European Heart Journal (2009) **30**, 74–80
doi:10.1093/eurheartj/ehn523

CLINICAL RESEARCH
Valvular and congenital heart disease

Overestimation of aortic valve replacement risk by EuroSCORE: implications for percutaneous valve replacement

Brigitte R. Osswald[1]*, Vassil Gegouskov[2], Dominika Badowski-Zyla[2], Ursula Tochtermann[2], Gisela Thomas[2], Siegfried Hagl[2], and Eugene H. Blackstone[3,4]

[1]Department of Thoracic and Cardiovascular Surgery, University of Essen, Hufelandstr. 55, 45147 Essen, Germany; [2]Department of Cardiac Surgery, University of Heidelberg, Heidelberg, Germany; [3]Department of Thoracic and Cardiovascular Surgery, Cleveland Clinic, Cleveland, OH, USA; and [4]Department of Quantitative Health Sciences, Cleveland Clinic, Cleveland, OH, USA

Received 24 August 2007; revised 10 October 2008; accepted 29 October 2008; online publish-ahead-of-print 24 November 2008

Aims The EuroSCORE has been proposed to identify patients at high risk for surgical aortic valve replacement (AVR) and estimate for them the risk-benefit of percutaneous valve replacement. The aim of our study was to investigate the validity of this proposal.

Methods and results From 1994 to March 2006, 1545 consecutive patients with aortic stenosis underwent isolated surgical AVR at the Department of Cardiac Surgery of Heidelberg. Both additive and logistic EuroSCOREs were calculated for each patient and summed for expected 30-day mortality. Expected and observed mortalities were compared, particularly with respect to 'high-risk' status and era of operation. Overall, 30-day mortality was low (34/1545, 2.2%) and substantially overestimated by both additive (6.1%) and logistic (9.3%) EuroSCOREs. Although both EuroSCOREs stratified patients monotonically with respect to mortality risk, high-risk patients had a 3.6% mortality (29/833), whereas additive and logistic EuroSCOREs predicted 8.3 and 14.8%. Indeed, none of the 71 patients with a EuroSCORE of 11–20 (extremely high risk) died. The more recent the era of operation, the more pronounced was the discrepancy between expected and observed mortalities.

Conclusion Although the EuroSCORE still successfully stratifies patients undergoing surgical AVR relative to 30-day mortality, it has become increasingly uncalibrated with absolute risk, resulting in overestimation of 30-day mortality. Inaccurately predicted mortality, especially in 'high-risk' patients, renders it unsuitable for assessing risk reduction of percutaneous valve replacement.

Keywords Aortic valve disease • Risk adjustment • High-risk patients

Introduction

It remains common for patients to present for valve replacement at an advanced stage of aortic valve stenosis.[1] This may be explained in part by current guidelines in western countries that support rather late surgical intervention.[2,3] The result is a substantial number of patients who do not come for the operation for a variety of reasons, such as old age and multiple morbidities, but who may benefit from a lower-risk percutaneous valve replacement. Appropriately, in clinical trials during this early developmental phase of percutaneous aortic valve replacement (AVR), patients at high risk for surgical AVR are being recruited. Various existing tools devised in part for stratifying patients according to expected surgical risk[4–6] could be proposed to identify these high-risk patients and to estimate the degree to which a percutaneous approach may lower that risk. It may not be appreciated that risk stratification and risk prediction are separable issues: one addresses the relative risk and the other the absolute risk. Thus, a tool that retains a strong monotonic and distinctive association with mortality may perform well in settings requiring relative risk stratification, but poorly in other settings requiring accurate absolute risk estimates.

* Corresponding author. Tel: +49 201 723 4901, Fax: +49 201 723 5451, Email: brigitte.osswald@uk-essen.de

Recently, one such tool, the EuroSCORE, has been used to select high-risk patients for percutaneous AVR and to compare survival after these procedures with that predicted had surgical AVR been performed.[7,8] However, the EuroSCORE is based on 1995 mortality across all of cardiac surgery, a time at which coronary artery bypass grafting dominated the patient population, not heart valve disease. Therefore, aims of this study were to discover (i) whether the EuroSCORE accurately predicts absolute 30-day mortality after contemporary AVR, (ii) whether it accurately stratifies such patients according to risk, and (iii) whether its utility for risk prediction and stratification has diminished across time.

Methods

Patients

From 1 January 1994 through 31 March 2006, 1545 consecutive patients underwent primary isolated AVR for aortic valve stenosis (including mixed lesions with predominant stenosis) at Department of Cardiac Surgery, University of Heidelberg. 'Isolated' AVR included procedures necessary to achieve adequate valve replacement, including a root enlarging procedure, simple wrapping, or plicating the ascending aorta, or resecting obstructing left ventricular outflow tract muscle. Patient characteristics and surgical details are given in *Table 1*. This patient population was conceived as the one most closely approximating the aortic valve pathology of candidates for percutaneous AVR.

Data acquisition and follow-up

All data were collected prospectively by healthcare providers concurrent with patient care during the hospitalization using the Heidelberg Association for multi-centric data analysis. This database includes about 1500 standardized variables per patient. It is used for direct patient management (reports), reimbursement, internal and external quality assurance programs, and research. The transparency and multifunctional use of the data provide multiple data checks, achieving a high level of reliability.[9] Routine patient follow-up was performed 180 days after AVR, with data available for evaluating 30-day hospital mortality in 99.8% of patients. We used 30-day hospital mortality because it is the focus of the EuroSCORE and percutaneous AVR assessment. Even before publication of the EuroSCORE in 1999, equivalent variables existed in our database, defined in the same fashion.

Definition of risk groups

Low-, medium-, and high-risk subgroups were identified according to the published risk-stratification definition.[5] An additive EuroSCORE of 0–2 or logistic EuroSCORE calculated probability of <3% defined low-risk patients; an additive score of 3–5 or logistic probability of 3%–<6% defined medium-risk patients; and an additive score of ≥6 or logistic probability of ≥6% defined high-risk patients. The high-risk group was further subdivided for some analyses between those with scores <12 and 12 or greater. Grube *et al.*[7] considered a patient to represent a high risk patient if there was a consensus among an independent cardiologist and cardiac surgeon that conventional surgery would be associated with excessive morbidity and mortality.

Data analysis

Categorical variables were summarized as frequencies and percentages, continuous variables by means, standard deviation, and median. Uncertainty of percentages and odds ratios are accompanied by 95% confidence intervals (CI).

Table 1 Patient characteristics, EuroSCORE strategy, and surgical details

Variable	($n = 1545$)	%
Patient characteristics		
Demography		
Age [years] (mean ± SD, median)	67.1 ± 12.9, 69.8	
Female	672	43.5
Weight [kg] (mean ± SD, median)	75.8 ± 14.8, 75.0	
Obese[a]	605	39.2
Symptomology		
NYHA I	68	4.4
NYHA II	299	19.3
NYHA III	828	53.6
NYHA IV	350	22.7
Dyspnoea at exercise	1332	86.2
Dyspnoea at rest	411	26.6
Episode of acute heart failure	390	25.2
Embolic event in history	41	2.6
Syncope in history	287	18.6
Stable angina	640	41.4
Unstable angina	196	12.8
Shock	30	1.9
Critical pre-operative state[b]	37	2.4
Emergency	62	4.0
Cardiac morbidity		
Transaortic gradient [mmHg] (mean ± SD, median)	62.2 ± 25.5, 60	
Hypokinetic LV wall movement	411	26.6
Moderate systolic LV function (EF 30–50%)	517	33.4
Poor systolic LV function (EF <30%)	103	6.7
Previous myocardial infarction	194	12.6
Recent (<90 days) myocardial infarction	0	0.0
Permanent atrial fibrillation	307	19.9
Premature ventricular ectopy	345	22.3
AV block (any degree)	141	9.1
Permanent pacemaker	35	2.3
Peripheral oedema	350	22.7
Arterial hypertension[c]	1045	67.6
Pulmonary hypertension[d]	107	6.9
Comorbidity		
Extracardiac arteriopathy	203	13.1
Neurological dysfunction	114	7.4
Pulmonary restrictive disease	175	11.3
Chronic obstructive pulmonary disease	268	17.3
Elevated creatinine (>200 μmol/L)	192	12.4
Diabetes, treated by diet	80	5.1
Diabetes, oral treatment	136	8.8
Diabetes, on insulin	96	6.2
On dialysis	33	2.1

Continued

Table 1 *Continued*

Variable	($n = 1545$)	%
EuroSCORE strata		
Logistic		
Low risk	239	15.5
Medium risk	439	31.9
High risk	813	52.6
Additive		
Low risk	183	11.8
Medium risk	529	34.2
High risk	833	53.9
Surgical details		
Surgical findings		
Congenital bicuspid valve	187	12.1
Severely calcified valve cusps	1344	87.0
Bicuspidalization of the leaflets	971	62.8
Mean ring diameter [mm] (mean ± SD, median)	23.3 ± 2.2, 23	
Severely calcified aortic ring	1317	85.2
Concomitant subvalvular membrane	11	0.7
Concomitant subvalvular myectomy	812	52.6
Surgical data		
Total time of procedure [min] (mean ± SD, median)	183 ± 56.9, 172	
On bypass [min] (mean ± SD, median)	96.6 ± 33.0, 90	
Aortic clamping time [min] (mean ± SD, median)	62 ± 18.5, 60	
Use of aprotinine	1225	79.3
Postoperative IABP support	5	0.3

[a]Obesity—BMI >27.
[b]Critical preoperative state—on catecholamines, severe hypotension, unstable circulation.
Arterial hypertension—values above WHO criteria for hypertension.
Pulmonary hypertension—>60 mmHg systolic pulmonary arterial pressure.

Both additive and logistic EuroSCOREs were calculated for each patient and summarized by adding these scores within risk strata to yield expected number of events, expressed as a percentage. Numbers of expected vs. observed deaths were compared by calculating a chi-square goodness-of-fit statistics. Sensitivity and specificity of expected vs. observed mortality were summarized by receiver–operator curves and the area under the resulting curve (AUC), expressed as a C-statistic. A decreasing value of this statistic from 1.0 toward 0.5 indicates decreasing distinctiveness or discrimination between patients living and dead. At any level of distinctiveness, risk stratification may remain monotonic (i.e. expected mortality increases progressively in concert with observed mortality). We quantitatively determined whether the EuroSCORE retained its relative risk association with 30-day mortality. For this, we incorporated the EuroSCORE into a logistic regression model and compared the beta coefficient (slope) with the expected value of 1.0, which would indicate 100% retention of relative risk. A slope of <1.0 indicates a decreased strength of association with EuroSCORE. A smaller logistic regression intercept with a slope of 1.0 indicates preserved strength of association, but lower overall risk of AVR at all levels of EuroSCORE.

We also examined whether across eras, the EuroSCORE became increasingly uncalibrated with respect to risk. For this, a separate logistic regression analysis was performed for three eras: 1994–1977, 1998–2001, and 2002–2006.

For calibration plots, observed vs. expected mortality was depicted from the model in 10 equal-sized groups, based on deciles of predicted mortality with calibration assessed by the Hosmer–Lemeshow statistic. For all calculations, SAS version 9.1 (SAS, Inc., Cary, NC, USA) was used.

Presentation

Continuous variables are summarized by mean ± standard deviation and median, and categorical variables by frequency and percentage. Mortality is accompanied by 95% CI.

Results

Observed vs. predicted 30-day mortality

The additive EuroSCORE predicted 94.0 deaths (6.1%, CI 4.9–7.3%; χ^2, 40.8; $P < 0.0001$) and the logistic EuroSCORE 143.5 deaths (9.3%, CI 7.8–10.7%; χ^2, 92.1; $P < 0.0001$) within 30 days of operation, whereas only 34 patients (2.2%, CI 1.5–3.1%) died. Calibration plots indicate substantial differences between expected and observed mortalities throughout the entire range of mortality between 0 and 9% for both additive and logistic EuroSCOREs (*Figure 1*). AUC for both EuroSCOREs had a low overall predictive value (additive EuroSCORE c-value 0.677, CI 0.606–0.748; logistic EuroSCORE c-value 0.666, CI 0.593–0.740).

Risk stratification

By logistic regression, the intercept for the additive EuroSCORE was −0.631 and beta (slope) was 1.171 ± 0.37, $P = 0.002$ ([P [Hosmer–Lemeshow] = 0.61), indicating strength of association with 30-day mortality was undiminished (not different from 1.0). For the logistic EuroSCORE, these two statistics were 2.699 and 0.447 ± 0.16, $P = 0.005$ (P [Hosmer–Lemeshow] = 0.006), indicating that the strength of the association was diminished, but not absent. Retention of the association of EuroSCORE with mortality, despite overestimation of mortality by both EuroSCOREs, resulted in monotonically increasing risk in stratified groups (*Table 2*). When the high-risk group is separately considered, out of 833 patients with an additive EuroSCORE >5, 762 had a score between 6 and 11, and 71 a score of 12–20. Mortality was 3.5% ($n = 29/833$, CI 2.2–4.7%) in this high-risk group, although none of the 71 patients (CI 0.0–5.1%) with a score of 12 or greater died within 30 days. Both receiver operating curves from additive and logistic EuroSCORE are given in *Figure 2*.

EuroSCORE and era of operation

Mortality predicted by the logistic EuroSCORE was stable across time (14.1% 1994–1997, 14.6% 1998–2001, and 13.8% 2002–2006), indicating comparable complexity of cases. However, in each era, actual mortality was only 26, 34, and 29% of predicted (*Table 3*). The most recent period (2002–2006, $n = 774$) was associated with the lowest AUC (0.638, CI 0.543–0.731, P [Hosmer–Lemeshow] = 0.14), and an AUC of only 0.641 (CI 0.486–0.797, P [Hosmer–Lemeshow] = 0.71) was observed

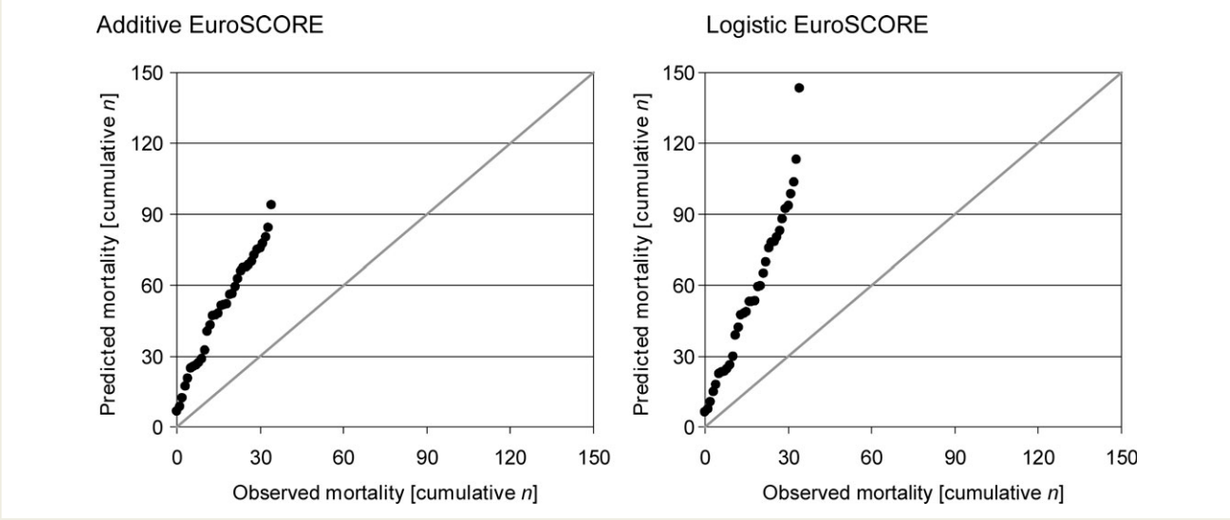

Figure 1 Cumulative observed 30-day mortality vs. cumulative predicted mortality for additive (left panel) and logistic (right panel) EuroSCORE. Diagonal solid line is line of identify.

Table 2 Difference between expected and observed mortalities according to the actual logistic EuroSCORE model and additive EuroSCORE in terms of EuroSCORE risk groups

	Group 1	Group 2	Group 3
Logistic EuroSCORE			
[*n* deaths/*n* total (%, CI)]—actual	0/239 (0%, 0–1.5%)	9/493 (1.8%, 0.6–3.0%)	25/813 (3.1%, 1.9–4.3%)
[*n* deaths/*n* total (%, CI)]—predicted	4.2/239 (1.3%, 0.1–3.6%)	18.6/493 (3.8%, 2.1–5.5%)	120.7/813 (14.8%, 12.4–17.3%)
χ^2-value, *P*	4.3, 0.04	5.1, 0.02	89.1, <0.0001
Additive EuroSCORE			
[*n* deaths/*n* total (%, CI)]—actual	0/183 (0%, 0–2.0%)	5/529 (1.0%, 0.1–1.8%)	29/833 (3.5%, 2.2–4.7%)
[*n* deaths/*n* total (%, CI)]—predicted	2.8/183 (1.5%, 0–3.3%)	21.6/529 (4.1%, 2.6–6.3%)	69.5/833 (8.3%, 6.5–10.2%)
χ^2-value, *P*	2.8, 0.09	13.3, 0.0003	25.8, <0.0001

for the operative period 1998 through 2001 ($n = 427$). Only in the period from 1994 through 1997 ($n = 344$) was good discrimination achieved (AUC 0.823, CI 0.763–0.883, *P* [Hosmer–Lemeshow] =0.45) (*Figure 3*).

Discussion

Risk estimation by the EuroSCORE

According to the general observation and the present study, advances in surgical and perioperative treatment have steadily reduced procedural risk of AVR to low levels, even in high-risk patients. A major shift in patient characteristics towards a higher proportion of so-called high-risk patients began in the 1980s and 1990s and still continues to some extent,[10] although this trend was not apparent in our 1994–2006 study group.

Failure of both EuroSCOREs to predict mortality accurately in high-risk patients in a mixed cardiac surgical patient cohort has already been described.[11] For patients with isolated aortic valve disease in the current era, overestimation of risk of AVR is substantial. The revised version of another widely used score in cardiac surgery, the Parsonnet score,[12] is rarely applied and possibly has the same weaknesses as other scores in part because neutralization of risk factors is an ongoing process[13] and in part because it is not disease specific. Other scoring systems, such as the STS models, are different for each patient subgroup and may be more accurate in predicting risk for primary isolated AVR. We did not investigate this possibility because in contrast to the EuroSCORE, which is publicly available, the STS models are proprietary and have never been released in a usable form as required by accepted guidelines for risk-scoring systems.[14]

Potential reasons for the low predictive capacity of the EuroSCORE for patients with isolated AVR can be summarized as follows:

(i) The present EuroSCORE was devised using a mixed patient population undergoing cardiac surgery, but the majority

were treated for coronary artery disease, and only a minority for primary isolated AVR.

(ii) The EuroSCORE is based on data from 1995 and has not as yet been updated or recalibrated, although efforts are under way to do so. Thus, predicted mortality after primary isolated AVR is underestimated and has progressively become less well calibrated to absolute risk across time since its development. Nevertheless, it still accurately stratifies risk because it retains a strong association with mortality.

(iii) The EuroSCORE as a risk-adjustment mechanism accounts for only the most common and prevalent risk factors for 30-day mortality. Unusual combinations of risk factors and rare ones not accounted for in the score tend to place patients at extremes of risk. These patients with unaccounted-for factors are expected to experience greater mortality than predicted.[15] Surprisingly, underestimation of risk was not observed in our study. This, then, does not help explain our observations.

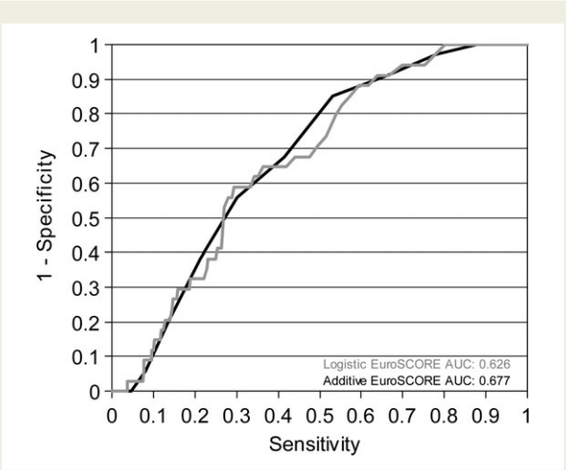

Figure 2 Receiver operating curve for additive (black) and logistic (grey) EuroSCOREs. Diagonal solid line represents a completely random relation and an area under the curve of 0.5.

(iv) The relatively low mortality observed in the highest risk subgroup of our patients may be a chance finding due to small numbers.

No matter which of these potential reasons resulted in low predictive capacity of both EuroSCOREs, what is clear is that neither accurately predicts risk for an individual patient. This fact must be taken into account if one aim of using the EuroSCORE is to estimate risk reduction from use of percutaneous vs. surgical AVR.

Potential interpretation of the results

Because of neutralization of risk factors, patients undergoing surgical AVR in the current era have a low procedural risk.[13] The substantial reduction of mortality observed throughout the total patient group, especially in the last decade, indicates that the 'Carthagesian dream'[16] of minimizing human error through standardization and medical progress seems to be becoming a reality.

Low procedural risk even in so-called high-risk patients should invite reconsideration of current guidelines for patients with aortic valve stenosis, which recommend restricting valve replacement for advanced symptomatic stages of disease.[1,2] However, patients with pronounced symptoms from longstanding disease not only have advanced valvular alterations, such as cusp and anulus calcifications, but also ventricular remodelling, including hypertrophy, irreversible ultrastructural myocardial damage of left ventricular myocardium,[17] and some degree of left ventricular outflow tract obstruction that often requires subvalvular myectomy to minimize the gradient between left ventricle and ascending aorta.[18] So, in contrast to the guidelines, in even low-risk patients with less extensive cardiac and non-cardiac comorbidity, an earlier surgical valve replacement is necessary to obtain optimal treatment at low risk and to preserve myocardial integrity.[19,20]

EuroSCORE for decision-making in percutaneous valve replacement

Functional and anatomic reconstruction of diseased structures has been the primary goal of surgical management over the years. Symptomatic relief by palliative approaches in cardiac surgery is generally accepted only in a subset of patients with complex congenital malformations. A variety of materials and designs for valve replacement have been created, and these have reached a high

Table 3 Relationship of observed vs. predicted mortality (additive EuroSCORE) according to the era of operation in terms of EuroSCORE risk groups

	Group 1	Group 2	Group 3
1994–1997			
Observed mortality [*n* deaths/*n* total (%, CI)]	0/42 (0%, 0–8.4%)	0/141 (0%, 0–2.6%)	6/161 (3.7%, 1.4–7.9%)
Expected mortality [*n* deaths/*n* total (%, CI)]	0.8/42 (1.9%, 0–6.0%)	5.8/141 (4.1%, 0.8–7.4%)	13.0/161 (8.1%, 4.4–13.4%)
1998–2001			
Observed mortality [*n* deaths/*n* total (%, CI)]	0/25 (0%, 0–13.7%)	3/139 (2.2%, 0–6.2%)	10/263 (3.8%, 1.5–6.1%)
Expected mortality [*n* deaths/*n* total (%, CI)]	0.5/25 (2.0%, 0–7.5%)	5.7/139 (4.1%, 0.8–7.4%)	22.3/263 (8.5%, 5.1–11.9%)
2002–2006			
Observed mortality [*n* deaths/*n* total (%, CI)]	0/116 (0%, 0–3.1%)	2/249 (0.8%, 0.1–2.9%)	13/409 (3.2%, 1.5–4.9%)
Expected mortality [*n* deaths/*n* total (%, CI)]	1.5/116 (1.3%, 0–3.3%)	10.2/249 (4.1%, 1.6–6.6%)	34.2/409 (8.4%, 5.7–11.0%)

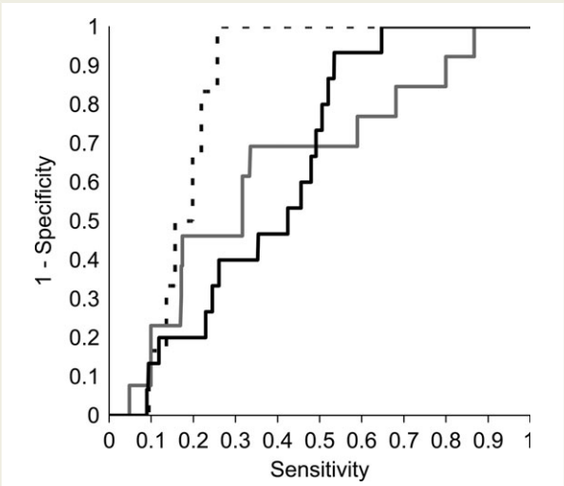

Figure 3 Receiver operating curve for logistic EuroSCORE according to era of operation. The broken black line indicates a good AUC (0.823) for the early era from 1994 to 1997. The grey line indicates the era from 1998 to 2001 (AUC: 0.641) and the straight black line the era from 2002 to 2006 (AUC: 0.638) with low AUC values.

standard for treating valvular disease. Periprosthetic leakage and residual gradient are low-frequency occurrences (and remain indications for reoperation).

Recently, a high individual additive EuroSCORE has served to recruit what are thought to be high-risk patients for percutaneous AVR.[7,8] Many of these patients have well-preserved ventricular function. Residual gradients and periprosthetic leakage are generally accepted after percutaneous AVR, based on the argument than an alternative treatment option is lacking. Although the technology is still at an experimental level, no restrictions exist on number of clinical sites permitted to perform percutaneous AVR, patient selection has not been clarified, best implant technique for each patient is still uncertain, and follow-up and definition of successful treatment are yet to be determined. Given the published results so far, an accurate definition of the patient who is ineligible for 'standard' surgical AVR seems mandatory.

As long as risk of the standard methods is far below risk of a new technology (early mortality of patients undergoing percutaneous valve replacement is 12–50%[7]), to say nothing of residual gradients and periprosthetic leakage,[21] the interventional community must refine inclusion criteria and wait for data from controlled studies, despite attractiveness of innovative technologies. As long as good and safe results are achievable from standard approaches, a liberal implementation of new techniques is unjustified without knowledge about intermediate and late results as well as early success. There are already examples of unrealized benefit of new technologies, such as laser revascularization[22] and ventricular net devices.[23]

Limitations of the study

The study was performed with data of a single University Hospital. A pre-selection of patients had been performed at least intuitively by cardiologists. The potential impact of patient selection in terms of a selection bias leading to a non-representative study population may be similar to the results of the Euro Heart Survey on Coronary Revascularization.[24] However, likely a large number of patients are not referred for surgery. All patients referred for primary isolated AVR were accepted for surgery independent of their risk profile. The proportion of high-risk patients supports liberal patient selection. At $n = 71$, however, the number of very high-risk patients is small.

Conclusions

The additive and logistic EuroSCOREs remain useful for relative risk stratification. Because of this, they may remain valuable for identifying the highest-risk patients for percutaneous AVR. However, advances in safety of cardiac surgery since their construction have led to inaccuracy in predicting absolute risk. Thus, when these scores are used to estimate reduction in expected surgical risk by percutaneous AVR, the magnitude of the reduction is likely exaggerated and may even be in the wrong direction (higher risk than conventional surgery). A more accurate tool than the current EuroSCOREs, possibly AVR specific, is needed to assist in selecting appropriate patients for percutaneous AVR and assessing early results.

Conflict of interest: none declared.

References

1. Pellikka PA, Sarano ME, Nishimura RA, Malouf JF, Bailey KR, Scott CG, Barnes ME, Tajik AJ. Outcome of 622 adults with asymptomatic, hemodynamically significant aortic stenosis during prolonged follow-up. *Circulation* 2005;**111**:3290–3295.
2. American College of Cardiology; American Heart Association Task Force on Practice Guidelines; Society of Anesthesiologists; Society for Cardiovascular Angiography Interventions; Society of Thoracic Surgeons, Bonow RO, Carabello RA, Kanu C, de Leon AC Jr, Faxon DP, Freed MD, Gaasch WH, Lytle BW, Nishimura RA, O'Gara PT, O'Rourke RA, Otto CM, Shah PM, Schanewise JS, Smith SC Jr, Jacobs AK, Adams CD, Anderson JL, Antman EM, Faxon DP, Fuster V, Halperin JL, Hiratzka LF, Hunt SA, Lytle BW, Nishimura R, Page RL, Riegel B. ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: 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): developed in collaboration with the Society of Cardiovascular Anaesthesiologists: endorsed by the Society for Cardiovascular Angiography and Interventions and the Society of Thoracic Surgeons. *Circulation* 2006;**114**:e84–e231.
3. American College of Cardiology; American Heart Association Task Force on Practice Guidelines; Society of Anesthesiologists; Society for Cardiovascular Angiography Interventions; Society of Thoracic Surgeons, Bonow RO, Carabello RA, Chatterjee K, de Leon AC Jr, Faxon DP, Freed MD, Gaasch WH, Lytle BW, Nishimura RA, O'Gara PT, O'Rourke RA, Otto CM, Shah PM, Schanewise JS, Smith SC Jr, Jacobs AK, Adams CD, Anderson JL, Antman EM, Fuster V, Halperin JL, Hiratzka LF, Hunt SA, Lytle BW, Nishimura R, Page RL, Riegel B. ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: 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) developed in collaboration with the Society of Cardiovascular Anesthesiologists endorsed by the Society for Cardiovascular Angiography and Interventions and the Society of Thoracic Surgeons. *J Am Coll Cardiol* 2006;**48**:e1–e148.
4. Parsonnet V, Dean D, Bernstein AD. A method of uniform stratification of risk for evaluating the results of surgery in acquired adult heart disease. *Circulation* 1989;**79**:I3–I12.

5. Nashel SAM, Roques F, Michel P, Gauducheau E, Lemeshow S, Salamon R, the EuroSCORE study group. European system for cardiac operative risk evaluation (EuroSCORE). *Eur J Cardiothorac Surg* 1999;**16**:9–13.
6. Roques F, Nashef SAM, Michel P, Gauducheau E, deVincentiis C, Baudet E, Cortina J, David M, Faichney A, Gabrielle F, Gams E, Harjula A, Jones MT, Pinna Pintor P, Salamon R, Thulin L. Risk factors and outcome in European cardiac surgery: analysis of the EuroSCORE multinational database of 19030 patients. *Eur J Cardiothorac Surg* 1999;**15**:816–823.
7. Grube E, Schuler G, Buellesfeld L, Gerckens U, Linke A, Wenaweser P, Sauren B, Mohr F, Walther T, Zickmann B. Percutaneous aortic valve replacement for severe aortic stenosis in high-risk patients using the second and current third-generation self-expanding core valve prosthesis device success and 30-day clinical outcome. *J Am Coll Cardiol* 2007;**50**:69–76.
8. Mohr F. Percutaneous valve intervention: the surgeon's view. Lecture at the 72. Annual Meeting of the German Cardiac Society. 2006.
9. Vahl CF, Tochtermann U, Gams E, Hagl S. Efficiency of a computer network in the administrative and medical field of cardiac surgery. Concept and experiences with a departmental system. *Eur J Cardiothorac Surg* 1990;**4**:632–638.
10. Osswald BR, Vahl CF, Hagl S. Increase of 'high-risk patients' undergoing CABG? *Cardiovasc Eng* 1997;**2**:228–230.
11. Shanmugam G, West M, Berg G. Additive and logistic EuroSCORE performance in high risk patients. *Interact Cardiovasc Thorac Surg* 2005;**4**:299–303.
12. Bernstein AD, Parsonnet V. Bedside estimation of risk as an aid for decision-making in cardiac surgery. *Ann Thorac Surg* 2000;**69**:823–828.
13. Blackstone EH. Thinking beyond the risk factors. *Eur J Cardiothorac Surg* 2006;**29**: 645–652.
14. Krumholz HM, Brindis RG, Brush JE, Cohen DJ, Epstein AJ, Furie K, Howard G, Peterson ED, Rathore SS, Smith SC Jr, Spertus JA, Wang Y, Normand SL. Standards for statistical models used for public reporting of health outcomes: an American Heart Association Scientific Statement from the Quality of Care and Outcomes Research Interdisciplinary Writing Group. *Circulation* 2006;**113**: 456–462.
15. Sergeant P, Blackstone E, Meyns B. Can the outcome of coronary bypass grafting be predicted reliably? *Eur J Cardiothorac Surg* 1997;**11**:2–9.
16. De Leval M. Human factors and heart surgery: a Cartesian dream. *Bull Mem Acad R Med Belg* 1996;**151**:359–366.
17. Tochtermann U, Osswald BR, Badowski-Zyla D, Thomas G, Hagl S. Timing of aortic valve replacement as a decisive factor for short-term survival. *J Cardiovasc Surg* 2005;**46**(Suppl. 1):61.
18. Tochtermann U, Schnabel P, Osswald BR, Badowski-Zyla D, Hagl S. Structural changes of the left ventricular outflow tract—an important issue in aortic valve replacement. *Thorac Cardiovasc Surg* 2005;**53**(Suppl. 3):S168.
19. Mihaljevic T, Nowicki ER, Rajeswaran J, Blackstone EH, Lagazzi L, Thomas J, Lytle BW, Cosgrove DM 3rd. Survival after valve replacement for aortic stenosis: implications for decision-making. *J Thorac Cardiovasc Surg* 2008;**135**:1270–1279.
20. Brown ML, Pellikka PA, Schaff HV, Scott CG, Mullany CJ, Sundt TM, Dearani JA, Daly RC, Orszulak TA. The benefits of early valve replacement in asymptomatic patients with severe aortic stenosis. *J Thorac Cardiovasc Surg* 2008;**135**:308–315.
21. Grube E, Laborde JC, Zickmann B, Gerckens U, Felderhoff T, Sauren B, Bootsveld A, Buellesfeld L, Iversen S. First report on a human percutaneous transluminal implantation of a self-expanding valve prosthesis for interventional treatment of aortic valve stenosis. *Catheter Cardiovasc Interv* 2005;**66**:465–469.
22. Hattan N, Ban K, Tanaka E, Abe S, Sekka T, Sugio Y, Mohammed MU, Sato E, Shinozai Y, Onishi Y, Suma H, Handa S, Kawada S, Hori S, Iida A, Nakazawa H, Mori H. Transmyocardial revascularization aggravates myocardial ischemia around the channels in the immediate phase. *Am J Physiol Heart Circ Physiol* 2000;**279**:H1392–H1396.
23. Olsson A, Bredin F, Franco-Cereceda A. Echocardiographic findings using tissue velocity imaging following passive containment surgery with the Acorn CorCap cardiac support device. *Eur J Cardiothorac Surg* 2005;**28**:448–453.
24. Hordijk-Trion M, Lenzen M, Wijns W, de Jaegre P, Simoons ML, Scholte op Reimer WJM, Bertrand ME, Mercado N, Boersma E, athon behalf of the EHS-CR Investigators. Patients enrolled in coronary intervention trials are not representative of patients in clinical practice: results from the Euro Heart Survey on Coronary Revascularization. *Eur Heart J* 2006;**27**:671–678.