Trans-catheter Aortic Valve Implantation Guidelines – Does the Latest Evidence Change our Views?

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Abstract

From the wealth of recent registries and trials scrutinising its performance, trans-catheter aortic valve implantation (TAVI) emerges as a viable and rapidly established option, both when compared to medical treatment in inoperable patients and when compared to conventional surgical treatment in high-risk patients. Results consistently demonstrate improvement in functional status and outcome; however, appropriate patient selection remains crucial as high-risk cohorts become apparent.

Keywords

Trans-catheter aortic valve implantation (TAVI), aortic stenosis

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Alain Cribier's determination in the 1980s to provide a definitive solution for high-risk surgical candidates with severe aortic stenosis was met with significant resistance. However, over many years trans-catheter aortic valve implantation (TAVI) was developed and refined, leading to the first human procedure in April 2002 in France. Since this first description by Cribier et al.,¹ there are now more than 2,000 TAVI-related articles in peer-reviewed journals. Currently, there are two main devices used in routine practice: the Sapien XT (Edwards Lifesciences, California, US), and the CoreValve (Medtronic Inc., Minneapolis, US), both of which consist of a trileaflet valve: the former delivered using a balloon expandable cobalt chromium open-cell stent and made from bovine pericardial tissue; the latter using a self-expandable nitinol stent and made from porcine tissue.

Valve disease strongly correlates with the phenomenon of population ageing.² The UK over-65 population has increased by 1.7 million in the last 15 years and by projection it is estimated that by 2034, 23 % of the population will be aged 65 or over. Moreover, the 2010 to 2011 adult cardiac surgery audit has noted that the population of patients being put forward for cardiac surgery is increasingly high risk, where the overall predicted mortality of the population as assessed by the mean logistic European System for Cardiac Operative Risk Evaluation (euroSCORE) has increased from 3.7 % in 2001 to 4.6 % in 2010.³ The treatment of valvular heart disease will therefore continue to be an increasing burden on healthcare resources, with clinicians often facing a dilemma of suitability for surgical intervention.

The current recommendations from the British Cardiovascular Intervention Society (BCIS) and the Society of Cardiothoracic Surgeons (SCTS) are that TAVI should be reserved for patients who have been

assessed by a multidisciplinary team (MDT) comprising two cardiac surgeons and two interventional cardiologists, and whose risk of open heart surgery is assessed to be too great (usually euroSCORE >20 and Society of Thoracic Surgeons (STS) score >10).⁴ Patients should have severe symptomatic aortic stenosis, and the procedure should be performed by an experienced team including interventional cardiologists, cardiac surgeons, cardiac anaesthetists and cardiac imaging specialists.⁵

TAVI has quickly evolved and programmes have grown considerably, and while TAVI is now considered a viable alternative to surgical aortic valve replacement (SAVR) where an open heart operation would be too precarious, careful consideration is required before proposing percutaneous valve implantation for a high-risk surgical patient. The long-term results are only beginning to emerge, and TAVI is not without risk.

Evidence

From cohort B of the Placement of AoRtic TranScathetER Valves (PARTNER) trial,⁶ we appreciate that the outcome after TAVI compared with medical therapy in a very high-risk patient group is favourable with significant improved 1-year survival and cardiac symptoms.

The Trans-catheter Valve Treatment Sentinel Pilot Registry⁷ prospectively collected patient data from 4,571 procedures carried out between January 2011 and May 2012, in 137 centres across 10 European countries, using both Sapien XT and CoreValve prostheses. The average age was 81.4 ± 7.1 years, logistic euroSCORE 20.2 ± 13.3 and New York Heart Association (NYHA) class III or IV was present in 76.9 % of patients. The left ventricular ejection fraction (LVEF) prior to undergoing TAVI was preserved in the majority of cases (mean 54.1 ± 13.8 %) (see *Figure 1*), with only 8.2 % of patients having significantly impaired LVEF ≤ 30 %.

Valve deployment was successful in 96.5 % of patients, although a second valve was required in 2.4 % of cases, and surgical conversion occurred in 4.3 %. Analysis of in-hospital mortality demonstrated a sizeable difference between approaches – total mortality reached 7.4 %, the transfemoral approach was associated with a notably lower risk at 5.9 %, while trans-apical (12.8 %) and trans-subclavian and other approaches (9.7 %) were associated with adverse outcomes (most likely as a consequence of differing clinical characteristics). A significant difference in permanent pacing requirements was also observed between devices used – the CoreValve resulting in 23.4 % versus 6 % for Sapien XT valves. Similarly, a lower rate of aortic regurgitation (AR) was associated with use of Sapien XT valve (3.8 % versus 6.7 % in the CoreValve valve for both grade 2 and 3 AR). The duration of hospital stay varied between countries (mean 9.3 ± 8.1 days), being more prolonged if general anaesthesia had been administered (10.2 ± 8.7 days versus 7.9 ± 6.1 days) and if a trans-apical or another surgical approach had been used (43.8 % and 39.5 % stayed in hospital >10 days versus 22.0 % of patients treated trans-femorally).

This registry has highlighted that, in Europe, TAVI is still reserved for older patients, and is rarely used in patients under the age of 70 (where special circumstances and/or prohibitive comorbidities may exist).

The 1-year outcomes of the SAPIEN Aortic Bioprosthesis European Outcome-XT (SOURCE) study were presented on behalf of the investigators by Dr Stephan Windecker during the European Association of Percutaneous Cardiovascular Interventions (EuroPCR) congress in 2013.⁸ This is a prospective, observational registry to assess the effectiveness and major adverse events in all patients implanted with a Sapien XT valve (Edwards Lifesciences), via trans-femoral or trans-apical access and worth noting that the patients included had a slightly lower mean euroSCORE when compared with the patients enrolled in the earlier SOURCE registry of recipients of the predecessor Sapien valve. From 93 centres in 17 countries, 2,688 patients were included in the study. Procedural complication risks (within 48 hours) were as follows: death 2.3 %, stroke 2.2 %, cardiac tamponade 0.9 %, permanent pacemaker implantation 5.7 %, major/life-threatening bleeding 10.8 % and vascular access-related complications 11 %.

Again, a significant disparity between vascular access and mortality was noted, with the highest 1-year survival in the trans-femorally treated patients (85 %), and other routes carrying apparent increased risk (trans-apical and trans-aortic 1-year survival 72.8 % and 73.9 %, respectively). However, the patients requiring an alternative to femoral access are likely to have comorbidities that make this route unsafe (severe peripheral vascular disease with associated cerebrovascular and coronary artery disease), and may therefore be considered inherently higher-risk patients.

The all-cause mortality at 1 year was 19.5 %, and cardiac mortality 10.8 %, which is encouraging in showing a downward trend in mortality rates after TAVI, and also demonstrating a lower incidence of para-valvular regurgitation (PAR) at 1 year than previously reported (6.2 % versus 10.5 % in the PARTNER B trial).⁶ In multivariate analyses, only porcelain aorta, liver disease, renal impairment, significant tricuspid regurgitation and coronary artery disease (not PAR) emerged as predictors of mortality.

Substantial symptomatic benefit is achieved one year after TAVI with the proportion of patients in NYHA class III or IV reducing from 75.3 % to 9.7 %. Similarly, quality of life (assessed by the EuroQoL 5D [EQ-

Figure 1: Haemodynamic Changes after Trans-catheter Aortic Valve Implantation

LV/AO = left ventricle/ascending aorta; LVEF = left ventricular ejection fraction.

Figure 2: PARTNER A – All-cause Mortality¹⁰

5D] scale) improved from 49.3 to 69.5, and the proportion of patients with angina reduced from 45 % at baseline to 20.6 %.⁹ Women fared better than men with 90.6 % versus 87.6 % free from cardiac events, and 82.5 % versus 77.9 % freedom from all-cause events at 1 year.

The 3-year outcome of the PARTNER cohort A trial in 699 operable high-risk patients with severe aortic stenosis after TAVI or sAVR was presented by Dr Vinod Thourani at the American College of Cardiology Scientific Session Summit in March 2013¹⁰ and revealed similar all-cause mortality (44.2 % versus 44.8 %, respectively; $p=0.483$) and stroke rates (8.2 % versus 9.3 %; $p=0.763$) between the two procedures (see Figure 2); therefore, very importantly confirming TAVI as a non-inferior treatment option in this high-risk group. Baseline outcome predictors for the two procedures differed when

Table 1: PARTNER A – Multivariate Baseline Predictors of Mortality¹⁰

TAVI	Hazard Ratio (95 % CI)	p Value	sAVR	Hazard Ratio (95 % CI)	p Value
Body mass index (lbs/in ²)	0.95 (0.92, 0.98)	0.0003	CABG	0.67 (0.49, 0.92)	0.0139
Atrial fibrillation	1.62 (1.15, 2.27)	0.0056	Pacemaker	1.46 (1.03, 2.08)	0.0353
Mean gradient (baseline)	0.98 (0.97, 0.99)	0.0033	Moderate/severe MR at baseline	1.52 (1.03, 2.23)	0.0330
Liver disease	2.39 (1.11, 5.14)	0.0254	Liver disease	2.34 (1.09, 5.04)	0.0302
Renal disease (CR ≥ 2)	1.61 (1.11, 2.35)	0.0131	STS risk score	1.07 (1.02, 1.12)	0.0048

CABG = coronary artery bypass graft; CI = confidence interval; CR = creatinine; MR = Mitral Regurgitation; sAVR = surgical aortic valve replacement; STS = Society of Thoracic Surgeons; TAVI = trans-catheter aortic valve implantation.

Table 2: PARTNER A – Clinical Outcomes at 1, 2 and 3 years¹⁰

Outcome	1 Year			2 Years			3 Years		
	sAVR (n=351)	TAVI (n=348)	p Value	sAVR (n=351)	TAVI (n=348)	p Value	sAVR (n=351)	TAVI (n=348)	p Value
Major vascular complications – no. (%)	13 (3.8)	42 (12.1)	<0.001	13 (3.8)	43 (12.5)	<0.001	13 (3.8)	43 (12.5)	<0.001
Major bleeding – no. (%)	88 (26.7)	52 (15.7)	<0.001	95 (29.5)	61 (19.3)	0.003	99 (31.5)	64 (20.8)	0.003
New PM – no. (%)	16 (5.0)	21 (6.4)	0.44	19 (6.3)	24 (7.6)	0.54	20 (6.8)	25 (8.1)	0.56
Endocarditis – no. (%)	3 (1.0)	2 (0.6)	0.63	3 (1.0)	4 (1.5)	0.62	6 (2.6)	4 (1.5)	0.37
Valve failure requiring AVR	0	0		0	0		0	0	
Myocardial infarction – no. (%)	2 (0.6)	0	0.16	4 (1.5)	0	0.05	6 (2.7)	2 (1.1)	0.23
Renal replacement therapy – no. (%)	20 (6.5)	18 (5.4)	0.57	22 (7.3)	20 (6.2)	0.59	23 (7.9)	22 (7.2)	0.76

AVR = aortic valve replacement; PM = permanent pacemaker; sAVR = surgical aortic valve replacement; TAVI = trans-catheter aortic valve implantation.

Figure 3: PARTNER A – Impact of Aortic Regurgitation on Mortality in Transcatheter Aortic Valve Replacement Patients¹⁰

Number at risk							
None-trace	131	121	114	102	93	80	63
Mild	171	146	125	117	110	94	62
Moderate-severe	34	24	21	18	15	12	9

assessed with multivariate analysis (see Table 1), and complications are shown in Table 2. There was a higher burden of moderate or severe PAR after TAVI than sAVR at 1, 2 and 3 years, which conferred a higher risk of mortality – this adverse effect was demonstrable even in patients with mild PAR (see Figure 3).

Repositionable percutaneous replacement of a stenotic aortic valve through implantation of the Lotus Valve System (REPRISE II) is a prospective registry of 120 patients evaluating the efficacy and safety of the Lotus Valve System, a differentiated second-generation TAVI technology which consists of a pre-loaded, stent-mounted tissue valve prosthesis and catheter for delivery and placement of the valve. Initial data presented by Dr Ian Meredith at EuroPCR in 2013,¹¹ demonstrated low 30-day mortality and stroke rates (1.7 % and 3.4 %, respectively) with a further 5.2 % suffering a non-disabling stroke. There was minimal aortic

Table 3: The UK TAVI Registry Long-term Outcomes – Predictors of Mortality at 1 Year¹²

Variables	Univariate Model	p Value
Route, trans-femoral	0.65 (0.48–0.88)	0.006
Route, other	1.00	
AR moderate/severe	1.49 (1.00–2.21)	0.048
LVEF 30%–49%	1.93 (1.40–2.66)	<0.001
LVEF <30%	1.89 (1.16–3.07)	0.01
Coronary disease	1.38 (1.01–1.87)	0.04
Any previous cardiac surgery	1.04 (0.75–1.43)	0.83
Peripheral vascular disease	1.28 (0.91–1.75)	0.16
Diabetes mellitus	1.36 (0.98–1.89)	0.07
COPD	1.40 (1.02–1.93)	0.04
Creatinine >200 mmol/l	1.84 (1.14–2.97)	0.012

AR = aortic regurgitation; COPD = chronic obstructive pulmonary disease; LVEF = left ventricular ejection fraction.

regurgitation and mean aortic gradient improved significantly from 47.5 ± 17.2 mmHg to 11.3 ± 5.2 mmHg at 30 days. There was, however, a need for permanent pacing in 29.3 % of patients.

The UK TAVI registry¹² followed the outcomes of all patients with severe symptomatic aortic stenosis undergoing TAVI with the CoreValve and Edwards Sapien valves in England and Wales between the first implant in January 2007 to December 2009 (877 implants in 870 patients). Here, 69 % of cases were carried out via the trans-femoral route, whereas patients with peripheral vascular disease, coronary artery disease, prior cardiac surgery, renal dysfunction, and NYHA class III or IV were more likely to have the procedure carried out through alternative access. The median age was 81.9 ± 7.1 years and median logistic euroSCORE 18.5 %. Eight cases were unsuccessful (0.9 %) and emergency conversion to sAVR occurred in 6 patients (0.7 %). Again, there was a higher need for permanent pacing following CoreValve implantation when compared with Sapien (24.4 % versus 7.4 %; p<0.0001). Survival at 30 days, 1 year and 2 years was 92.9 %, 78.6 % and 73.7 %, respectively, with no statistical difference between the Sapien and CoreValve cohort. However, a maintained survival benefit was noted with

Figure 4: Long-term Survival after Transcatheter Aortic Valve Implantation and the Outcome Affected by the Presence and Absence of Chronic Obstructive Pulmonary Disease and Physical Activity¹⁴

COPD = chronic obstructive pulmonary disease; PAP = pulmonary arterial pressure; PAR = paravalvular regurgitation; TAVI = transcatheter aortic valve implantation.

the trans-femoral route compared with alternative access (81.5 % versus 72.3 % at 1 year; $p=0.002$; 77.5 % versus 65.3 % at 2 years; p -value <0.001). The UK TAVI investigators also noted that these survival rates are consistent with outcomes in the UK surgical database for octogenarians undergoing SAVR or SAVR with coronary artery bypass grafting.¹³

A 5-year outcome analysis of the first 111 TAVIs performed between 2005 and 2007 using the Cribier-Edwards or Edwards SAPIEN valve in a single centre in Canada¹⁴, reported unsuccessful implantation in 8 cases and 15 deaths occurred within 30 days. Of the remaining 88, 84 (median age 83 ± 7 years) were followed up with a median survival time of 3.4 years (survival rates at 1 to 5 years were 83 %, 74 %, 53 %, 42 % and 35 %, respectively). The presence of chronic obstructive pulmonary disease (COPD) and at least moderate PAR post-TAVI were

Figure 5: The UK TAVI Registry Long-Term Outcomes – Survival Curves by Log euroSCORE¹²

associated with a higher risk of mortality (hazard ratio 2.17 [95 % confidence interval 1.18 to 3.70] and 2.98 [95 % confidence interval 1.44 to 6.17] respectively) (Figure 4). Post-procedure, 25 % of patients had no PAR, 63 % had mild PAR and 11.4 % had at least moderate PAR.

Predictors of mortality at 1 year are listed in Table 3, and the survival curves according to logistic euroSCORE plotted in Figure 5. Although there is significantly worse prognosis for the patients with euroSCOREs >40 after 30 days, no survival difference emerged among lower-risk cohorts.

Haemodynamic benefits were impressive and sustained. There was a significant improvement in aortic valve area from 0.62 ± 0.17 cm² to 1.67 ± 0.41 cm², with persistence of this benefit 5 years post procedure (1.40 ± 0.25 cm²). The same trend was seen with mean aortic valve gradient from 46 ± 18 mmHg to 10 ± 4.5 mmHg pre and immediately post procedure, to 11.8 ± 5.7 mmHg at 5 years. At 4 years, there were no features of prosthetic valve failure, although three patients (3.4 %) developed moderate trans-valvular regurgitation and/or stenosis at 5 years.

Interestingly, nearly half of the patients (48 %) had concomitant moderate/severe mitral regurgitation (MR) at the time of TAVI which improved to no/mild MR in 57 % of cases post-operatively.

Stroke

Neurological sequelae following TAVI remain highly debated, and the adverse event most feared by patients and their families. Thromboembolic events with cerebrovascular injury may occur at various stages during the TAVI procedure itself (retrograde crossing of the calcified aortic valve, preliminary valvuloplasty, manipulation of the delivery catheter through the aortic arch and valve deployment)¹⁵ and may also arise as a result of other post-procedural influences (e.g. atrial fibrillation [AF]). As yet, there is no accepted or evidence-based guidance as to the optimal peri- and post-procedural anti-platelet or anticoagulant regime. However, the ongoing Aspirin versus aspirin and clopidogrel following Transcatheter aortic valve implantation (ARTE) pilot trial will provide some useful data.

The PARTNER A trial of TAVI versus surgical AVR in high-risk patients with symptomatic aortic stenosis¹⁶ showed that the incidence of all stroke and transient ischaemic attack (TIA) following TAVI was 5.5 % at 30 days and 8.3 % at 1 year, and 3.8 % and 5.1 %, respectively, for major stroke. In the surgical arm, all stroke and TIA incidence

Table 4: Risk of stroke – a meta-analysis of 10,037 TAVI patients²⁰

	Number of publications with available data (n)	Overall number of patients with available data (n)	Number of events (n)	Weighted mean $\pm$ SD
Procedural stroke (<24h)	24	3041	47	1.5 $\pm$ 1.4 %
30-day stroke/TIA	53	10037	334	3.3 $\pm$ 1.8 %
30-day major stroke	42	5514	158	2.9 $\pm$ 1.8 %
30-day minor stroke/TIA	42	5514	53	1.0 $\pm$ 1.3 %
30-day overall mortality	52	10022	812	8.1 $\pm$ 3.9 %
30-day mortality in patients suffering stroke	29	4430	41	25.5 $\pm$ 21.9 %
30-day mortality in patients without stroke	29	4430	312	6.9 $\pm$ 4.2 %
6-month stroke	9	669	29	4.3 $\pm$ 1.6 %
12-month stroke	7	1507	78	5.2 $\pm$ 3.4 %

was 2.4 % and 4.3 % at 30 days and 1 year, respectively, and 2.1 % and 2.4 % for major stroke. These data, suggesting an early excess of stroke following TAVI, were balanced by longer-term follow-up data showing equivalent stroke rates at 36 months (8.2 % versus 9.3 %, respectively, $p=0.763$).

In the PARTNER B trial,⁶ patients deemed unsuitable for surgery due to comorbidities associated with a predicted probability of ≥ 50 % of death after surgery, were randomised to undergo TAVI or continue with medical therapy. There was a significant reduction in mortality associated with TAVI at 1-year follow up (30.7 % versus 50.7 %, hazard ratio [HR] 0.58; 95 % confidence interval [CI] 0.43 to 0.78; $p<0.001$) although major strokes were more common in the TAVI group (5.0 % versus 1.1 % at 30 days; $p=0.06$; 7.8 % versus 3.9 % at 1 year; $p=0.18$).

A small study conducting diffusion-weighted magnetic resonance imaging (MRI) scans to detect subclinical cerebral ischaemic post-TAVI with CoreValve valves identified that silent cerebral embolism is frequent (73 %) compared with the incidence of clinically apparent cerebral embolism (3.6 %).¹⁷ This high subclinical uncovering was again shown in a small study that carried out neurological testing and serial cerebral diffusion weighted MRI at baseline, at 3.4 days (2.5–4.4) post-procedure and at 3 months. New ischaemic lesions were identified in 84 % of cases, which is considerably more when compared with 48 % of sAVR patients, and were usually multiple but smaller than after sAVR. No patients were symptomatic, there was no demonstrable neurocognitive impairment and no further events were reported at 3 months.¹⁸

A meta-analysis of TAVI versus sAVR derived from 14 studies found no significant difference in stroke risk, either at the time of the procedure (2.6 % versus 2.3 %, relative risk [RR] 1.16, 95 % CI 0.72–1.87; $p=0.54$) or at 1-year follow up (4.5 % versus 3.4 %, RR 1.27, 95 % CI 0.68–2.37; $p=0.46$).¹⁹ However, a subgroup analysis of two randomised controlled trials did identify higher incidence of stroke/TIAs associated with TAVI (5.8 % versus 2.3 %; $p=0.02$).

In a prospective single-centre registry (Bern TAVI registry) of 389 high-risk elderly patients with severe symptomatic aortic stenosis undergoing TAVI from August 2007 to October 2011, 14 patients (3.6 %) experienced at least one stroke (major in 3.1 %; minor in 0.5 %) and 71.4 % of these occurred within 1 day of the procedure.¹⁵ Smaller body mass index (BMI ≥ 25 adjusted odds ratio [AOR] 0.78 compared with BMI <25), previous stroke (AOR 1.87) and chronic obstructive pulmonary disease (COPD) (AOR 4.73) were all risk factors for cerebrovascular complications. However, conventional risk factors for stroke including age, hypertension, male gender, diabetes

mellitus, smoking and AF were not found to have an effect, nor anti-thrombotic treatment at baseline. Surprisingly, the number of aortic valve pre-dilatations was not associated with a higher incidence of stroke, whereas the converse is true with post-dilatation (AOR 2.00). Significant risk was also associated with more than one implantation attempt (AOR 8.32). All-cause mortality at 30 days was significantly higher in the group who suffered a stroke (42.3 % versus 5.1 %, OR 11.7, 95 % CI 3.4–40.3; $p<0.001$) with cardiovascular mortality accounting for 38.4 % in the stroke group, and 4.6 % in the group with no neurological consequences.

Similarly, a higher 30-day mortality was associated with stroke in a meta-analysis including 10,037 patients undergoing TAVI between January 2004 and November 2011.²⁰ Here, procedural stroke (<24 hours) occurred in 1.5 $\pm$ 1.4 %, increasing to 3.3 $\pm$ 1.8 % at 30 days, 4.3 $\pm$ 1.6 % at 6 months and 5.2 $\pm$ 3.4 % at 1 year. *Table 4* shows the incidence of stroke and associated mortality.

In a 5-year follow-up period, cumulative major ischaemic stroke rates were 9.7 % and haemorrhagic stroke rates 7.3 % (50 % fatal). The calculated annual risk of ischaemic stroke was consistently around 2 %, whereas the risk of haemorrhagic stroke increased each year, being 2.8 % in the first year, and reaching 7.3 % in years 4 and 5.¹⁴

Conclusion

From the wealth of registries and trials scrutinising its performance, TAVI emerges as a viable and rapidly established option, both when compared with medical treatment in inoperable patients and when compared with conventional surgical treatment in high-risk patients. It has revolutionised the treatment of high-risk patients with severe calcific aortic stenosis, and results continue to improve as operator experience grows and technology develops.

Long-term results in well-selected patients are excellent, although choosing the right patient is vital. From the trials mentioned, the independent predictors of outcome are BMI, COPD, post-TAVI AR, porcelain aorta, liver disease, AF, renal disease and impaired LVEF, many of which are not accounted for within currently available risk stratification tools. A more recent publication assessing predictors of 6-month poor clinical outcome after TAVI has shown AF, severe baseline pulmonary hypertension and right ventricular dysfunction to be associated with poor outcome, and baseline AR to be protective.²¹ While TAVI is an excellent option, it is important to consider which patients are least likely to benefit, including those with a euroSCORE >40 , severe left or right ventricular systolic dysfunction, severe respiratory disease and restricted mobility.

Trans-femoral access is associated with improved overall survival, although it is clear that the cohort of patients treated via an alternative route already have a more adverse risk profile. Advances in technology will hopefully address areas of concern such as para-valvular AR and pacing requirements.

Current risk scores have good discrimination (low versus high risk), but poor calibration (predicted versus observed risk)²² and we need more rigorous risk stratification tools. However, the role of the heart team remains central in optimal patient selection. Nearly 12 years since the first procedure, TAVI is flourishing, and with ongoing development, will continue to do so. ■

1. 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(24):3006–8.
2. Nkomo VT, Gardin JM, Skelton TN, et al., Burden of valvular heart diseases: a population-based study, *Lancet*, 2006;368:1005–11.
3. The National Adult Cardiac Surgery Audit Report, Annual Report 2010–2011. Available at: http://www.ucl.ac.uk/nicor/audits/Adultcardiacsurgery/publications/pdfs/NACSA_annual_report_FINAL (accessed 20 February 2014).
4. Transcatheter Aortic Valve Implantation (TAVI), A position statement of the British Cardiovascular Intervention Society (BCIS) and the Society of Cardiothoracic Surgeons (SCTS). December 2008. Available at: <http://www.bcis.org.uk/resources/documents/BCIS%20SCTS%20position%20statement.pdf> (accessed 20 February 2014).
5. Vahanian A, Alfieri O, Andreotti F, et al., ESC/EACTS Guidelines on the management of valvular heart disease, *Eur Heart J*, 2012;33:2451–96.
6. Leon MB, Smith CR, Mack M, et al., PARTNER Trial Investigators, Transcatheter aortic-valve implantation for aortic stenosis in patients who cannot undergo surgery, *N Engl J Med*, 2010;363:1597–1607.
7. Di Mario C, Eltchaninoff H, Moat N, et al., Transcatheter Valve Treatment Sentinel Registry (TCVT) Investigators of the EURObservational Research Programme (EORP) of the European Society of Cardiology. The 2011–12 pilot European Sentinel Registry of Transcatheter Aortic Valve Implantation: in-hospital results in 4,571 patients, *EuroIntervention*, 2013;8:1362–71.
8. SOURCE XT Post-Approval Study, presented at EuroPCR 2013. Available at: <http://www.pcronline.com/About/Daily-News/2013/EuroPCR/Wrap-up/Late-breaking-trials> (accessed 20 February 2014).
9. Available at: <http://www.medscape.com/viewarticle/804576> (accessed 5 January 2014).
10. Three-Year Outcomes after Transcatheter or Surgical Aortic Valve Replacement in High-Risk Patients with Severe Aortic Stenosis, presented at ACC 2013. Available at: http://clinicaltrialsresults.org/Slides/ACC%202013/Thourani_PARTNER%20Cohort%20A_ACC%202013.ppt (accessed 20 February 2014).
11. Repositionable Percutaneous Replacement of a Stenotic Aortic Valve through Implantation of the Lotus Valve System. 30-day Outcomes for the first 60 patients in the REPRISE II Study, presented at EuroPCR 2013. Available at: http://solaci.org/en/ian_meredith_europcr.php (accessed 20 February 2014).
12. Moat NE, Ludman P, de Belder, et al., Long-term outcomes after transcatheter aortic valve implantation in high-risk patients with severe aortic stenosis: the U.K. TAVI (United Kingdom Transcatheter Aortic Valve Implantation) Registry, *J Am Coll Cardiol*, 2011;58:2130–8.
13. Bridgewater B, Keogh B, Sixth National Adult Cardiac Surgical Database Report, Society for Cardiothoracic Surgery, 2008. Available at: <http://www.e-dendrite.com/files/13/file/Pages%20from%20NACSD%202008.pdf> (accessed 20 February 2014).
14. Toggweiler S, Humphries KH, Lee M, et al., 5-year outcome after transcatheter aortic valve implantation, *J Am Coll Cardiol*, 2013;61:413–19.
15. Stortecky S, Windecker S, Pilgrim T, et al., Cerebrovascular accidents complicating transcatheter aortic valve implantation: frequency, timing and impact on outcomes, *EuroIntervention*, 2012;8:62–70.
16. Smith CR, Leon MB, Mack MJ, et al., for the PARTNER Trial Investigators Transcatheter versus Surgical Aortic-Valve Replacement in High-Risk Patients, *N Engl J Med*, 2011; 364:2187–98.
17. Ghanem A, Müller A, Nöhle CP, et al., Risk and fate of cerebral embolism after transfemoral aortic valve implantation: a prospective pilot study with diffusion-weighted magnetic resonance imaging, *J Am Coll Cardiol*, 2010;55:1427–32.
18. Kahlert P, Knipp SC, Schlamann M, et al., Silent and apparent cerebral ischemia after percutaneous transfemoral aortic valve implantation: a diffusion-weighted magnetic resonance imaging study, *Circulation*, 2010;121:870–8.
19. Cao C, Ang SC, Indraratna P, et al., Systematic review and meta-analysis of transcatheter aortic valve implantation versus surgical aortic valve replacement for severe aortic stenosis, *Ann Cardiothorac Surg*, 2013;2(1):10–23.
20. Eggebrecht H, Schermmund A, Voigtlander T, et al., Risk of stroke after transcatheter aortic valve implantation (TAVI): a meta-analysis of 10,037 published patients, *EuroIntervention*, 2012;8:129–38.
21. Auffret V, Bouilmiere D, Oger E, et al., Predictors of 6-month poor clinical outcomes after transcatheter aortic valve implantation. *Arch Cardiovasc Dis*, 2013;S1875-2136(13)00331-8.
22. Kovac J, Baron JH, Chin DT, Are the standard criteria for TAVI too lax or too strict?, *Heart*, 2010;96(1):5–6.