " Clinical outcome in patients with 19mm and 21-mm St. Jude aortic prosthesis: comparison at long-term follow-up". Ann Thorac Surg. 2002; 73:37-43.

54. Yamanaka K, et al. " The problem of 19-mm St. Jude medical valve prosthesis in the small aortic annulusvs 23 mm St. Jude medical valve". Nippon Kyobu Geka Gakkai. 1996;

44:906-11.

55. Okuyama H, et al." Midterm results of Manouguian double valve replacement: comparison with standard double valve replacement". J Thorac Cardiovasc Surg. 2005; 129:869-74.

56. Kawachi Y, et al." Eleven-year follow-up study of aortic or aortic-mitral annulus-enlarging procedure by Manouguian's technique". J Thorac Cardiovasc Surg. 1992; 104:1259-63.

57. Seybold-Epting W, et al." Clinical experience with enlargement of the aortic annulus by extension of the aortic incision into the anterior mitral leaflet". Thorac Cardiovasc Surg. 1980; 28:420-2.

58. Mori T, et al." Results of aortic valve replacement in patients with a narrow aortic annulus: effects of enlargement of the aortic annulus". Ann Thorac Surg. 1981; 31:111-6.

59. Aka SA, et al." Functional results in aortic root enlargement". Heart Surg Forum. 2004; 7:E160-3.

60. Manouguian S, et al." Patch enlargement of the aortic valve ring by extending the aortic incision into the anterior mitral leaflet. New operative technique". J Thorac Cardiovasc Surg. 1979; 78:402-12.

61. Wu HB, et al." Long-term follow-up of enlargement annulus aortic valve replacement in small aortic root". Zhonghua Wai Ke Za Zi. 2003; 41:247-9.

62. Maekawa A, et al." Optimal size prosthesis for functioning of the aortic prosthesis valve in aortic and mitral valve replacement with annular enlargement through manouguian's technique". Artif Organs. 2002;26:833-9.

63. Kitamura M, et al." Aortic valve replacement in small aortic annulus with or without annular enlargement". J Heart Valve Dis. 1996; 5:S289-93.

64. Tasca G, et al." Impact of valve prosthesis-patient mismatch on left ventricular mass regression following aortic valve replacement'. Ann Thorac Surg. 2005; 79:505-10.

65. Tabatabaie MB, et al." Classic konno-Rastan procedure: indications and results in the current era".Asian Cardiovasc Thorac Ann. 2006;14:377-81.