Transcatheter Aortic Valve Implantation

The Acute and 3-Month Outcomes of Transcatheter Aortic Valve Implantation in Taiwan

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Background: Transcatheter aortic valve implantation (TAVI) has emerged as an alternative to surgical aortic valve replacement for symptomatic severe aortic stenosis (AS) patients with high surgical risk. This study demonstrates the acute and 3-month outcomes of the first case series of TAVI in Taiwan.

Methods: This study enrolled severe symptomatic AS patients who were evaluated by surgeons as having high surgical risk. The procedural and 3-month outcomes were evaluated. The Edwards SAPIEN valves were delivered via the transfemoral (TF) or transapical (TA) approaches.

Results: Between May and October 2010, 10 patients received TAVI (4 via TF and 6 via TA approach). The procedures were successful in all cases. No major complications occurred within the first 24 hours after the procedure. At 3-month follow-up, no cardiovascular death occurred. One patient died of pneumonia after the TA procedure. Another TA patient developed myocardial tear 3 days after the procedure. After TAVI, none of the patients had more than grade 2 AR at discharge and 3-month follow-up. The aortic-valve area increased from 0.61 ± 0.19 cm^2 to 1.42 ± 0.20 cm^2 ($p < 0.001$), and the mean aortic valve gradient decreased from 48 ± 16 mm Hg to 11 ± 2 mm Hg ($p < 0.001$).

Conclusion: The immediate and short-term outcomes were encouraging in our first 10 TAVI cases. Nevertheless, multi-specialty collaboration, pre-procedural evaluation with multimodality imaging, and proper patient selection are the cornerstones of success in treating these high-risk patients.

Key Words: Aortic stenosis • Transcatheter aortic valve implantation

INTRODUCTION

Degenerative aortic stenosis (AS) is the most common valvular heart disease in adults. Its prevalence is about 4% in patients over 80 years of age. After the onset symptoms (angina, syncope, heart failure), the average survival time is 2 to 3 years, with a high risk of sudden death.[1] Surgical replacement of the aortic valve (AVR) has been the only effective treatment in adults with severe symptomatic AS, which provides symptomatic relief and long-term survival.[2] However, in clinical practice, more than 30% of patients with severe symptomatic AS do not undergo surgical replacement of the aortic valve, due to advanced age, left ventricular dysfunction, or the presence of multiple coexisting conditions.[3-6]

Transcatheter aortic valve implantation (TAVI) has emerged as an alternative to surgical AVR for severe AS patients with high operative risk. This is a new procedure, in which a bioprosthetic valve is inserted through a catheter and implanted within the diseased native aortic

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valve. Since the procedure was first performed in 2002,[7] this technology has evolved tremendously for the treatment of severe AS patients with high surgical risk.[8-18] The Edwards SAPIEN valve was approved in the European Union (the transfemoral delivery [TF] was approved in November 2007 and transapical delivery [TA] in January 2008 and FDA in November 2011). Recently, the PARTNER (Placement of AoRTic TraNscathetER Valve) trial included 358 otherwise inoperative patients with severe symptomatic AS who were randomized to receive either TF transcatheter implantation of an Edwards SAPIEN valve or standard medical therapy (including balloon aortic valvuloplasty). The one-year follow-up showed that the death rate was 30.7% in the TAVI group, compared to 50.7% in the standard therapy group.[19]

In Taiwan, our multidisciplinary team was the first to apply for approval of the TAVI program to the Department of Health (DOH), R.O.C., and the program was approved in January 2010. This study demonstrates the acute and 3-month outcomes of the first case series of TAVI for treating severe symptomatic AS patients with high surgical risk.

MATERIALS AND METHODS

Patients

From March 2009, all patients with severe symptomatic AS at our institution (Taipei Veterans General Hospital, Taipei, Taiwan) were enrolled. All potential candidates for TAVI were evaluated by a multidisciplinary team composed of interventional cardiologists, cardiac surgeons, anesthetists, and imaging specialists who determined the eligibility of the patient for TAVI. Patients considered eligible for TAVI underwent a systematic workup protocol that included transesophageal echocardiography (TEE), coronary angiography, aortoiliofemoral angiography, and computed tomography.

In January 2010, the TAVI program was approved by the DOH, R.O.C., and was performed in severe symptomatic AS patients who were evaluated by surgeons as having high surgical risk. All subjects provided written informed consent to participate in the study.

Inclusion/exclusion criteria

Severe AS was defined as an aortic-valve area of less than 1.0 cm^2, a mean aortic-valve gradient of 40 mm Hg or more, or a peak aortic-jet velocity of 4.0 m per second or more. All the patients had New York Heart Association (NYHA) symptoms greater than class II. The decision to perform TAVI was made in patients with the following characteristics: severe symptomatic AS plus a logistic European System for Cardiac Operative Risk Evaluation (logistic EuroSCORE) ≥ 20%.

Main exclusion criteria were a bicuspid or non-calcified aortic valve, acute myocardial infarction < 14 days, a left ventricular ejection fraction of < 20%, a diameter of the aortic annulus of less than 18 mm or more than 25 mm by TEE, severe (≥ grade 3) mitral or aortic regurgitation, active infection, haemodynamic instability, or life expectancy < 12 months.

Study device and procedure

The Edwards SAPIEN transcatheter heart valve (THV) used in this study is a second-generation system consisting of a trileaflet bovine pericardial valve and a balloon-expandable, stainless-steel support frame. The 23-mm valve was implanted if the TEE measurement of the aortic annulus was between 17 and 21 mm, and the 26-mm valve was implanted if the aortic annulus was between 22 and 25 mm. TF or TA approach was selected on the basis of the size, the tortuosity, and/or disease of iliofemoral arteries. The TF delivery system is suitable for iliofemoral vessels with a diameter ≥ 7 mm for the 23-mm valve and ≥ 8 mm for the 26-mm valve. The TA approach incorporates a shorter and larger diameter (33 French) delivery system compatible with the 23 or 26 mm Edwards SAPIEN valve.

Starting in May 2010, the procedures were performed in the catheterization laboratory, with the patient under general anesthesia and continuous TEE monitoring. TF procedures were performed by surgical cut-down of femoral arteries, followed by insertion of either a 22- or 24-French sheath, depending on the selected size of the valve (23 mm or 26 mm). After retrograde pre-dilation of the native valve, the THV, crimped onto a balloon catheter, was advanced across the native aortic valve, and then delivered by balloon inflation under rapid ventricular pacing (Figures 1 and 2). For the TA procedure, a left anterolateral mini-thoracotomy and pericardiotomy were performed, and a double pledgeted pursestring suture or U stitches were placed at the left

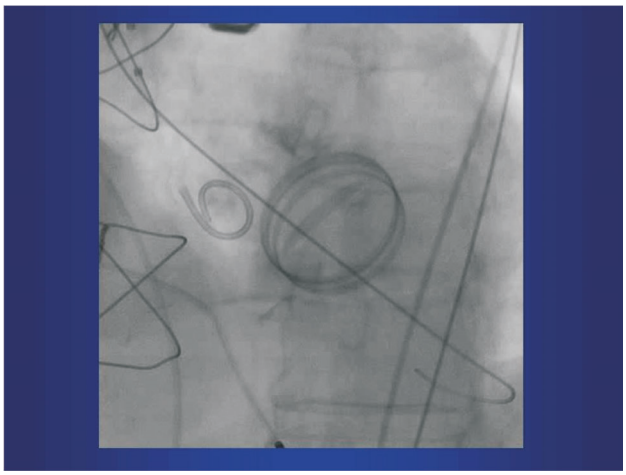

Figure 1. *A 80-year-old female presented with decreasing exertional tolerance [New York Heart Association (NYHA) Class III] due to severe aortic stenosis (valve area 0.3 cm^2, mean gradient 76 mmHg, ejection fraction 50%). Ten years before, she underwent a mitral valve replacement with a St. Jude mechanical prosthesis (St. Jude Medical, Inc., St. Paul, Minnesota) for rheumatic mitral stenosis. Her logistic EuroSCORE was 25.4%.*

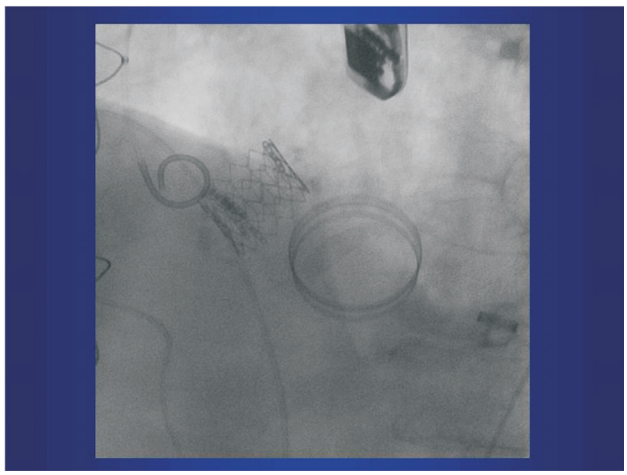

Figure 2. *The transfemoral (TF) approach was selected because of adequate size of both iliofemoral arteries. TF-TAVI was performed under general anesthesia and continuous transesophageal echocardiographic (TEE) monitoring. A 23 mm Edwards Sapien valve was then deployed. Subsequently, TEE and fluoroscopy showed good positioning of the aortic prosthesis with trivial aortic paravalvular leak. Post-procedural echocardiography showed mean aortic gradient of 9 mmHg, and mild aortic valve regurgitation.*

ventricular apex. After puncture of the apex, antegrade crossing, and pre-dilatation, THV was deployed under rapid ventricular pacing. Adjunctive pharmacologic therapy included heparin during the procedure and aspirin (100 mg/day) indefinitely and clopidogrel (75 mg/day) for 3 to 6 months after the procedure.

Definitions and follow-up

"Device success" was defined as implantation of the device with final mean transaortic gradient ≤ 20 mm Hg without aortic regurgitation grade ≥ 3 (effective implantation) and no valve embolization or need to implant a second valve. "Procedural success" was defined as an effective valve implantation without intraprocedural mortality or conversion to open heart surgery. "Vascular complications" were divided into major and minor complications according to the previously described definitions.[20] "Major vascular complications" were defined as vessel rupture and/or limb-threatening ischemia or bleeding requiring additional percutaneous treatment with stent implantation and/or nonplanned vascular surgery; aortic dissection was also included. In the TA approach, the occurrence of myocardial tears required further surgical repair and accidental damage of a coronary artery during apical repair were also considered major vascular complications. Major post-procedural complications included death, stroke, myocardial infarction, sepsis, need for hemodialysis, and need for a permanent pacemaker. Clinical and echocardiographic data were obtained at baseline, before discharge, and at 30 days, 3 months, 6 months, and 1 year.

Statistical analysis

Continuous variables with a normal distribution were expressed as mean ± SD, and categorical data as percentages. The data were analyzed by nonparametric methods to avoid assumptions about the distribution of measured variables. The differences between baseline and post-treatment values were analyzed using the Wilcoxon signed-rank test. For all comparisons, a p value of < 0.05 was considered statistically significant.

RESULTS

Baseline characteristics

Between May and October 2010, 10 patients with symptomatic severe AS underwent TAVI in our center were included in this analysis. Baseline clinical and echocardiographic characteristics of the study population are shown in Table 1. The approach for TAVI was

Table 1. Baseline characteristics of the study population and the PARTNER trial TAVI cohort

Variable	All patients (N = 10)	Transfemoral (N = 4)	Transapical (N = 6)	PARTNER TAVI cohort (N = 358)
Age (years)	81.5 ± 2.9	78.5 ± 1.3	83.5 ± 1.5	83.1 ± 8.6
Male (%)	50	25	66.7	45.8
Logistic EuroSCORE	28.3 ± 7.9	27.1 ± 8.8	29.1 ± 8.1	26.4 ± 17.2
NYHA class, n (%)				
I or II	0	0	0	7.8
III or IV	10 (100)	10 (100)	10 (100)	165 (92.2)
Diabetes, n (%)	2 (20)	1 (25)	1 (16.7)	–
CAD, n (%)	3 (30)	0	3 (50)	121 (67.6)
Prior MI, n (%)	1 (10)	1 (25)	0	33/177 (18.6)
Prior PCI	3 (30)	0	3 (50)	47/154 (30.5)
Prior CABG	0	0	0	58/155 (37.4)
Cerebrovascular disease, n (%)	3 (30)	1 (25)	2 (33.3)	48/175 (27.4)
PVD, n (%)	1 (10)	1 (25)	0	54/178 (30.3)
Pulmonary disease, n (%)	8 (80)	3 (75)	5 (83.3)	74 (41.3)
Serum creatinine (mg/dL)	1.3 ± 0.6	1.1 ± 0.4	1.4 ± 0.7	–
eGFR < 60 ml/min, n (%)	8 (80)	4 (100)	4 (66.7)	–
Atrial fibrillation, n (%)	1 (10)	1 (25)	0	28/85 (32.9)
Permanent pacemaker, n (%)	0	0	0	35/153 (22.9)
Echocardiographic findings				
Mean aortic gradient (mmHG)	48 ± 16	63 ± 13	38 ± 8	45 ± 16
Aortic valve area (cm^2)	0.61 ± 0.19	0.50 ± 0.24	0.68 ± 0.14	0.60 ± 0.20
LVEF (%)	61 ± 9	61 ± 9	61 ± 10	54 ± 13

Values are expressed as n (%).

Logistic EuroSCORE, logistic European System for Cardiac Operative Risk Evaluation; NYHA, New York Heart Association; CAD, coronary artery disease; MI, myocardial infarction; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; PVD, peripheral vascular disease; eGFR, estimated glomerular filtration rate.

TF in 4 patients (40%), and TA in 6 (60%). Compared with the PARTNER trial,[19] our patients tended to have a higher logistic EuroSCORE and have a higher prevalence of pulmonary disease and renal dysfunction, and were more likely to present with heart failure. But our cohort tended to be younger and had a lower prevalence of coronary artery disease, previous coronary intervention, and peripheral vascular disease. Between TF and TA patients, differences were observed in respect to the incidence of coronary artery disease, prior coronary intervention, peripheral vascular disease, and serum creatinine. These resulted in a higher logistic EuroSCOREs (27.1% for the TF and 29.1% for the TA group, respectively) in the TA group, indicating that the TA cohort tended to represent a higher-risk patient population.

Procedural and 3-month outcomes

Procedural and 3-month outcomes are summarized in Tables 2 and 3, respectively. The procedure was successful in all cases. During the TAVI procedure or in the first 24 hours after the procedure, no intra-procedural death occurred. There were no major complications. Cardiac tamponade occurred in one TF case immediately after THV deployment and was successfully treated with pericardiocentesis. We speculate that heavy calcification of both left and non-coronary cusps of this patient made the expanded bioprosthesis to overstretch the relatively pliable right aortic cusp and sinus, thus leading to an aortic tear.

At 3-month clinical follow-up, no cardiovascular death occurred. One patient died 25 days after a TA procedure because of pneumonia and subsequent sepsis. Major vascular complication occurred in one patient in the TA group. The patient developed impending cardiac tamponade and cardiac enzyme elevation 3 days after the procedure; myocardial tear of right ventricular apex was

Table 2. Procedural outcomes (first 24 hours)

Variable	All procedures (N = 10)	Transfemoral (N = 4)	Transapical (N = 6)
Successful procedure	10 (100)	10 (100)	10 (100)
Procedural death	0	0	0
Valve embolization	0	0	0
Need for a second valve	0	0	0
Conversion to open-heart surgery	0	0	0
Need for hemodynamic support	0	0	0
Major vascular complications	0	0	0
Stroke	0	0	0
Coronary obstruction	0	0	0
Need for permanent pacemaker	0	0	0
New atrial fibrillation	0	0	0
AR > 2+	0	0	0

Values are expressed as n (%).
AR, aortic regurgitation.

Table 3. 3-month cumulative clinical outcomes

Variable	All procedures (N = 10)	Transfemoral (N = 4)	Transapical (N = 6)
Death	1 (10)	0	1 (16.7)
Cardiac death	0	0	0
Major vascular complication	1 (10)	0	1 (16.7)
Myocardial infarction	1 (10)	0	1 (16.7)
Stroke	0	0	0
Need for hemodialysis	1 (10)	0	1 (16.7)
Need for permanent pacemaker	0	0	0
New atrial fibrillation	0	0	0
Sepsis	1 (10)	0	1 (16.7)
AR > 2+	0	0	0

Values are expressed as n (%).
AR, aortic regurgitation.

found and was successfully treated with placement of a patch. One patient in the TA group, who had chronic kidney disease with estimated glomerular filtration rate of 17.8 ml/min before the procedure, required hemodialysis at 3-month follow-up. There was no stroke or need for permanent pacemaker implantation during follow-up period.

Echocardiographic findings and neurohormonal response

Echocardiographic findings and neurohormonal changes are shown in Table 4. Among patients who underwent TAVI, the mean aortic-valve area increased from 0.61 ± 0.19 cm^2 at baseline to 1.42 ± 0.20 cm^2, and the mean aortic valve gradient decreased from 48 ± 16 mm Hg to 11 ± 2 mm Hg at discharge ($p < 0.001$ for both). At 3-month follow-up assessment, the improvement in aortic valve area and mean gradient remained significant. After the TAVI procedure, there was a trend towards a lower plasma N-terminal brain natriuretic peptide (NT-proBNP) concentration at discharge (539 ± 222 vs. 1238 ± 1886 pg/mL; $p = 0.2$), and the levels showed further decrease at 3-month follow-up (466 ± 215 pg/mL).

Moderate paravalvular aortic regurgitation (AR) was present in 20% of the patients before the procedure. After TAVI, paravalvular AR was generally mild, and none

Table 4. Echocardiographic findings and neurohormonal response after TAVI

Variables	Baseline (N = 10)	At discharge (N = 9)	3 months (N = 9)
Aortic valve area (cm^2)	0.61 ± 0.19	1.42 ± 0.20	1.45 ± 0.31
Mean aortic gradient (mmHG)	48 ± 16	11 ± 2	10 ± 4
Peak aortic gradient (mmHG)	72 ± 22	18 ± 7	17 ± 8
Systolic PAP (mmHG)	37 ± 11	34 ± 7	35 ± 4
LV wall thickness			
Septum (mm)	13 ± 1	12 ± 2	12 ± 3
Posterior wall (mm)	13 ± 1	12 ± 2	11 ± 2
LVEDD (mm)	50 ± 6	49 ± 4	49 ± 5
LVESD (mm)	27 ± 6	27 ± 6	27 ± 8
LVEF (%)	61 ± 9	58 ± 8	59 ± 8
MR			
None/trivial	2 (20)	2 (22)	2 (22)
Mild	7 (70)	6 (66.7)	5 (55.6)
Moderate	1 (10)	1 (11.1)	2 (22.2)
Severe	0	0	0
NT-ProBNP, pg/mL	1238 ± 1886	539 ± 222	466 ± 215

Values are expressed as n (%).
MR, mitral regurgitation; NT-ProBNP, N-terminal brain natriuretic peptide.

of our patients had more than grade 2 AR at discharge and 3-month follow-up (Figure 3).

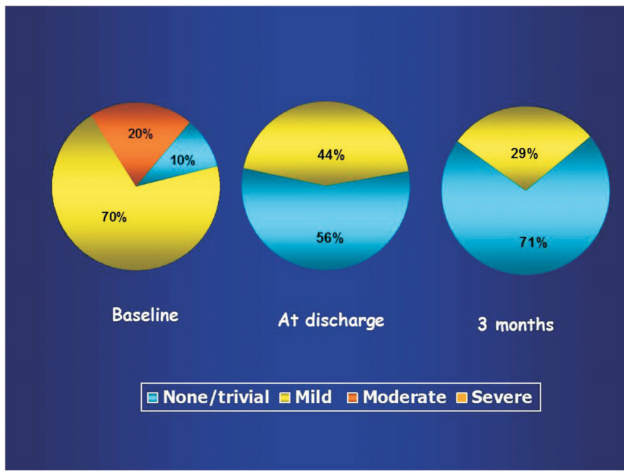

Figure 3. *Incidence and degree of aortic regurgitation for patients who underwent TAVI before the procedure, at discharge, and at 3-month follow-up.*

DISCUSSION

Although surgical AVR is the gold-standard therapy for patients with symptomatic severe AS, a significant proportion of patients are not offered or are denied opportunity to undergo surgical treatment.[3-6] Balloon valvuloplasty was developed in the hope of offering symptomatic relief for some of these non-operable patients, but restenosis was almost universal within 1-2 years, and it also did not change the dismal prognosis of the disease.[19] TAVI, therefore, has emerged as an alternative to surgical AVR.

The Edwards SAPIEN transcatheter heart valve consists of a trileaflet bovine pericardial valve and a balloon-expandable, stainless-steel support frame. The PARTNER trial investigated the efficacy and safety of transcatheter implantation of an Edwards SAPIEN valve in otherwise inoperable patients with severe symptomatic AS, as compared with standard therapy (including balloon aortic valvuloplasty).[19] At 1-year follow-up, TAVI significantly reduced the rates of death from any cause (30.7% vs. 50.7%, $p < 0.001$), the composite end point of death from any cause or repeat hospitalization, and cardiac symptoms (42.5% vs. 71.6%, $p < 0.0001$), despite the higher incidence of major strokes (5.0% vs. 1.1%, $p = 0.06$) and major vascular events (16.2% vs. 1.1%, $p < 0.001$).

This emerging therapy, although very promising and exciting, has several problems and potential complica-

tions. The learning curve is steep,[13,21,22] and although improvement of the early experience, procedural success rates are still approximately 90%-95%. The 30-day rate of death was 8.5% in the combined transapical and transfemoral arms of the SOURCE (SAPIEN Aortic Bioprosthesis European Outcome) Registry, the largest consecutive patient TAVI registry reported to date.[18] Webb et al.[15] reported a 30-day mortality of 11.3%, lower in the transfemoral group than transapical (8.0% vs. 18.2%), whereas in a more recent multicenter report on Edwards SAPIEN valve from Canada, the overall death rate at 30 days was 10.4% with no significant difference between the transfemoral and the transapical approach.[17] In the PARTNER trial, periprocedural stroke risk was 5% and is one of the most concerning complications of TAVI. The large access sheaths that are required to insert this delivery system contributed to the high frequency of vascular complications and bleeding events. Device embolization into the ascending aorta or back into the left ventricle may occur, particularly if there was suboptimal positioning during THV deployment. Occlusion of the coronary artery by a bulky calcified native leaflet may rarely occur. Significant heart block necessitating permanent pacemaker implantation has been documented, and serious vascular injury, including perforation leading to mortality, has also been reported. Thus, at this time, this therapy should only be considered for patients with symptomatic severe AS and high surgical risk, or who are non-operable for surgical AVR.

TAVI have been performed mainly in Europe and North America. In Taiwan, our multidisciplinary team first applied for approval of the TAVI program to the DOH, R.O.C., and the program received approval in January 2010. Between May and October 2010, 10 patients with symptomatic severe AS underwent TAVI at our institution. The procedure was successful in all cases. During the TAVI procedure or in the first 24 hours after the procedure, no intra-procedural death or major complications occurred. At 3-month clinical follow-up, there was no cardiovascular death. One patient died 25 days after a TA procedure because of pneumonia and subsequent sepsis. In the TA arm, one patient developed major vascular complication and another one with chronic kidney disease required hemodialysis at 3-month follow-up. There was no stroke or need for permanent pacemaker implantation during follow-up period.

Despite the fact that the native leaflets are not removed, valve areas of 1.42-1.45 cm^2 have been consistently achieved with mean pressure gradients around the range of 10-11 mmHg in our patients after the procedure. None of the patients had more than moderate AR at 3-month follow-up, although moderate AR was present in 20% of the patients before the procedure.

The primary limitations of the present trial are the small size of the study population and the single-center experience.

CONCLUSION

In conclusion, TAVI has emerged as an alternative to surgical AVR for selected patients with symptomatic severe AS, who are at high surgical risk or are non-operable. Although encouraging immediate and short-term outcomes were demonstrated in our first 10 TAVI cases, multi-specialty collaboration, pre-procedural evaluation with multimodality imaging, and proper patient selection are the cornerstones of success in treating these high-risk patients.

REFERENCES

1. A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Revise the 1998 Guidelines for the Management of Patients With Valvular Heart Disease 2008). Focused update incorporated into the ACC/AHA 2006 guidelines for the management of patients with valvular heart disease. C*irculation* 2008;15:e523-661.
2. Birkmeyer JD, Stukel TA, Siewers AE, et al. Surgeon volume and operative mortality in the United States. *N Engl J Med* 2003; 349:2117-27.
3. Bouma BJ, van den Brink RBA, van der Meulen JHP, et al. To operate or not on elderly patients with aortic stenosis: the decision and its consequences. *Heart* 1999;82:143-8.
4. Iung B, Cachier A, Baron G, et al. Decision-making in elderly patients with severe aortic stenosis: Why are so many denied surgery? *Eur Heart J* 2005;26:2714-20.
5. Varadarajan P, Kapoor N, Bansal RC, et al. Clinical profile and natural history of 453 nonsurgically managed patients with severe aortic stenosis. *Ann Thorac Surg* 2006;82:2111-5.
6. Bach DS, Siao D, Girard SE, et al. Evaluation of patients with severe symptomatic aortic stenosis who do not undergo aortic valve replacement. *Circ Cardiovasc Qual Outcomes* 2009;2:533-9.

7. Cribier A, Eltchaninoff H, Bash A, et al. Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: first human case description. *Circulation* 2002; 106:3006-8.
8. Cribier A, Eltchaninoff H, Tron C, et al. Treatment of calcific aortic stenosis with the percutaneous heart valve: midterm follow-up from the initial feasibility studies: the French experience. *J Am Coll Cardiol* 2006;47:1214-23.
9. Webb JG, Chandavimol M, Thompson CR, et al. Percutaneous aortic valve implantation retrograde from the femoral artery. *Circulation* 2006;113:842-50.
10. Grube E, Laborde JC, Gerckens U, et al. Percutaneous implantation of the CoreValve self-expanding valve prosthesis in high-risk patients with aortic valve disease. *Circulation* 2006;114:1616-24.
11. Walther T, Simon P, Dewey T, et al. Transapical minimally invasive aortic valve implantation: multicenter experience. *Circulation* 2007;116:I-240-5.
12. Svensson LG, Dewey T, Kapadia S, et al. United States feasibility study of transcatheter insertion of a stented aortic valve by the left ventricular apex. *Ann Thorac Surg* 2008;86:46-55.
13. Grube E, Buellesfeld L, Mueller R, et al. Progress and current status of percutaneous aortic valve replacement: results of three device generations of the CoreValve revalving system. *Circ Cardiovasc Interv* 2008;1:167-75.
14. Himbert D, Descoutures F, Al-Attar N, et al. Results of transfemoral or transapical aortic valve implantation following a uniform assessment in high-risk patients with aortic stenosis. *J Am Coll Cardiol* 2009;54:303-11.
15. Webb JG, Altwegg L, Boone RH, et al. Transcatheter aortic valve implantation: impact on clinical and valve-related outcomes. *Circulation* 2009;119:3009-16.
16. Piazza N, Grube E, Gerckens U, et al. Procedural and 30-day outcomes following transcatheter aortic valve implantation using the third generation (18 Fr) CoreValve revalving system: results from the multicentre, expanded evaluation registry 1-year following CE mark approval. *EuroIntervention* 2008;4:242-9.
17. Rodes-Cabau J, Webb JG, Cheung A, et al. Transcatheter aortic valve implantation for the treatment of severe symptomatic aortic stenosis in patients at very high or prohibitive surgical risk. *J Am Coll Cardiol* 2010;55:1080-90.
18. Thomas M, Schymik G, Walther T, et al. Thirty-day results of the SAPIEN Aortic Bioprosthesis European Outcome (SOURCE) registry. *Circulation* 2010;122:62-9.
19. Leon MB, Smith CR, Mack M, et al. Transcatheter aortic-valve implantation for aortic stenosis in patients who cannot undergo surgery. *N Engl J Med* 2010;363:1597-607.
20. Van Mieghem N, Nuis R, Piazza N, et al. Vascular complications with transcatheter aortic valve implantation using the 18 Fr Medtronic CoreValve system(R): the Rotterdam experience. *EuroIntervention* 2010;5:673-9.
21. Webb JG, Pasupati S, Humphries K, et al. Percutaneous transarterial aortic valve replacement in selected high-risk patients with aortic stenosis. *Circulation* 2007;116:755-63.
22. Leu S, Chang WN, Chen SF, Yip HK. Cerebral protection for carotid artery stenting: safety, efficacy and limitations. *Acta Cardiol Sin* 2009;25:177-82.