

Original Studies

Single Center TAVR Experience With a Focus on the Prevention and Management of Catastrophic Complications

Samir R. Kapadia, MD, FSCAI, Lars G. Svensson, MD, PhD, Eric Roselli, MD, Paul Schoenhagen, MD, Zoran Popovic, MD, Andrej Alfirovic, MD, Benico Barzilai, MD, Amar Krishnaswamy, MD, William Stewart, MD, Anand Mehta, MD, Kanhaiya Lal Poddar, MD, Akhil Parashar, MD, Dhruv Modi, MD, Alper Ozkan, MD, Umesh Khot, MD, Bruce W. Lytle, MD, and E. Murat Tuzcu,* MD, FSCAI

Background: Transcatheter aortic valve replacement (TAVR) is an important treatment option for patients with severe symptomatic aortic stenosis (AS) who are inoperable or at high risk for complications with surgical aortic valve replacement. We report here our single-center data on consecutive patients undergoing transfemoral (TF) TAVR since the inception of our program, with a special focus on minimizing and managing complications. **Methods:** The patient population consists of all consecutive patients who underwent an attempted TF-TAVR at our institution, beginning with the first procotored case in May 2006, through December 2012. Clinical, procedural, and echocardiographic data were collected by chart review and echo database query. All events are reported according to Valve Academic Research Consortium-2. **Results:** During the study period, 255 patients with AS had attempted TF-TAVR. The procedure was successful in 244 (95.7%) patients. Serious complications including aortic annular rupture ($n = 2$), coronary occlusion ($n = 2$), iliac artery rupture ($n = 1$), and ventricular embolization ($n = 1$) were successfully managed. Death and stroke rate at 30 days was 0.4% and 1.6%, respectively. One-year follow-up was complete in 171 (76%) patients. One-year mortality was 17.5% with a 3.5% stroke rate. Descending aortic rupture, while advancing the valve, was the only fatal procedural event. There were 24.4% patients with $\geq 2+$ aortic regurgitation. **Conclusions:** TAVR can be accomplished with excellent safety in a tertiary center with a well-developed infrastructure for the management of serious complications. The data presented here provide support for TAVR as an important treatment option, and results from randomized trials of patients with lower surgical risk are eagerly awaited. © 2014 Wiley Periodicals, Inc.

Key words: aortic stenosis; percutaneous intervention; TAVR; complications; vascular access; comparative effectiveness/patient centered outcomes research

INTRODUCTION

Transcatheter aortic valve replacement (TAVR) has revolutionized the management of patients with aortic

stenosis (AS) since the first valve was implanted by Professor Alan Cribier in 2002 (Rouen, France). Our understanding of the procedure and insights into patient

Heart and Vascular Institute, Cleveland Clinic, Cleveland, Ohio

*Correspondence to: E. Murat Tuzcu, MD, FACC, Professor of Medicine, Vice chairman, Department of Cardiology, 9500 Euclid Ave, J2-3, Cleveland, OH 44195. E-mail: tuzcue@ccf.org

© 2014 The Authors. Catheterization and Cardiovascular Interventions. Published by Wiley Periodicals, Inc. This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

Received 14 August 2013; Revision accepted 3 January 2014

DOI: 10.1002/ccd.25356

Published online 9 January 2014 in Wiley Online Library (wileyonlinelibrary.com)

Conflict of interest: Nothing to report.

selection has rapidly evolved, supported by encouraging retrospective and prospective clinical outcomes data [1–6]. Cardiologists and cardiac surgeons have worked together in an unprecedented manner to ensure the success of this joint venture, resulting in the first US Food and Drug Administration (FDA) approval for a transcatheter valve in November 2011.

Since commercial approval, many centers in the US have begun offering TAVR to patients with AS. Essential criteria for the performance of TAVR by these sites have been carefully delineated through a joint effort by cardiology and cardiac surgery organizations, including the American College of Cardiology (ACC), the Society of Thoracic Surgery (STS), and the Society for Cardiovascular Angiography and Interventions [7–9]. An imperative for the performance of commercial TAVR is the comprehensive reporting of patient and procedural data to the STS/ACC Transcatheter Valve Therapies (TVT) national database. This will provide an understanding of patient selection and outcomes as TAVR is applied on a broader scale [7,10].

These newer centers face important challenges including team-building, patient selection, physical infrastructure, and procedural education and competency, all while maintaining the high standard to which this new therapy must be held. One of the most difficult challenges to overcome is unexpected complications. The potentially catastrophic complications of TAVR can be managed successfully only when the entire team is fully prepared. Although guidelines for this exist, many insights can be gained by analyzing a single-center's comprehensive experience with TAVR. We have learned a great many lessons in our performance of transfemoral (TF)-TAVR and other access sites including TA, TAO, etc. In order to analyze our experience in a methodical fashion and focus on specific organizational and learning points, we have divided our experience into TF cases (presented here) and surgical (TA/TAo) cases.

Therefore, we provide here data on all patients undergoing TF-TAVR at our institution since the procedure's introduction to the US in 2006, with a special focus on our processes for the successful management of complications.

METHODS

Patient Population

The patient population consists of all consecutive patients who underwent an attempted TF-TAVR at our institution, from the first proctored case on May 5, 2006 (as part of the three center FDA feasibility trial) through December 2012. This includes patients enrolled in various clinical trials, as well as patients undergoing commercial valve replacement. The trials in which patients were enrolled include: transcatheter endovascular im-

plantation of valves (REVIVAL), placement of aortic transcatheter valve (PARTNER) trial (randomized cohorts A and B as well as continued access registries), and PARTNER II (randomized cohorts A and B as well as continued access registries); the inclusion and exclusion criteria for these trials have been previously published [2–5]. All patients who underwent TF-TAVR were assessed by both cardiologists and cardiac surgeons.

The following evaluations were performed: clinical assessment, complete metabolic profile, complete blood count, CT scan to evaluate the aortic annulus and iliofemoral access, transthoracic echocardiogram, coronary angiography, and full pulmonary function testing. In patients with impaired renal function, noncontrast CT scan was used to assess the chest, but iliofemoral access was assessed using a CT scan performed with intra-arterial contrast injection (total 12–14 cc dye) via a pigtail catheter placed in the infrarenal aorta. After 2009, all patients underwent transesophageal echocardiography (TEE) before the procedure to assess the aortic annulus size, the presence of other valvular heart disease, aortic atheroma, and intracardiac masses including thrombus. In some patients with “borderline” iliofemoral vasculature for the TF approach, intravascular ultrasound was used to further evaluate vessel diameter.

Procedural Details

All TF-TAVR procedures but one were performed under general endotracheal anesthesia and TEE guidance. A Swan-Ganz catheter and a radial or brachial arterial line were used in all patients at the time of the procedure. All procedures were performed in a hybrid catheterization laboratory with biplane fluoroscopic imaging.

In our initial experience, femoral cut-down was used until February 2010, after which percutaneous preclosure of the arteriotomy with Perclose devices (one 10 F Prostar™ or two perpendicular 8 F Proglide™, Abbott Vascular, Santa Clara, CA) was performed. In the percutaneous era, femoral cut-down was used only for patients with prior surgical aortobifemoral grafting. Bilateral arterial access was obtained in all patients with confirmation angiogram to confirm optimal puncture at a site in the common femoral artery proximal to the femoral bifurcation and distal to the inferior epigastric artery takeoff. As above, preclosure was performed for both arterial access sites. Femoral venous access was obtained on both sides; a temporary pacemaker wire was placed via the left venous access and the right venous access was kept available in case of emergency cardiopulmonary bypass (CPB). Since July 2011, a 0.018" crossover wire was routinely placed in all cases via the femoral artery access contralateral to the intended side of TAVR delivery sheath insertion (and extending to the ipsilateral superficial femoral

artery) in order to secure wire access to the true lumen in case of vascular complication due to delivery sheath insertion and manipulation. This was performed before delivery sheath insertion but after the preclosure. A 5 F pigtail catheter was always placed in the noncoronary sinus from the contralateral femoral access to perform aortic root angiography to confirm valve positioning before deployment. All patients were anticoagulated before insertion of the large sheath. In 253 patients, unfractionated heparin (UFH) was used with a target ACT of 300 sec; in two patients with contraindication to UFH use, bivalirudin was substituted.

The aortic valve was crossed using a 5 F AL-1 diagnostic catheter and an 0.035" straight wire. After obtaining initial hemodynamics, an 0.035" extra-stiff Amplatz wire (curved to provide atraumatic placement in the left ventricle (LV)) was advanced to secure position across the valve. Balloon aortic valvuloplasty (BAV) was performed with a balloon smaller than the intended valve size (20 mm balloon for 23 mm valve and 22 or 23 mm balloon for 26 or 29 mm valve, respectively). BAV was performed under rapid ventricular pacing, usually at a rate of 180 bpm. Lower rates (170 or 160 bpm) were used in a few patients who demonstrated inconsistent capture at 180 bpm. The valve was prepped and ready to implant before performance of the BAV, in case severe aortic regurgitation (AR) complicated the BAV. All patients at our center underwent TAVR using the Edwards SAPIEN balloon-expandable prosthesis (Edwards Lifesciences, Irvine, CA).

Fluoroscopic angles perpendicular to the AV plane were determined by prior angiography or CT scan in all patients. At the time of valve implantation, position in the annulus was confirmed by aortic root injection under biplane imaging (typically one camera in RAO Caudal and another in LAO Cranial projection) and TEE. For all procedures, at least one cardiovascular surgeon and two interventional cardiologists with structural and peripheral interventional skills were "scrubbed" at the bedside. TEE was performed by cardiologists board-certified in cardiac imaging in all cases. Board-certified cardiac anesthesiologists were present in all cases at the time of valve deployment. AR and valve placement were assessed by comprehensive hemodynamic analysis; simultaneous pressure measurement in the LV and aorta was obtained in all patients after valve deployment. After removal of the delivery sheath, selective angiography of the delivery-side iliofemoral tree was performed in all patients. Patients received protamine if access site closure was successful without vascular complications. The majority of patients were extubated in the catheterization laboratory before transfer to an intensive care unit.

Clopidogrel was continued through the periprocedural period if patients were already taking clopidogrel. For those patients who were not on clopidogrel, a 300 mg

bolus was given after valve replacement. Clopidogrel was continued for 6 months (unless there was a strong contraindication to its use), and aspirin 81 mg prescribed indefinitely. In patients requiring warfarin, clopidogrel was given for 7 days postprocedure or until patients demonstrated a therapeutic international normalized ratio.

All patients were scheduled for clinical follow-up at 30 days, 6 months, and 1 year. If patients could not travel to Cleveland, local physicians were contacted for follow-up. Echocardiograms were performed on follow-up visits.

Data Collection

Data collection was performed under approval by the institutional review board. All patients who had attempted TF-TAVR were identified in our institutional database of AS patients. Baseline characteristics, complications, and events were collected by an extensive review of the individual patient medical records and adjudicated by S.R.K., E.M.T., L.G.S., and A.K. The social security death index and the institutional clinical databases were analyzed for every patient to ensure comprehensive and complete clinical outcomes data.

Definitions

All outcomes were defined according to the standardized Valve Academic Research Consortium-2 (VARC-2) guidelines [11]. Stroke was defined as duration of a focal or global neurological deficit ≥ 24 h; or < 24 h if available neuroimaging demonstrated a new hemorrhage or infarct; or the neurological deficit resulted in death. Major bleeding included life-threatening bleeding, disabling bleeding, or major bleeding as per VARC-2 [11]. Renal failure events were defined as chronic dialysis of any sort (hemodialysis, CVVHD, and peritoneal) for a duration of greater than 30 days. In addition, any episode of renal replacement therapy, either transient or greater than 30 days duration, was considered as renal failure. The date of event was based on the date of the first treatment with renal replacement therapy. Clinical data were collected from systematic follow-up of all patients.

Peripheral vascular disease was defined as documented severe ($> 50\%$) stenosis of the arch vessels, lower extremity vessels, renal arteries, or aortic aneurysmal disease. Catastrophic complications were defined as those complications that would most likely result in death if not promptly diagnosed and treated within minutes. These included: coronary artery occlusion, annulus rupture, aortic rupture, vascular rupture, cardiac perforation, severe AR, and valve embolization.

Statistical Analysis

Continuous variables are reported as mean \pm standard deviation and categorical variables are reported as

TABLE I. Baseline Characteristics

Characteristics	All patients (N = 255)	Inoperable (N = 144)	Operable (N = 111)	P-value
Age	80.71 ± 9.86	79.43 ± 10.03	82.39 ± 5.80	0.015
Male sex	149/255 (58.43)	79/144 (54.9)	70/111 (63.1)	0.202
Hypertension	215/255 (84.31)	122/144 (84.7)	93/111 (83.8)	0.863
Diabetes	113/255 (44.31)	61/144 (42.4)	52/111 (46.8)	0.526
Hyperlipidemia	194/255 (76.1)	105/144 (72.9)	89/111 (80.2)	0.187
Society of thoracic surgeons (STS) score (%)	9.74 ± 5.16	9.48 ± 5.76	10.07 ± 4.51	0.367
Logistic EuroSCORE (%)	26.12 ± 19.09	23.35 ± 18.85	30.04 ± 18.82	0.012
New York Heart Association Class III/IV	238/255 (93.33)	129/144 (89.6)	109/111 (98.2)	0.009
Coronary artery disease	213/255 (83.53)	117/144 (81.3)	96/111 (86.5)	0.309
Previous myocardial Infarction	73/255 (28.63)	43/144 (29.9)	30/111 (27.0)	0.676
Previous CABG	123/255 (48.23)	65/144 (45.1)	58/111 (52.3)	0.312
Previous PCI	75/255 (29.41)	32/144 (25.9)	43/111 (38.7)	0.005
Previous balloon aortic valvuloplasty	45/255 (17.65)	24/144 (26.7)	21/111 (18.9)	0.741
Cerebrovascular disease	49/255 (19.22)	27/144 (18.8)	22/111 (19.8)	0.873
Peripheral vascular disease	64/255 (25.10)	44/144 (30.6)	20/111 (18.0)	0.029
COPD	102/255 (40.0)	71/144 (49.3)	31/111 (27.9)	0.001
Creatinine (mL/kg)	1.16 ± 0.46	1.16 ± 0.44	1.20 ± 0.48	0.973
Ejection fraction (%)	48.72 ± 14.37	48.98 ± 14.63	49.39 ± 14.07	0.742

a percentage (%). *T*-test, chi square test, survival analysis, and other statistical analysis were performed according to standard methods using SPSS 18.0 statistical software (IBM Corporation). Baseline variables (Table I) were used in the multivariate analysis to determine predictors of mortality.

RESULTS

Patient Population

Between 2006 and 2012, a total of 255 patients with AS underwent attempted TF-TAVR. Eleven patients were enrolled in the REVIVAL study, 25 in PARTNER IB, 105 in PARTNER IA, 42 in PARTNER IIB, and six patients in PARTNER IIA. Sixty-six patients underwent attempted commercial-approved TF-TAVR. All patients were designated as either inoperable ($N = 144$, 56.5%) or operable with moderate or high surgical risk ($N = 111$, 43.5%) after a thorough heart team assessment before the procedure. Baseline characteristics of these patients are listed in Table I. The patients were elderly (mean age 80.71 ± 9.86) and 58% of them were male. They demonstrated multiple comorbidities including diabetes, coronary artery disease, COPD, and impaired LV systolic function. Figure 1 indicates the volume of TF-TAVR procedures and individual complications encountered during each year from 2006 to 2012.

Procedural Outcomes

The procedure was successful in 244 (95.7%) patients. There was one intraprocedural death which was the result of descending aortic rupture; the patient died during emergent open surgical repair due to

friable tissues and uncontrolled bleeding. Procedural outcomes are listed in Table II.

Unsuccessful Procedures

The majority of unsuccessful procedures were due to the inability to insert the delivery sheath successfully, whereas others were due to an inability to cross the native AV with the TAVR prosthesis. We were unable to insert the delivery sheath in eight patients. Four of eight (50%) of them had successful BAV, whereas transapical TAVR (TA-TAVR) was successfully performed in the remaining 4/8 (50%) patients. In three patients, we were unable to cross the native valve with the prosthetic valve; all three of these patients had successful BAV. The decision to perform TA-TAVR in these patients was governed by their operative risk and granting of pre-procedural consent.

Catastrophic Complications

Acute, life-threatening complications encountered in our experience included: ventricular valve embolization ($n = 1$), iliac artery rupture ($n = 1$), annular rupture ($n = 2$), descending aorta rupture ($n = 1$), and coronary occlusion ($n = 2$). The management of these patients in the cardiac catheterization laboratory is outlined in Table III. Aside from the descending aorta rupture, all other complications were managed successfully without 30-day mortality or stroke. A valve-in-valve was placed in 10 (3.9%) of patients during the index TAVR procedure. Severe valvular regurgitation was the reason for a 2nd valve in two patients. In eight patients, the second valve was placed due to severe paravalvular leak that resulted from malpositioning of the first valve.

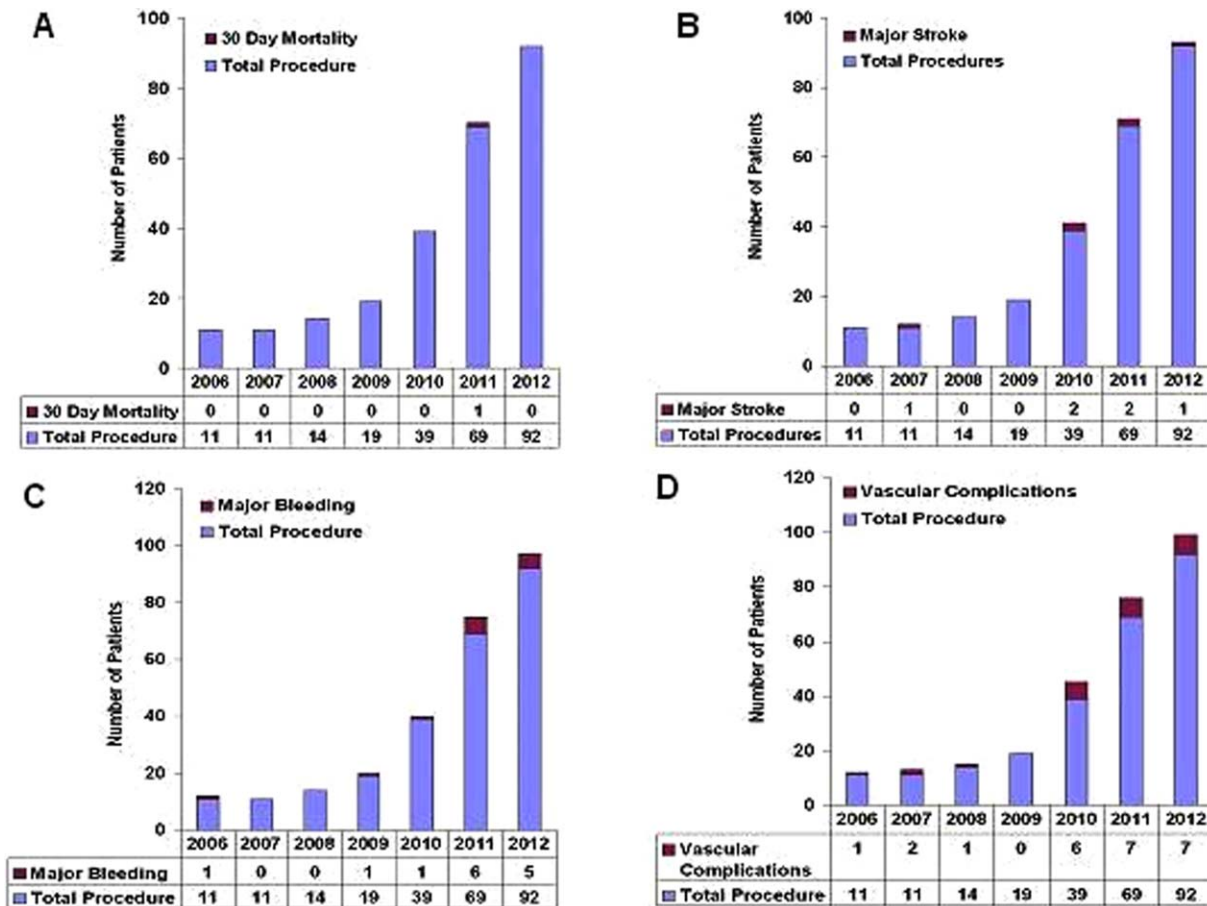


Fig. 1. Total number of transfemoral TAVI procedures performed and complications each year from 2006 to 2012. Panel shows (A) 30 days mortality, (B) major stroke in a year, (C) major bleeding events, and (D) vascular complications. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

30-Day Outcomes

One patient (0.4%) died within 30-days, and four patients (1.6%) suffered a stroke within 30-days. Outcomes of patients according to the year in which the procedure was performed are shown in Fig. 1.

1-Year Outcomes

One-year outcomes are listed in Table II. Overall actuarial mortality at 1-year was 17.5% (17.3% among operable patients and 17.9% among inoperable patients) of the 171 patients with 1-year follow-up. In these patients, two additional strokes occurred between 30 days and 1 year. Most patients (76.6%) had NYHA class I or II symptoms, 19.9% had class III symptoms, and 3.5% had NYHA IV symptoms. Kaplan-Meier estimates revealed no significant difference in mortality or the combination of mortality and stroke between the operable and inoperable groups. Total outcomes for each year, along with number of patients at risk at the start of the year, are shown in Fig. 2.

In the multivariate model, long-term mortality was associated with prior BAV (P value = 0.03; odds ratio (OR) 2.18; 95% confidence interval (CI) 1.07–4.42), no CABG before TAVR (P value = 0.01; OR 0.46; 95% CI 1.10–6.43), and higher STS score (P value = 0.02; OR 1.07; 95% CI 1.01–1.13).

Echocardiographic Follow-Up

Echocardiograms were independently reviewed by imaging specialists not involved in the TAVR procedure, and severity of valve disease pre- and post-procedure was graded based upon the consensus definitions of the American Society of Echocardiography [12]. Echocardiographic data at baseline and follow-up are reported in Table IV. The peak and mean aortic valve gradient was 76.73 ± 25.10 mm Hg and 45.05 ± 15.04 mm Hg, respectively. Baseline aortic insufficiency $\geq 2+$ was present in 31.4% patients. On 30-day or pre-discharge echocardiogram, mild (2+)

TABLE II. 30-Day and 1-Year Outcomes

Outcomes	30=Day outcomes			1-Year outcomes		
	Total (n = 255)	Inoperable (n = 144)	Operable (n = 111)	Total (n = 171)	Inoperable (n = 67)	Operable (n = 104)
Mortality	1 (0.4)	1 (0.7)	0 (0.0)	30 (17.5)	12 (17.9)	18 (17.3)
Stroke	4 (1.6)	2 (1.4)	2 (1.8)	6 (3.5)	2 (3.0)	4 (3.8)
Rehospitalization	12 (4.7)	7 (4.9)	5 (4.5)	31 (18.1)	15 (22.4)	16 (15.4)
NYHA III/IV	20 (7.8)	10 (6.9)	10 (9.0)	40 (23.4)	17 (25.4)	23 (22.1)
NYHA III	18 (7.1)	9 (6.3)	9 (8.1)	34 (19.9)	15 (22.4)	19 (18.3)
NYHA IV	2 (0.8)	1 (0.7)	1 (0.9)	6 (3.5)	2 (3.0)	4 (3.8)
MI	2 (0.8)	2 (1.4)	0 (0.0)	2 (1.2)	2 (3.0)	0 (0.0)
Renal failure	6 (2.4)	4 (2.8)	2 (1.8)	4 (2.3)	1 (1.5)	3 (2.9)
Cr > 3 mg/dL (>265 μmol/L)	5 (2.0)	4 (2.8)	1 (0.9)	1 (0.6)	0 (0.0)	1 (1.0)
Major bleeding	14 (5.5) ^a	6 (4.2)	8 (7.2)	9 (5.3)	1 (1.5)	8 (1.0)
Major vascular complications	24 (9.4) ^b	11 (7.6)	13 (11.7)	18 (10.5)	6 (9.0)	12 (11.5)
BAV only	3 (1.2)	2 (1.4)	1 (0.9)	2 (1.2)	1 (1.5)	1 (1.0)
Surgical AVR	2 (0.8)	1 (0.7)	1 (0.9)	2 (1.2)	1 (1.5)	1 (1.0)
Endocarditis	1 (0.4)	1 (0.7)	0 (0.0)	1 (0.6)	1 (1.5)	0 (0.0)
Pacemaker	10 (3.9)	6 (4.2)	4 (3.6)	9 (5.3)	5 (7.5)	4 (3.8)
Valve embolization	2 (0.8)	0 (0.0)	2 (.8)	2 (1.2)	0 (0.0)	2 (1.9)

^aAll cases of major bleeding within 30 days occurred either during the procedure or before discharge. All numbers are actuarial outcomes.

^bMajor vascular complication after the procedure.

TABLE III. Management of Catastrophic Complications During TF-TAVR

Details of complication	Management	Learning point
LM occlusion	TandemHeart Successful stenting of LM	Prediction of this complication by measurement of coronary ostium height versus coronary leaflet length. Emergent use of support devices until perfusion is restored
RCA occlusion	Successful, brief AV ECMO support	Occlusion from aortic hematoma, managed conservatively as RCA was small; patient weaned from ECMO in the cath. lab.
Ventricular valve embolization	Successful conversion to open AVR	Capability of open AVR in the hybrid room
Rupture of tortuous descending aorta when advancing Sapien XT	Immediate thoracotomy with attempt to control bleeding and Fem-Fem support was unsuccessful	Inability to suture due to friable tissue in the setting of old age (91 years) and chronic steroid use. Immediate stent graft from contralateral groin could have been useful; now included in our "perforation cart."
Rupture of aortic annulus during valve deployment	Successful conversion to surgical AVR and control of bleeding.	Valve sizing was appropriate, but calcification of the LVOT should be assessed.

AVR, aortic valve replacement; ECMO, extracorporeal membrane oxygenation; LMT, left main trunk; LVOT, left ventricular outflow tract; RCA, right coronary artery.

AR was present in 22.4% of patients. Moderate or severe AR (>2+) was present in 2% of patients. Moderate or severe mitral regurgitation was present in 12.9% of the patients at baseline but in 7.9% at 30 days follow-up. Also, ejection fraction was <40% in 59 (23.1%) patients at baseline.

DISCUSSION

This single-center report of all consecutive patients undergoing TF-TAVR (including the initial US experience) highlights several points. TF-TAVR can be accomplished with extremely low 30-day mortality (0.4%) in sick patients in a well-organized cardiovascular facility, mainly because of expeditious manage-

ment of catastrophic complications. Preparedness of the entire team to manage uncommon, life-threatening complications is critical for patient survival. The collaboration of specialists in cardiac imaging, cardiac anesthesia, nurses, and technicians, in addition to interventional cardiologists trained in peripheral, structural, and coronary intervention, cardiac surgeons, and the immediate availability of cardiopulmonary support were thought to be important for patient survival.

Our TAVR program began in 2006 as part of the REVIVAL study of inoperable patients [6,12]. Subsequently, inoperable patients were treated as part of the PARTNER I and II Cohort B study groups, and high surgical risk patients were treated under the PARTNER I Cohort A study [4,5]. More recently, inoperable patients have been treated with commercial availability

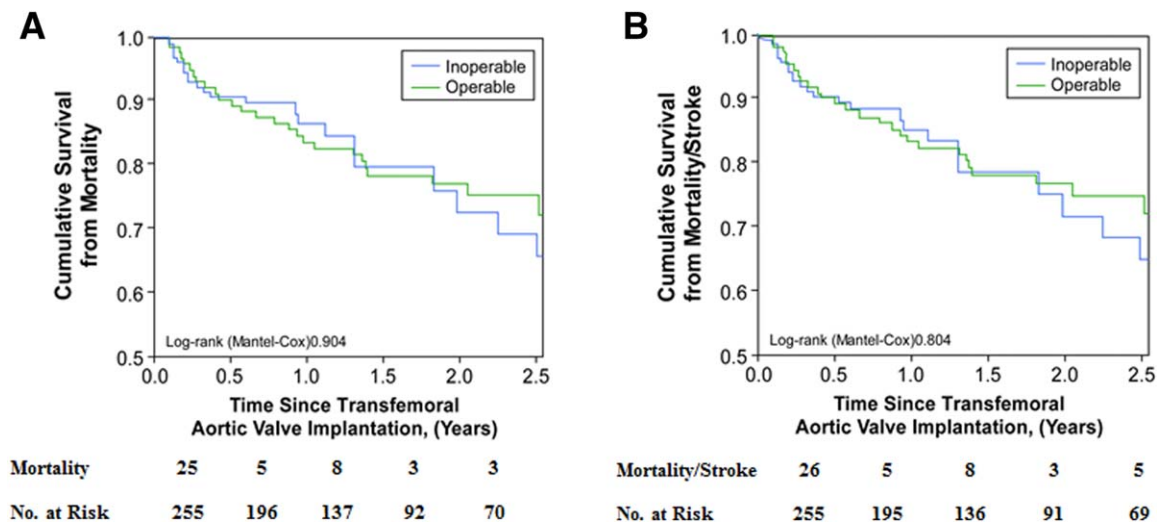


Fig. 2. (a) Kaplan Meier curve showing mortality in patients undergoing TF-TAVR. X-axis denotes the time period, in years, since the procedure, whereas Y-axis denotes the cumulative survival. (b) Kaplan Meier curve showing mortality or stroke in patients undergoing TF-TAVR. X-axis denotes the time period, in years, since the procedure, whereas Y-axis denotes the cumulative survival. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE IV. Echocardiographic Characteristics

	Preprocedure (n = 255 pts)	1-Month follow-up (n = 254 pts) ^a
Aortic valve gradient (Mean)	45.05 ± 15.04	11.86 ± 5.95 ^b
Mitral regurgitation		
<2+	135/255 (52.9)	144/254 (65.4) ^b
2+	86/255 (33.7)	68/254 (26.8)
>2+	33/255 (12.9)	20/254 (7.9)
Aortic insufficiency		
<2+	175/255 (67.5)	192/254 (75.6)
2+	69/255 (27.1)	57/254 (22.4)
>2+	11/255 (4.3)	5/254 (2.0)
Ejection Fraction	48.93 ± 14.64	51.97 ± 13.03

^aOne patient could not complete 1-month follow-up.

^bP value <0.05 as compared with baseline.

of the Sapien valve since October 2011, and a small number of moderate surgical risk patients were treated in 2012 as part of the PARTNER II Cohort A study. The program initially began with two interventional cardiologists, two cardiac surgeons, three imaging cardiologists, two cardiac anesthesiologists, and one research nurse; it has now grown to include four interventional cardiologists, four cardiac surgeons, more than 12 imaging cardiologists, three clinical cardiologists, more than eight cardiac anesthesiologists, and four nurses.

Importantly, with the evolution of our infrastructure to handle increasing demands, good outcomes persisted. We believe that the outstanding communication in the “TAVR community” that has been fostered by PARTNER trial conference calls to aide patient selection, and multicenter and international conferences to

discuss the prevention and management of complications contributed to the absence of a “learning curve” phenomenon seen in our experience (Fig. 1). Another important contribution, although difficult to quantify, came from our center’s surgical experience in treating AS. This created an existing infrastructure into which the TAVR procedure was welcomed, and catastrophic complications were often dealt with emergently and effectively by our surgical partners.

The set-up and procedural resources deserve special attention. All TF-TAVR procedures were performed with at least two interventional cardiologists with structural and peripheral interventional skills and at least one cardiac surgeon “scrubbed” at the bedside. Two sets of nurses were present to provide both operating room and catheterization lab experience. A CPB machine was immediately available in the room and primed for all cases.

Plans for management of complications were discussed and rehearsed with the entire team before the procedure. Dedicated “crash carts” containing necessary equipment for emergent surgical or peripheral “bail-out” were present at all cases. It is clear that a number of successful salvages could be attributed to this infrastructure and personnel utilization. However, we must recognize that resource utilization for this effort is considerable and may not be sustainable under current reimbursement schedules. To be proactive in a changing climate of health economics, we are reorganizing the location of our hybrid room to provide more proximity to the traditional operating rooms in order

to reduce resource utilization, although the impact of this intervention remains to be seen.

As TAVR evolves with next-generation devices and is applied to lower risk patient populations, it will be important to see how programs adapt to the changing landscape. Several new programs are emerging under close monitoring by the STS and ACC using the TVT registry [7–9]. In order to maintain the historically low complication rates demonstrated in ours and others' early experience, thorough patient assessment and selection, advanced peripheral and structural interventional training, continued multi-center discourse, and institutional teamwork is imperative.

While not directly comparable, the data from our single center demonstrate lower mortality than most reported series, with higher survival at 12 months in both operable and inoperable patients. Although the average STS score in our group (9.74) was slightly lower than the average in the PARTNER Cohort A (11.8) and Cohort B (11.2) trials, it remains well within the range of high-risk or inoperability, as also deemed by our surgical team [3–5]. Interestingly, the mortality of patients who were operable versus inoperable is not substantially different. This suggests that there are other factors that determine mortality [3]. We found that the STS score was one of the most important factors determining 1-year mortality, confirming the contribution of comorbid conditions to long-term outcome and as demonstrated in recent analyses of the PARTNER I trial [13]. Prior BAV was also a predictor of higher mortality after TF-TAVR, likely due to the fact that BAV was invariably performed in patients whose comorbidities precluded a direct pathway to an AVR procedure [14,15].

Limitations

The most important limitation of this report is that generalizability of single-center findings may be limited. Our institution has a very large surgical experience in aortic valve surgeries and cardiovascular surgeries in general. This provides a unique infrastructure that may be difficult to duplicate in other programs. Further, our collaborative model and the utilization of multiple physicians in the same procedure are difficult to sustain. Finally, the ability to learn from our experience was influenced by several physicians who have dedicated their practices to this newer treatment modality, which may be difficult to do in other centers for a procedure with a complicated reimbursement scheme.

CONCLUSIONS

In summary, this single-center experience details several important messages for centers starting their

initial experience in TAVR, including procedural techniques and strategies to manage life-threatening complications. It highlights several challenges including resource utilization and infrastructure setup in the current health care environment. The encouraging outcomes presented herein provide support to previously published multicenter randomized and registry data of TF-TAVR among high-risk and inoperable patients. Given the broad base of data in these groups, more data supporting TAVR among lower risk surgical groups is eagerly awaited.

REFERENCES

1. Cribier A, Eltchaninoff H, Bash A, Borenstein N, Tron C, Bauer F, Derumeaux G, Anselme F, Laborde F, Leon MB. Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: First human case description. *Circulation* 2002;106:3006–3008.
2. Kodali SK, Williams MR, Smith CR, Svensson LG, Webb JG, Makkarr RR, Fontana GP, Dewey TM, Thourani VH, Pichard AD, Fischbein M, Szeto WY, Lim S, Greason KL, Teirstein PS, Malaisrie SC, Douglas PS, Hahn RT, Whisenant B, Zajarias A, Wang D, Akin JJ, Anderson WN, Leon MB. Two-year outcomes after transcatheter or surgical aortic-valve replacement. *N Engl J Med* 2012;366:1686–1695.
3. Makkarr RR, Fontana GP, Jilaihawi H, Kapadia S, Pichard AD, Douglas PS, Thourani VH, Babaliaros VC, Webb JG, Herrmann HC, Bavaria JE, Kodali S, Brown DL, Bowers B, Dewey TM, Svensson LG, Tuzcu M, Moses JW, Williams MR, Siegel RJ, Akin JJ, Anderson WN, Pocock S, Smith CR, Leon MB. Transcatheter aortic-valve replacement for inoperable severe aortic stenosis. *N Engl J Med* 2012;366:1696–1704.
4. Smith CR, Leon MB, Mack MJ, Miller DC, Moses JW, Svensson LG, Tuzcu EM, Webb JG, Fontana GP, Makkarr RR, Williams M, Dewey T, Kapadia S, Babaliaros V, Thourani VH, Corso P, Pichard AD, Bavaria JE, Herrmann HC, Akin JJ, Anderson WN, Wang D, Pocock SJ. Transcatheter versus surgical aortic-valve replacement in high-risk patients. *N Engl J Med* 2011;364:2187–2198.
5. Leon MB, Smith CR, Mack M, Miller DC, Moses JW, Svensson LG, Tuzcu EM, Webb JG, Fontana GP, Makkarr RR, Brown DL, Block PC, Guyton RA, Pichard AD, Bavaria JE, Herrmann HC, Douglas PS, Petersen JL, Akin JJ, Anderson WN, Wang D, Pocock S. Transcatheter aortic-valve implantation for aortic stenosis in patients who cannot undergo surgery. *N Engl J Med* 2010;363:1597–1607.
6. Svensson LG, Dewey T, Kapadia S, Roselli EE, Stewart A, Williams M, Anderson WN, Brown D, Leon M, Lytle B, Moses J, Mack M, Tuzcu M, Smith C. United States feasibility study of transcatheter insertion of a stented aortic valve by the left ventricular apex. *Ann Thorac Surg* 2008;86:46–54; discussion 54–55.
7. Carroll JD, Edwards FH, Marinac-Dabic D, Brindis RG, Grover FL, Peterson ED, Tuzcu M, Shahian DM, Rumsfeld JS, Shewan CM, Hewitt K, Holmes DR Jr, Mack MJ. The STS-ACC Transcatheter Valve Therapy National Registry: A new partnership and infrastructure for the introduction and surveillance of medical devices and therapies. *J Am Coll Cardiol* 2013;62:1026–1034.
8. Holmes DR Jr, Mack MJ, Kaul S, Agnihotri A, Alexander KP, Bailey SR, Calhoun JH, Carabello BA, Desai MY, Edwards FH, Francis GS, Gardner TJ, Kappetein AP, Linderbaum JA, Mukherjee C, Mukherjee D, Otto CM, Ruiz CE, Sacco RL,

- Smith D, Thomas JD, Harrington RA, Bhatt DL, Ferrari VA, Fisher JD, Garcia MJ, Gardner TJ, Gentile F, Gilson MF, Hernandez AF, Jacobs AK, Kaul S, Linderbaum JA, Moliterno DJ, Weitz HH; American Heart Association; American Society of Echocardiography; European Association for Cardio-Thoracic Surgery; Heart Failure Society of America; Mended Hearts; Society of Cardiovascular Anesthesiologists; Society of Cardiovascular Computed Tomography; Society for Cardiovascular Magnetic Resonance. 2012 ACCF/AATS/SCAI/STS expert consensus document on transcatheter aortic valve replacement: Developed in collaboration with the American Heart Association, American Society of Echocardiography, European Association for Cardio-Thoracic Surgery, Heart Failure Society of America, Mended Hearts, Society of Cardiovascular Anesthesiologists, Society of Cardiovascular Computed Tomography, and Society for Cardiovascular Magnetic Resonance. *J Thorac Cardiovasc Surg* 2012;144:e29–e84.
9. Tommaso CL, Bolman RM III, Feldman T. Multisociety (AATS, ACCF, SCAI, and STS) expert consensus statement: Operator and institutional requirements for transcatheter valve repair and replacement, part 1: Transcatheter aortic valve replacement. *J Thorac Cardiovasc Surg* 2012;143:1254–1263.
 10. Mack MJ, Holmes DR Jr. Rational dispersion for the introduction of transcatheter valve therapy. *JAMA* 2011;306:2149–2150.
 11. Kappetein AP, Head SJ, Genereux P, Piazza N, van Mieghem NM, Blackstone EH, Brott TG, Cohen DJ, Cutlip DE, van Es GA, Hahn RT, Kirtane AJ, Krucoff MW, Kodali S, Mack MJ, Mehran R, Rodes-Cabau J, Vranckx P, Webb JG, Windecker S, Serruys PW, Leon MB. Updated standardized endpoint definitions for transcatheter aortic valve implantation: The Valve Academic Research Consortium-2 consensus document. *J Thorac Cardiovasc Surg* 2013;145:6–23.
 12. Kodali SK, O'Neill WW, Moses JW, Williams M, Smith CR, Tuzcu M, Svensson LG, Kapadia S, Hanzel G, Kirtane AJ, Leon MB. Early and late (one year) outcomes following transcatheter aortic valve implantation in patients with severe aortic stenosis (from the United States REVIVAL trial). *Am J Cardiol* 2011;107:1058–1064.
 13. Kapadia SR, PARTNER Trial Investigators. Three-year outcomes of transcatheter aortic valve replacement (TAVR) in inoperable patients with severe aortic stenosis: The PARTNER trial. In: *Transcatheter Cardiovascular Therapeutics 24th Annual Scientific Symposium*, October 22–26, Miami, Florida, 2012.
 14. Kapadia SR, Goel SS, Yuksel U, Agarwal S, Pettersson G, Svensson LG, Smedira NG, Whitlow PL, Lytle BW, Tuzcu EM. Lessons learned from balloon aortic valvuloplasty experience from the pre-transcatheter aortic valve implantation era. *J Interv Cardiol* 2010;23:499–508.
 15. Krishnaswamy A, Tuzcu EM. Balloon aortic valvuloplasty for the triage of patients with aortic stenosis. *Catheter Cardiovasc Interv* 2013;81:364–365.