ORİJİNAL ARAŞTIRMA / *ORIGINAL RESEARCH*

The Effect of Preoperative Left Ventricular Filling Patterns on Prognosis in Patients with Aortic Valve Replacement

AORTİK KAPAK REPLASMANI YAPILAN HASTALARDA PREOPERATİF DÖNEMDEKİ SOL VENTRİKÜL DOLUMUNUN PROGNOZA OLAN ETKİSİ

Ahmet AKGÜL, MD,[a] Larry O. THOMPSON, MD,[b] Ülkü YILDIZ, MD,[a] Sebahattin GÖKSEL, MD,[a] Ümit KERVAN, MD,[a] Mustafa SOYLU, MD,[c] Oğuz TAŞDEMİR, MD[a]

Departments of [a]Cardiovascular Surgery and [c]Cardiology, Yüksek İhtisas Hospital, ANKARA
[b]Department of Emergency, Bunbury Regional Hospital, South West Health Campus, Bunbury, AUSTRALIA

Abstract

Objective: Although many studies have been performed to evaluate the effects of a variety of heart valves on left ventricular function, the alterations in diastolic function seen in patients with preoperatively restrictive filling patterns after aortic valve replacement (AVR) with various mechanical, stented or stentless prosthesis have not been sufficiently examined. This study aimed to assess and compare the changes in diastolic function in such patients following AVR.

Material and Methods: In accordance with preoperative echocardiographic findings in patients of similar age groups and body size, 24 patients were selected as having restrictive filling patterns (i.e. deceleration time (DT)≤150 msec, iso-volumetric relaxation time (IVRT)<100 msec). The patients underwent AVR with either St. Jude Medical (SJM) (n= 8) or CarboMedics (CM) mechanical valves (n= 6), or Medtronic Freestyle® (MF) (n= 6) or CryoLife-O'Brien (CO) (n= 4) stentless bioprotheses. Another 24 patients were selected as a non-restrictive, physiologic group. The effect of valve replacement on diastolic parameters was evaluated preoperatively and postoperatively at discharge and after 4 and 8 weeks by comparing the parameters before and after valve replacement.

Results: Improvement in DT, IVRT and ejection fraction occurred in all patients with restrictive filling patterns irrespective of valve type. Although the difference between the various types was not statistically significant, left ventricular mass regression was higher in patients with mechanical valves.

Conclusion: Preoperatively determined restrictive patterns appear to convey more benefit than that derived by patients with preoperative non-restrictive filling patterns. A greater improvement is to be expected in more advanced disease states in patients following AVR.

Key Words: Left ventricular, hypertrophy, aortic valve, heart valve prosthesis

Özet

Amaç: Çeşitli kalp kapaklarının sol ventrikül fonksiyonlarına olan etkisi birçok çalışmada gösterilmiş olsa da, stentli veya stentsiz biyoprotez ve mekanik aortik kapak replasmanlı hastalarda preoperatif dönemdeki dolum paterninin diyastolik fonksiyonlarda yarattığı değişiklikler tam olarak incelenememiştir. Bu çalışmada, bu tip aort kapak replasmanı (AVR) yapılan hastalardaki diyastolik değişiklikler incelenmiş ve birbirleriyle karşılaştırılmıştır.

Gereç ve Yöntemler: Benzer yaş ve vücut kitlesine sahip hastalar preoperatif dönemdeki ekokardiyografik bulgularına göre seçilmişlerdir. Restriktif grup (deselerasyon zamanı (DT)≤150 ms, izo-volumetrik gevşeme zamanı (IVRT)<100 ms) olarak 24 hasta seçildi. Bu hastalara St. Jude Medical (SJM) (n= 8) veya CarboMedics (CM) mekanik kapaklar (n= 6) veya Medtronic Freestyle® (MF) (n= 6) veya CryoLife-O'Brien (CO) (n= 4) stentless biyoprotez kullanılarak AVR yapıldı. Diğer 24 hasta ise non-restriktif grup olarak seçildi. Preoperatif dönemde ve operasyon sonrası 4 ve 8. haftalardaki diyastolik parametreler değerlendirildi ve birbirleriyle karşılaştırıldı.

Bulgular: Restriktif gruptaki tüm hastalarda kullanılan kalp kapak tipinden bağımsız olarak DT, IVRT ve ejeksiyon fraksiyonunda artış gözlendi. Kalp kapakları arasında istatistiksel olarak anlamlı fark olmasa da sol ventrikül kitle hacminde küçülme özellikle mekanik kapak replase edilenlerde daha fazla idi.

Sonuç: Preoperatif dönemdeki restriktif fizyoloji bu tip bir dolum paterni göstermeyen kalplere oranla AVR sonrası daha fazla düzelme göstermektedir. Daha ileri evredeki kalplerde AVR sonrası düzelme daha fazla olacaktır.

Anahtar Kelimeler: Sol ventrikül, hipertrofi, aort kapak replasmanı, prostetik mekanik kalp kapakları

Turkiye Klinikleri J Med Sci 2006, 26:258-264

Geliş Tarihi/*Received:* 01.11.2005 **Kabul Tarihi/*Accepted:*** 05.04.2006

Yazışma Adresi/*Correspondence:* Ahmet AKGÜL, MD
Yüksek İhtisas Hospital,
Department of Cardiovascular Surgery, ANKARA
aakgul@hotmail.com

Although mechanical heart valves offer more durability and better hemodynamic profiles when compared with stentless bioprostheses, the requirement of lifetime anticoagulation is a decided drawback. Indeed, related complications such as thromboembolism, hemolysis and bleeding still constitute the major morbidities. However, structural valve deterioration remains the major risk factor that has served to diminish the use of bioprosthetic valves. To date, there exists no unique guideline for decision-making in prosthesis selection for elective valvular surgery.

The SJM (St. Jude Medical, Inc., St. Paul, MN) and CM (CarboMedics, Inc., Austin, TX) mechanical heart valves are both bileaflet mechanical prosthetic valves constructed of pyrolytic carbon with excellent in vitro and in vivo hemodynamics and with proven reliability and freedom from adverse events.[1-4] Bioprosthetic valves are made of biological materials treated with glutaraldehyde in order to prevent degeneration, which can in time lead to calcification.

The aim of the present study was to compare the prognostic efficacy of preoperative echocardiographic parameters as determinants of restrictive or non-restrictive filling patterns of diastolic function in patients following AVR with various types of mechanical and stentless bioprosthetic valves.

Material and Methods

In accordance with preoperative echocardiographic findings, 24 patients were determined as having restrictive filling patterns (DT≤150 msec, IVRT<100 msec) and another 24 patients with non-restrictive patterns (DT>150 msec, IVRT≥100 msec).[5] The two groups were assigned to an equal distribution of various types of valves, i.e. the patients in each group underwent AVR with either SJM or CM mechanical valves, or MF (Medtronics, Inc., Minneapolis, MN) or CO (Cryolife, Inc., Kennesaw, GA) stentless bioprostheses. Patients were candidates for AVR due to aortic stenosis and regurgitation without previous history or evidence of arrhythmia, mitral valve disease, or coronary artery disease. Informed consent was obtained from all patients. The choice of valve type was individually determined by either patient option or some prevailing condition (i.e. age, contraindication for anticoagulation usage, etc.). The choice of stentless bioprosthesis valve was made intraoperatively according to aortic valve pathology and aortic root morphology. In patients with mainly fibrotic aortic valve pathology, O'Brien valves were preferred. For those with larger aortic roots who may have been candidates for root inclusion, MF valves were preferred, as this type of valve more readily accommodates to this procedure.

The patients were divided into two groups according to Doppler mitral flow velocity profiles: group A, consisting of 24 patients (10 females, 14 male; mean age 59.6 ± 8.4; SJM: n= 8; CM: n= 6; MF: n= 6; CO: n= 4) with restrictive physiology, and group B, consisting of another 24 patients (9 females, 15 males; mean age 61.2 ± 5.2; SJM: n= 8; CM: n= 6; MF: n= 6; CO: n= 4) with non-restrictive physiology.

All patients were evaluated preoperatively and postoperatively, at discharge and at 4 and 8 weeks by comparing echocardiographic parameters before and after valve replacement. Parameters measured in pre- and postoperative trans-thoracic echocardiography were ejection fraction (EF), fractional shortening (FS), trans-aortic peak gradient, aortic regurgitation, left ventricular end-diastolic diameter (LVEDD), left ventricular mass (LVM), interventricular septum thickness (IVS), and left ventricular posterior wall thickness (PW).

LVM was calculated according to Penn's modified 3D formula:

$$LVM= 1.04\{[(LVID + IVS + PW)3][(LVID)3]\}-13.6\ gr/m^3$$

Left ventricular mass index (LVMI) was calculated by dividing the values obtained from the formula by patient body surface area.

Operative Technique

Standard operative technique was employed for all operations. Following cannulation of the ascending aorta and right atrium with a two-stage cannula, hypothermic cardiopulmonary bypass was established and myocardial preservation was obtained by administrating 500 mL of cold (+4ºC) Plegisol (Abbott Laboratories, Abbott Park, IL) antegrade to the aortic root, followed by the infusion of 500 mL of the same solution retrograde via the coronary sinus. Cardioplegic arrest was maintained by 400 mL of the same solution with retrograde application every 20 minutes. The native valve was excised through oblique aortomy, the annulus was decalcified and sized, and the prosthesis was implanted. SJM and CM mechanical valves were implanted in the aortic annulus with interrupted 2/0 non-absorbable sutures. The techniques used for MF stentless porcine valves were aortic root inclusion or total root replacement with interrupted pledged sutures. The coronary ostia were implanted on the prosthesis with 6/0 polyprolene sutures. O'Brien valves were implanted on the aortic root with a continuous suture technique, using three double 2/0 polyprolene sutures.

Echocardiography

All patients were followed by echocardiography. Examinations were performed before the operation and at 6 months. Acceleration times (AT), DT, IVRT, and LVMI were evaluated. Echocardiograms were performed by a single cardiologist using a Toshiba SSH-140A Ultrasound system in accordance with the specifications of the American Society of Echocardiography. After measuring the left atrial diameter using two-dimensional echocardiography in the parasternal plane, systolic and diastolic diameters as well as wall thicknesses were studied with M-mode echocardiography. The Teicholz method for left ventricular EF and the modified Simpson method for dyskinetic interventricular septi were used. Left ventricular diastolic filling patterns were determined by mitral flow pulse-wave Doppler examination with a 2.5-MHz transducer. In the apical 4-chamber view, the Doppler sample volume was infused into the middle of the left ventricular inflow tract, 1 cm below the mitral annulus plane between the mitral leaflet tips, where flow velocity is maximum in early diastole.[5-8]

Statistical analysis

The variables of the groups were compared using the chi-square test, and comparisons of the continuous variables between groups were performed with Student's t and Spearman's correlation coefficient tests. When multiple pairwise comparisons were needed, Bonferroni corrections were made. The variables are presented as mean ± SD in the tables and a p value less than 0.05 was considered significant.

Results

The demographics of the patients including mean age, gender distribution, weight, and body mass index were similar in both groups (Table 1). All patients underwent AVR without statistically significant differences in prosthetic valve size.

All patients in the study manifested sinus rhythm and a normal heart rate of 82.0 ± 2.0/min.

Aortic stenosis was the most common pathology among patients. Only two patients in each group had severe aortic insufficiency and 4 had aortic stenosis as well as insufficiency (Table 1). In these patients, LVMI was higher when compared to the other patients. As the number of such pa-

Table 1. Patient characteristics.

	Group A (restrictive)	Group B (non-restrictive)
Number of patients	24	24
Mean age (years)	59.6 ± 8.4	61.2 ± 5.2
Gender (females/males)	10 female/14 male	9 female/15 male
Body surface area (m²)	1.72 ± 0.12	1.71 ± 0.18
New York Heart Association class III-IV (%)	82	78
Preoperative aortic valve lesion		
Stenosis	14	13
Insufficiency		
Moderate	4	5
Severe	2	2
Mixed	4	4

tients was equal in both groups, statistical comparison between the two groups was moot.

There were two operative mortalities in each group. In group A, two patients died in the early postoperative period due to low cardiac output. The first patient had undergone combined coronary bypass surgery and AVR with a MF aortic bioprosthesis. The second one died due to low cardiac output following SJM mechanical valve implantation. In group B, the first patient had undergone coronary bypass 7 years earlier and died due to blood loss after combined surgery for coronary bypass and O'Brien aortic valve implantation. The other fatality in this group was due to low cardiac output following MF aortic valve implantation.

Intra-operatively logged data indicated that the cross-clamp time and cardiopulmonary bypass duration were higher in patients receiving AVR with MF prosthesis.

All surviving patients were requested to present for echocardiographic evaluation of left ventricular performance at 4 and 8 weeks postoperatively. Significant regression was observed in both groups (Table 2). E/A ratios, left ventricular end-diastolic diameters and ejection fractions were significantly decreased in patients with restrictive physiology when preoperative and postoperative values were compared (2.2 ± 0.4 versus 1.2 ± 0.6, 56.4 ± 6.4 versus 42.6 ± 4.8, and 46.7 ± 4.2 versus 56.4 ± 6.6, respectively).

Discussion

Aortic valve pathologies lead to left ventricular hypertrophy, which is characterized by myocardial fibrosis and structural changes in the extracellular matrix.[9] The aim of this study was to examine the prognostic impact of preoperatively-determined left ventricular diastolic filling patterns on diastolic function in patients following AVR with mechanical and stentless bioprosthetic valves.

In hypertrophic hearts, as in aortic stenosis, diastole abnormalities are common sequelae of a delayed onset of normal relaxation, and may precede systolic dysfunction. Impaired relaxation is associated with a lengthening of the atrial filling phase, so that the E/A ratio evinced in the mitral Doppler pattern declines. In the normal pattern, there is a large E wave and a small A wave. However, three abnormal patterns of mitral filling represent impaired left ventricular diastolic performance. "Delayed relaxation" is characterized by larger A waves (E<A), and the left ventricular DM is normal or prolonged. In the "pseudo-normalized" pattern, the E wave is larger than the A wave (E>A), but with a shortened DT. In the restricted filling pattern, E is much larger than A (E>>A) with a very short DT.[7-9]

The Standard® St. Jude disk valve has been in clinical use for over 20 years. The valve in its current form is the consequence of some unfortunate developments during the late 1970s: High degeneration rates of xenograft valves and the frequent mechanical failure of the single-disc valve types.[10] The valve has become very popular, and the standard valve together with its modifications remains the dominant mechanical valve currently, exhibiting a low rate of valve-related deaths, acceptably low thrombogenicity, and an absence of mechanical failure, all of which were verified through long-term studies of a large series of patients.[10] The designers of the original St. Jude mechanical valve implemented further refinements of this prosthesis in creating the Advanced The Standard (ATS)® (ATS Medical, Inc., Minneapolis, MN).[10]

The other prosthetic valve included in this study was the CM bileaflet mechanical valve, which is introduced for clinical use in 1986.[4] The CM device is a bileaflet pyrolytic carbon heart valve, and differs from the SJM prosthesis on several aspects, including the Biolite® carbon-covered blood-contacting surface on the sewing ring, the valve pivot design with its absence of pivot guards, the presence of a titanium stiffening ring, and particularly, the rotate-ability of the valve after implantation.[4] The most comprehensive clinical experience with this prosthesis was described by Copeland et al in an international multi-center study featuring an average follow-up of 30.2 months.[4]

Table 2. Preoperative and postoperative echocardiographic data.

Variable	Group A (restrictive)	Group B (non-restrictive)
Ejection fraction (%)		
Pre	46.7 ± 4.2	48.8 ± 2.8
Post (4 weeks)	54.6 ± 2.8	50.8 ± 4.2
Post (8 weeks)	56.4 ± 6.6	53.8 ± 6.8
p	< 0.05*	NS*
Fractional shortening (%)		
Pre	32.6 ± 7.8	33.6 ± 8.8
Post (4 weeks)	34.8 ± 4.2	35.8 ± 2.6
Post (8 weeks)	35.8 ± 6.4	36.0 ± 6.2
p	NS*	NS*
Transaortic peak gradient (mmHg)		
Pre	72.4 ± 8.0	70.8 ± 2.4
Post (4 weeks)	38.8 ± 6.2	36.8 ± 6.2
Post (8 weeks)	16.4 ± 2.2	15.6 ± 6.8
p	< 0.01*	< 0.01*
Aortic regurgitation (preoperative)		
Moderate	4	5
Severe	2	2
Left ventricular end diastolic diameter (mm)		
Pre	56.4 ± 6.4	52.8 ± 8.8
Post (4 weeks)	48.8 ± 4.2	48.8 ± 6.2
Post (8 weeks)	42.6 ± 4.8	46.2 ± 5.6
p	< 0.05*	NS*
Left ventricular mass index (g/m²)		
Pre	210.2 ± 18.6	192.8 ± 18.4
Post (4 weeks)	180.8 ± 4.2	168.8 ± 4.2
Post (8 weeks)	162.8 ± 20.4	140 ± 14.6
p	< 0.01*	< 0.01*
Interventricular septum thickness (mm)		
Pre	12.4 ± 3.2	11.7 ± 4.7
Post (4 weeks)	11.8 ± 4.2	10.8 ± 4.2
Post (8 weeks)	11.4 ± 5.2	10.2 ± 2.1
p	NS*	NS*
Left ventricular posterior wall thickness (mm)		
Pre	12.4 ± 4.2	10.9 ± 6.2
Post (4 weeks)	11.8 ± 4.2	10.8 ± 5.2
Post (8 weeks)	11.4 ± 4.8	10.2 ± 3.2
p	NS*	NS*
E/A		
Pre	2.2 ± 0.4	1.0 ± 0.2
Post (4 weeks)	1.8 ± 0.2	0.9 ± 0.8
Post (8 weeks)	1.2 ± 0.6	0.9 ± 0.8
p	< 0.05*	NS*

*: Pre vs post at 4 weeks.

The CO stentless porcine aortic bioprosthesis is of a composite design, constructed with non-coronary leaflets obtained from three porcine valves. Leaflets are carefully excised from valves fixed in glutaraldehyde under very low or near zero pressure. The matched set of leaflets are sutured together along the free edges of the aortic wall at the leaflet commissures. Having no Dacron reinforcement in the structure of the xenograft remains the significant difference between this and the other stentless valves. The O'Brien valve has exhibited a satisfactory early hemodynamic profile. Promising 5-year follow-up results have been cited in recent studies.[11,12]

The MF bioprosthesis is another stentless valve that was used in our patients. This is a porcine aortic root cross-linked in buffered glutaraldehyde solution with 40 mmHg pressure applied to the root and a zero pressure differential across the valve leaflets.

The valve is pre-treated with alpha-amino oleic acid to reduce the potential for leaflet calcification. The device is suitable for root replacement, mini-root inclusion cylinder AVR, partial scalloped sub-coronary valve implantation or completely scalloped sub-coronary implantation.[13,14]

This study examined outcomes with respect to hemodynamic function in 48 consecutive patients who underwent AVR with a variety of valves. Kon and Westaby demonstrated that the hemodynamic performance of stentless porcine aortic valves was to some degree dependent upon the implant technique employed. In patients receiving the valve as a sub-coronary implant, there was a decrease in gradient and increase in effective orifice area as a function of time. Therefore, it is important to compare similar groups with respect to surgical technique, which should ideally be identical in both groups.

According to deceleration and iso-volumetric relaxation times, patients were categorized as demonstrating restrictive versus non-restrictive physiology based on preoperative Doppler-echo assessment. Patients in the restrictive group were considered to have more severe aortic stenosis as evidenced by higher preoperative aortic valve gradients and a tendency towards greater left ventricular mass index. In both groups, a significant reduction in aortic valve gradient and left ventricular mass index was identified. Many studies demonstrated similar results, such as a lessening of LVM following AVR due to regression of myocardial cellular hypertrophy and interstitial fibrosis.[15,16]

Before AVR, single mitral flow wave with a DM of less than 150 ms reflected the restrictive filling pattern of hearts. Four weeks after valve replacement the DM reached to over 500 ms, which suggests an improved left ventricle filling profile. These findings indicate that the restrictive filling pattern of the left ventricle in aortic stenosis may be reversed within 4 weeks of left ventricular offloading with the AVR. This interesting finding is similar to the results of the study by Westaby and associates, which shows the improvement in left ventricular filling profile in 4 weeks under ventricular assist device support.[17] In another study, we showed that 40 days of unloading of left ventricle with left ventricular assist device (LVAD) led to recovery in the myopathic hearts.[18.] In fact, although LVAD implantation is unlike AVR, the two procedures have parallel effects such as unloading the left ventricle.

Restrictive pattern generally indicates elevated left atrial pressures (i.e. filling pressures) which suggest a more advanced clinical stage of dysfunction. This is consistent with higher preop gradients, dilated ventricles and greater wall thickness and muscle mass. A greater improvement is expected in more advanced disease states. The non-restrictive groups with less severe dysfunction have smaller margins for improvement. This finding is clinically significant, since surgery might have better outcomes in patients with more advanced disease states, who are candidates for AVR.

In several previous reports, an increase in EF as well as a decrease in ventricular wall thickness was observed in patients who had undergone AVR for aortic stenosis. Unfortunately, classification with regard to preoperative diastolic parameters was not noted in these studies. Pei-Ying and associates, however, divided their patients into restrictive and non-restrictive subgroups.[6]

The association of preoperative restrictive patterns on echocardiography and mechanical heart valves seems to confer more benefit when compared with those patients with preoperative non-restrictive filling patterns who received bioprosthetic valves. In the present study, we were able to show significant improvements in DT and IVRT values in patients with preoperatively restrictive pattern, as did Pei-Ying. However, unlike our study, they found no improvement in patients with non-restrictive physiology.

In our patients, LVMI decreased independently of valve replacement type at 8 weeks after AVR. The hemodynamic performance of the stentless valves was similar to that of the mechanical valves, as demonstrated by low trans-valvular gradients and decreased LVMI percentages.

Until recently, many studies were performed to compare the effects and prognostic consequences between two valve types, prosthetic and mechanical.[15,19] The comparison was performed in various parameters such as age, valve position, type and size, myocardial status, functional status, anticoagulation requirements, complications, etc.[9,10] The common consequences of these studies suggest that bioprosthetic valves do not offer a survival advantage over mechanical valves. The rates of survival and freedom from all valve-related complications were similar for patients who received mechanical heart valves and those who received bioprosthetic heart valves. However, structural failure was observed only with the bioprosthetic valves, whereas bleeding complications and anticoagulant-related mortality and morbidity were more frequent among patients who received mechanical valves.

In accordance with these studies, we showed that patients undergoing AVR had an improvement in functional status, as well as systolic and diastolic left ventricular function, and a reduction in LVMI, irrespective of prosthesis size.[9,10] In addition, we suggest that these parameters may be sensitive to the type of the valve as well as the physiologic status of the left ventricle. Mechanical valves are somewhat less obstructive than stented bioprosthetic valves of the same size. They are also associated with a concomitantly more pronounced reduction of LVM especially when implanted in an aortic position of a left ventricle, which shows restrictive filling pattern.

In conclusion, preoperatively determined restrictive patterns appear to convey more benefit than that derived by patients with preoperative non-restrictive filling patterns. A greater improvement is expected in more advanced disease states in patients following AVR.

REFERENCES

1. Lund O, Nielsen SL, Arildsen H, Ilkjaer LB, Pilegaard HK. Standard aortic St. Jude valve at 18 years: Performance profile and determinants of outcome. Ann Thorac Surg 2000;69:1459-65.
2. Bernal JM, Rabasa JM, Gutierrez-Garcia F, Morales C, Nistal JF, Revuelta JM. The CarboMedics Valve: Experience with 1.049 implants. Ann Thorac Surg 1998;65:137-43.
3. Karpuz H, Jeanrenaud X, Aebischer N, Hurni M, Sadeghi H, Kappenberger L. Comparison of aortic valve prosthesis: ATS versus St. Jude Medical. Turkiye Klinikleri J Cardiol 1995;8:156-9.
4. Copeland JG. An international experience with the CarboMedics prosthetic heart valve. J Heart Valve Dis 1995;4:56-62.
5. Appleton CP, Hattle LK. The natural history of left ventricular filling abnormalities assessed by 2-dimensional and Doppler echocardiography. Echocardiography 1992; 9:437-57.
6. Nishimura RA, Tajik AJ. Evaluation of diastolic filling of left ventricle in health and disease: Doppler echocardiography is the clinician's Rosetta Stone? J Am Coll Cardiol 1997;30:8-18.
7. Brutsaert DL, Sys SU, Gillebert TC. Diastolic failure: Pathophysiology and therapeutic implications. J Am Coll Cardiol 1993;22:318-25.
8. Cory CR, Grange RW, Houston ME. Role of sarcoplasmic reticulum in loss of load-sensitive relaxation in pressure overload cardiac hypertrophy. Am J Physiol 1994;266:H68-78.
9. Bech-Hanssen O, Caidahl K, Wall B, Myken P, Larsson S, Wallentin I. Influence of aortic valve replacement, prosthesis type, and size on functional outcome and ventricular mass in patients with aortic stenosis. J Thorac Cardiovasc Surg 1999;118:57-65.
10. Horstkotte D, Schulte H, Bircks W, Strauer B. Unexpected findings concerning thromboembolic complications and anticoagulation after complete 10 year follow up of patients with St. Jude Medical prosthesis. J Heart Valve Dis 1993;2:291-301.
11. O'Brien MF. Composite stentless xenograft for aortic valve replacement. Clinical evaluation of function. Ann Thorac Surg 1995;60:S406-9.
12. Hvass U, O'Brien MF. The stentless Cryolife-O'Brien aortic porcine xenograft: A 5-year follow-up. Ann Thorac Surg 1998;66:S134-8.
13. Westaby S, Amarasena N, Long V, et al. Time-related hemodynamic changes after aortic replacement with the freestyle stentless xenograft. Ann Thorac Surg 1995;60:1633-8.
14. Dumesnil JG, LeBlanc MH, Cartier PC, et al. Hemodynamic features of the frestyle aortic bioprosthesis compared with stented bioprosthesis. Ann Thorac Surg 1998;66:130-3.
15. Hammermeister KE, Sethi GK, Henderson WG, Oprian C, Kim T, Rahimtoola S. A comparison of outcomes in men 11 years after heart-valve replacement with a mechanical valve or bioprosthesis. Veterans Affairs Cooperative Study on Valvular Heart Disease. N Engl J Med 1993;328:1289-96.
16. Lund O, Magnussen K, Knudsen M, Pilegaard H, Nielsen TT, Albrechtsen OK. The potential for normal long term survival and morbidity rates after valve replacement for aortic stenosis. J Heart Valve Dis 1996;5:258-67.
17. Westaby S, Jin XY, Katsumata T, Taggart DP, Coats AJ, Frazier OH. Mechanical support in dilated cardiomyopathy: Signs of early left ventricular recovery. Ann Thorac Surg 1997;64:1303-8.
18. Akgul A, Skrabal CA, Thompson LO, et al. Role of mast cells and their mediators in failing myocardium under mechanical ventricular support. J Heart Lung Transplant 2004;23:709-15.
19. Kobayashi Y, Eishi K, Nagata S, et al. Choice of replacement valve in elderly. J Heart Valve Dis 1997;6:404-9.