Risk factors for 1-year mortality after thoracic endovascular aortic repair

Asad A. Shah, MD,^a Damian M. Craig, MA,^b Nicholas D. Andersen, MD,^a Judson B. Williams, MD,^a Syamal D. Bhattacharya, MD,^a Svati H. Shah, MD, MHS,^b Richard L. McCann, MD,^a and G. Chad Hughes, MD^a

Objective: Thoracic endovascular aortic repair, although physiologically well tolerated, may fail to confer significant survival benefit in some high-risk patients. In an effort to identify patients most likely to benefit from intervention, the present study sought to determine the risk factors for 1-year mortality after thoracic endovascular aortic repair.

Methods: A retrospective review was performed on prospectively collected data from all patients undergoing thoracic endovascular aortic repair from 2002 to 2010 at a single institution. Univariate analysis and multivariate Cox proportional hazards regression analysis were used to identify risk factors associated with mortality within 1 year after thoracic endovascular aortic repair.

Results: During the study period, 282 patients underwent at least 1 thoracic endovascular aortic repair; index procedures included descending aortic repair (n = 189), hybrid arch repair (n = 55), and hybrid thoracoabdominal repair (n = 38). The 30-day/in-hospital mortality was 7.4% (n = 21) and the overall 1-year mortality was 19% (n = 54). Cardiopulmonary pathologies were the most common cause of nonperioperative 1-year mortality (22%, n = 12). Multivariate modeling demonstrated 3 variables independently associated with 1-year mortality: age older than 75 years (hazard ratio, 2.26; *P* = .005), aortic diameter greater than 6.5 cm (hazard ratio, 2.20; *P* = .007), and American Society of Anesthesiologists class 4 (hazard ratio, 1.85; *P* = .049). A baseline creatinine greater than 1.5 mg/dL (hazard ratio, 1.79; *P* = .05) and congestive heart failure (hazard ratio, 1.87; *P* = .08) were also retained in the final model. These 5 variables explained a large proportion of the risk of 1-year mortality (C statistic = 0.74).

Conclusions: Age older than 75 years, aortic diameter greater than 6.5 cm, and American Society of Anesthesiologists class 4 are independently associated with 1-year mortality after thoracic endovascular aortic repair. These clinical characteristics may help risk-stratify patients undergoing thoracic endovascular aortic repair and identify those unlikely to derive a long-term survival benefit from the procedure. (*J Thorac Cardiovasc Surg* 2013;145:1242-7)

Thoracic endovascular aortic repair (TEVAR) is being increasingly used to treat a variety of thoracic aortic pathologies.¹ The short-term benefits of TEVAR versus open repair have been demonstrated and include decreased operative mortality,²⁻⁵ decreased morbidity,^{2,5,6} and decreased hospital length of stay.⁶ The low perioperative risk of TEVAR has led to its application to a wider range of

patients, including higher risk patients who might not have been offered traditional open repair in the past.^{7,8} It has been previously shown in patients undergoing endovascular abdominal aortic aneurysm repair (EVAR) that the early perioperative benefits of an endovascular approach were not sustained in longer term analyses.⁹ Therefore, although physiologically well tolerated, some patients offered TEVAR may still experience significant mortality risk beyond the perioperative period¹⁰ and, thus, not obtain an overall survival benefit from the procedure.

The risk factors for death after TEVAR have been partially elucidated, including the predictors of 30-day and long-term mortality.^{11,12} However, many patients survive the initial postoperative period, but die after discharge and within 1 year of surgery.¹⁰ The risk factors for death within this period have yet to be specifically defined. The identification of such risk factors might lead to more appropriate application of TEVAR, improved risk stratification, and better patient prognostic information. Therefore, the objective of the present study was to determine the risk factors for 1-year mortality after TEVAR. We hypothesized that specific

From the Departments of Surgery^a and Medicine,^b Duke University Medical Center, Durham, NC.

Disclosures: Dr Hughes is a consultant for W.L. Gore and a consultant and speaker for Vascutek Terumo. The other authors have nothing to disclose with regard to commercial support.

This study was presented in part at the Society for Vascular Surgery 2011 Vascular Annual Meeting, June 17, 2011, Chicago, Ill.

Received for publication Jan 3, 2012; revisions received April 13, 2012; accepted for publication May 4, 2012; available ahead of print June 14, 2012.

Address for reprints: G. Chad Hughes, MD, Director, Aortic Surgery Program, Division of Cardiovascular and Thoracic Surgery, Department of Surgery, Duke University Medical Center, Box 3051, Durham, NC 27710 (E-mail: gchad.hughes@duke.edu).

0022-5223/\$36.00

Copyright © 2013 by The American Association for Thoracic Surgery

doi:10.1016/j.jtcvs.2012.05.005

Abbreviations and Acronyms

ASA	= American Society of Anesthesiologists
EVAR	= endovascular abdominal aortic aneurysm repair
TEVAR	= thoracic endovascular aortic repair

preoperative patient characteristics and intraoperative variables are associated with 1-year mortality after TEVAR.

METHODS

Patients and Data Source

A retrospective review was performed on prospectively collected data from all patients undergoing TEVAR from May 2002 to December 2010 at a single referral institution. Preoperative, intraoperative, and postoperative variables were abstracted from the Duke Thoracic Aortic Surgery Database, a prospectively maintained clinical registry of all patients undergoing thoracic aortic surgery at Duke University Medical Center (Durham, NC). For patients with multiple TEVAR procedures, the first was used as the index procedure for the time-to-event analyses. The institutional review board of Duke University reviewed and approved the study, and the need for individual patient consent was waived. All procedures and management were a part of routine clinical care as determined by the clinical care team.

TEVAR Procedures

TEVAR patient selection, techniques of device delivery and deployment, and postoperative surveillance have been previously described.¹³⁻¹⁵ All 5 currently Food and Drug Administration–approved thoracic stent grafts and the investigational Zenith TX2-LP (Cook Medical, Bloomington, Ind) device were used. The indications for each TEVAR procedure were classified as degenerative aneurysm (including penetrating atherosclerotic ulcers), acute and chronic dissection, or acute blunt traumatic aortic injury (transection). The procedures were further classified as descending-only repair,¹⁶ hybrid arch repair (aortic arch debranching with aortic endograft coverage),¹³ and hybrid thoracoabdominal repair (visceral abdominal debranching with aortic endograft coverage).^{14,17}

Variables and Outcomes

The primary study outcome was 1-year mortality, defined as death occurring between postoperative day 0 and postoperative day 365. The causes of death were classified as perioperative (death within 30 days of TEVAR or within the same hospitalization as the initial TEVAR procedure), aortic-related, cardiopulmonary, cancer, sepsis, failure to thrive, neurologic, other, and unknown. The cause of death was determined by autopsy, medical records, or family interview. The present report included all data collected through the patients' 1-year follow-up visit, a review of outside medical records, or patient/family telephone interview in the case of missing 1-year follow-up information. Deaths from all causes were included in the analysis. In addition, the Social Security Death Index was queried (available from <http://ssdi.rootsweb.com/>) to confirm all patient deaths.

Those variables previously identified in peer-reviewed literature^{11,12,18,19} as potential predictors of outcome in aortic surgery were included as candidate variables for the analysis. The final list of preoperative model variables assessed included age, race, gender, body mass index, left ventricular ejection fraction (from echocardiography, cardiac magnetic resonance imaging, or cardiac catheterization), aortic diameter, preoperative hemoglobin concentration, preoperative serum creatinine level, congestive heart failure, a history of myocardial infarction, gastroesophageal reflux disease, peripheral vascular disease,

steroid use, angiotensin-converting enzyme inhibitor or angiotensin II receptor blocker use, a history of alcohol abuse, type 1 or 2 diabetes, hypertension, a history of stroke, chronic obstructive pulmonary disease, restrictive lung disease, a history of previous aortic surgery, the presence of aortic-related symptoms (ie, chest pain, back pain, malperfusion), American Society of Anesthesiologists (ASA) physical status classification system, indication for procedure, urgency of case, and preoperative white blood cell count. The intraoperative variables assessed included procedure performed, number of endografts placed, extent of aortic pavement, endograft type, subclavian artery coverage, and use of cerebrospinal fluid drainage.

Statistical Analysis

The preoperative and intraoperative variables were compared between patients who died within 1 year of TEVAR (event group) and those who survived until at least 1 year after TEVAR (nonevent group) using univariate linear regression analysis and chi-square tests for continuous and discrete variables, respectively. Continuous variables were checked for normality using Kolmogorov-Smirnov tests and are presented as the mean $\pm$ standard deviation. Categorical variables are presented as percentages (raw numbers). For the variable "aortic diameter," a threshold of greater than 6.5 cm was chosen because this value represented the 75th percentile within the distribution of aortic diameters in the cohort. We have previously performed this analysis using aortic diameter as a continuous variable and found similar results. We chose to use aortic diameter as a categorical, rather than a continuous, variable to give the reader a more clinically relevant cutoff to use when risk stratifying these patients.

Multivariable Cox proportional hazards regression analysis was then used to determine the risk factors for 1-year mortality. Variables with a nominal $P < .1$ on univariate analysis were entered into the multivariable model. The maximum time-to-event was set at 365 days, and the entire study population was therefore censored at that point. Events were defined as death occurring within 1 year of TEVAR. Statistical analysis was performed by 2 authors (D.M.C. and A.A.S.) using SAS, version 9.1 (SAS Institute, Cary, NC).

RESULTS

A total of 316 procedures were performed on 282 patients. The preoperative and intraoperative characteristics of the study population are listed in Tables 1 and 2, respectively. Indications for the index TEVAR procedure included degenerative aneurysm ($n = 183$), aortic dissection ($n = 82$), and blunt aortic injury ($n = 17$). The procedures performed included descending aortic repair ($n = 189$), hybrid arch repair ($n = 55$), and hybrid thoracoabdominal repair ($n = 38$). Concomitant procedures were performed in 21% ($n = 58$) and most frequently included carotid-subclavian bypass ($n = 26$). Aortic-related reintervention was required in 9.6% ($n = 27$) of the patients in the initial year after TEVAR. Follow-up was 100% complete.

The 30-day/in-hospital mortality was 7.4% ($n = 21$), and the overall 1-year mortality was 19% ($n = 54$). Cardiopulmonary pathologies were the most common cause of non-perioperative mortality within 1 year of TEVAR (22% of all 1-year deaths [$n = 12$]; Table 3). The patient variables associated with 1-year mortality on univariate analysis were age older than 75 years ($P < .001$), congestive heart failure ($P = .03$), peripheral vascular disease ($P = .02$), a history of stroke ($P = .04$), creatinine greater than 1.5

TABLE 1. Preoperative patient characteristics

Variable	All patients (n = 282)	Nonevent group (n = 228)	Event group (n = 54)	P value*
Age >75 y	24% (68)	20% (45)	43% (23)	.0004
Sex (male)	59% (166)	57% (131)	65% (35)	.32
Race (white)	65% (182)	62% (142)	74% (40)	.10
BMI >30 kg/m ²	27% (76)	29% (66)	19% (10)	.12
LVEF (%)	53 ± 6	53 ± 5	51 ± 8	.30
CHF	12% (33)	10% (22)	20% (11)	.03
History of MI	13% (36)	11% (25)	20% (11)	.06
Hypertension	83% (233)	82% (187)	85% (46)	.58
ACEI/ARB use	40% (113)	38% (86)	50% (27)	.10
PVD	23 (64%)	20% (45)	35% (19)	.02
History of stroke	11% (30)	9% (20)	19% (10)	.04
Diabetes	13% (38)	14% (33)	9% (5)	.31
Smoking	56% (157)	58% (131)	48% (26)	.18
COPD	28% (80)	28% (63)	31% (17)	.57
Restrictive lung disease	2% (7)	2% (5)	4% (2)	.62
GERD	33% (93)	31% (71)	41% (22)	.18
Steroid use	3% (9)	3% (7)	4% (2)	.68
Alcohol abuse	7% (20)	8% (19)	2% (1)	.14
Hemoglobin (g/dL)	12 ± 2	12 ± 2	12 ± 2	.79
Creatinine >1.5 mg/dL	21% (60)	18% (41)	35% (19)	.006
Preoperative WBC count >10K	19% (50)	19% (39)	22% (11)	.55
ASA class 4 (vs 3)	51% (132)	47% (96)	71% (36)	.002
Previous aortic surgery	39% (111)	37% (85)	48% (26)	.14
Presence of aortic-related symptoms	49% (137)	49% (112)	46% (25)	.69
Aortic diameter >6.5 cm	25% (71)	20% (45)	48% (26)	<.0001
Indication				.02
Aneurysm	65% (183)	61% (140)	80% (43)	
Dissection	29% (82)	31% (71)	20% (11)	
Blunt aortic injury	6% (17)	7% (17)	0% (0)	
Procedure status				.99
Elective	62% (171)	62% (139)	62% (32)	
Urgent	25% (68)	25% (55)	25% (13)	
Emergent	13% (36)	13% (29)	13% (7)	

Data presented as percentages, with numbers in parentheses, or mean ± standard deviation. BMI, Body mass index; LVEF, left ventricular ejection fraction; CHF, congestive heart failure; MI, myocardial infarction; ACEI, angiotensin-converting enzyme inhibitor; ARB, angiotensin II receptor blocker; PVD, peripheral vascular disease; COPD, chronic obstructive pulmonary disease; GERD, gastroesophageal reflux disease; WBC, white blood cell; ASA, American Society of Anesthesiologists. *P value for univariate comparison of living versus 1-year mortality groups.

mg/dL ($P = .006$), ASA class 4 ($P = .002$), and aortic diameter greater than 6.5 cm ($P < .001$; Tables 1 and 2). The 1-year mortality differed according to the indication for TEVAR, with patients who underwent TEVAR for blunt aortic injury having 0% 1-year mortality and those undergoing TEVAR for aortic dissections and degenerative aneurysms having 13% and 24% 1-year mortality, respectively ($P = .02$). The type of TEVAR procedure performed was also associated with 1-year mortality, with patients undergoing hybrid arch repairs having the greatest 1-year mortality (29%), followed by 27% for hybrid thoracoabdominal repair and 15% for descending-only repair ($P = .03$).

Multivariable modeling demonstrated that 3 of these variables were independently associated with 1-year mortality: age older than 75 years (hazard ratio [HR], 2.26; 95% confidence interval [CI], 1.28-3.98; $P = .005$), aortic diameter greater than 6.5 cm (HR, 2.20; 95% CI, 1.25-3.88;

$P = .007$), and ASA class 4 (HR, 1.85; 95% CI, 1.003-3.43; $P = .049$; Table 4). A baseline creatinine greater than 1.5 mg/dL (HR, 1.79; 95% CI, 0.99-3.21; $P = .05$) and congestive heart failure (HR, 1.87; 95% CI, 0.93-3.80; $P = .08$) were also retained in the final model. These 5 variables explained a large proportion of the risk of 1-year mortality (C statistic = 0.74).

DISCUSSION

TEVAR has been used to treat a variety of pathologic entities of the thoracic aorta. Because the procedure is generally well tolerated from a physiologic standpoint, even in many patients who would not be considered candidates for conventional open repair, the application of this technology appears to be increasing.¹ However, some patients offered TEVAR may suffer significant 1-year mortality¹⁰ and thus not obtain a meaningful survival benefit from the procedure.

TABLE 2. Intraoperative patient characteristics

Variable	All patients (n = 282)	Nonevent group (n = 228)	Event group (n = 54)	P value*
TEVAR				.03
Descending	67% (189)	71% (161)	52% (28)	
Hybrid arch	20% (55)	18% (40)	28% (15)	
Hybrid TAAA	13% (38)	12% (27)	20% (11)	
Aortic pavement				.71
Left subclavian to T6	41% (116)	41% (94)	41% (22)	
Mid-thoracic aorta to celiac axis	11% (32)	12% (27)	9% (5)	
Left subclavian artery to celiac axis	27% (76)	28% (63)	24% (13)	
Other	21% (58)	19% (44)	26% (14)	
Stent graft type				.78
Gore TAG/C-TAG	59% (167)	59% (135)	59% (32)	
Medtronic Talent/Valiant	13% (37)	14% (31)	11% (6)	
Zenith TX2/TX2-LP	19% (54)	19% (44)	19% (10)	
Other	1% (3)	1% (3)	0% (0)	
Combination	7% (21)	7% (15)	11% (6)	
No. of stent grafts	1.9 ± 1.0	1.8 ± 0.96	2.2 ± 1.1	.28
CSF drain	21% (58)	19% (44)	26% (14)	.29
Subclavian artery coverage	54% (152)	54% (124)	52% (28)	.74

Data presented as percentages, with numbers in parentheses, or mean ± standard deviation. TEVAR, Thoracic endovascular aortic repair; TAAA, thoracoabdominal aortic aneurysm; CSF, cerebrospinal fluid. *P value for univariate comparison of living versus 1-year mortality groups.

Goodney and colleagues²⁰ recently examined the short- and long-term survival after open and endovascular descending thoracic aortic aneurysm repair in the Medicare population. They found that the short-term survival advantage of TEVAR compared with open repair was lost within 2 years of surgery.²⁰ Furthermore, the long-term (5-year) survival was shown to be worse after TEVAR than after open repair, even after adjustment for patient comorbidities.²⁰ Although unknown, these recent data may indicate that certain patients who would not have traditionally been offered open repair are now being offered TEVAR and that these patients are not obtaining a survival benefit from the procedure. The investigators concluded that additional work is needed to identify this group of patients unlikely to benefit from TEVAR.²⁰ The present study has addressed this issue by delineating several preoperatively identifiable risk factors that might lead to more appropriate application of TEVAR.

Previous work has documented significant interval mortality within 1 year after conventional thoracoabdominal

aortic aneurysm repair,²¹ findings that led the investigators to suggest that 1-year mortality data should play a role in clinical decision making for thoracoabdominal aortic aneurysm repair. The results of the present study, with nearly 20% mortality within 1 year postoperatively, extend this finding to thoracic endovascular repair and suggest a similar logic should apply to TEVAR as well. Because the prevalence of thoracic aortic disease increases with age,²² and because the U.S. population aged older than 65 years is expected to increase by 50% within the next decade,²³ the overall need for TEVAR procedures is likely to increase. Thus, given this increased need among an older and sicker population, a risk model examining 1-year mortality should prove helpful to clinicians and patients and their families in identifying patients unlikely to benefit from repair.

Furthermore, given the expense of these procedures with typical device costs of \$10,000 to 15,000 per component, economic questions regarding appropriate use are likely to arise in this era of increasing healthcare costs. Although a rigorous cost-effectiveness analysis has not been performed for TEVAR, given the high cost of the devices,

TABLE 3. Causes of 1-year mortality

Cause	% (n)
Perioperative*	39 (21)
Cardiopulmonary	22 (12)
Aortic related	9 (5)
Neurologic	6 (3)
Failure to thrive	6 (3)
Sepsis	4 (2)
Other	7 (4)
Unknown	7 (4)

*Thirty-day/in-hospital mortality after thoracic endovascular aortic repair.

TABLE 4. Multivariate model for 1-year mortality

Variable	HR (95% CI)	P value
Age >75 y	2.26 (1.28-3.98)	.005
Aortic diameter >6.5 cm	2.20 (1.25-3.88)	.007
ASA class 4	1.85 (1.003-3.43)	.049
Creatinine >1.5 mg/dL	1.79 (0.99-3.21)	.05
Congestive heart failure	1.87 (0.93-3.80)	.08

HR, Hazard ratio; CI, confidence interval; ASA, American Society of Anesthesiologists.

surgical implantation, and radiographic follow-up, it is unlikely that these costs would meet accepted cost-effectiveness thresholds²⁴ if patients experience less than 1 year of added survival. In the abdominal aortic aneurysm data, EVAR quickly becomes cost-ineffective when mortality rates from the procedure increase to more than 4.4%.²⁵ Furthermore, given that the estimated yearly risk of death is 10.8% for a patient with a greater than 6-cm thoracic aneurysm,²⁶ the vast majority of patients who undergo elective TEVAR and die within 1 year of intervention experience no survival benefit from the procedure.

To our knowledge, this is the largest study describing the risk factors for 1-year mortality after TEVAR. The present study included patients undergoing descending TEVAR only and patients undergoing more complex hybrid arch and hybrid thoracoabdominal aortic aneurysm repairs. Although the inclusion of hybrid repairs adds heterogeneity to the study population, all 3 treatment groups were included, given that all share the common intervention of endograft placement in the thoracic aorta. Furthermore, the vast majority of all 3 of these procedures are performed to treat the same 2 disease processes, namely degenerative aneurysm and aortic dissection. Finally, most published TEVAR series have included hybrid cases, which can constitute one third or more of the patients; therefore, including these patients represents “real world” risk stratification for TEVAR as used in clinical practice.¹⁵

The present report has demonstrated that age older than 75 years, aortic diameter greater than 6.5 cm, and ASA class 4 are associated with 1-year mortality after TEVAR. The finding of aortic diameter as an independent risk factor for 1-year mortality has support from previous studies. Chung and colleagues¹¹ found aneurysm size to be a predictor of mortality at any point after TEVAR in a general group of TEVAR patients, as well as in a subset of patients with asymptomatic, nonruptured degenerative aneurysms. Dillavou and Makaroun¹⁹ showed increasing aneurysm size to be a predictor of major adverse events²⁷ in patients undergoing endovascular or open thoracic aortic repair ($P < .001$), although aneurysm size did not reach statistical significance in the endovascular group alone ($P = .082$). Patients presenting with a larger aortic size frequently manifest more advanced aortic disease, which can be associated with greater atherosclerotic burden,²⁸ as well as greater systemic disease burden, such as chronic obstructive pulmonary disease. In the present study, patients with chronic obstructive pulmonary disease had larger aneurysms, although this difference did not reach statistical significance (6.0 vs 5.6 cm, $P = .13$).

The ASA class was associated with 1-year mortality and, similarly, has been associated with morbidity and mortality after a variety of surgical procedures. In patients undergoing TEVAR for type B dissection, ASA class has been associated with postintervention mortality.²⁹ ASA class has also

been associated with increased morbidity, mortality, and hospitalization rates in patients undergoing EVAR.³⁰ The present data thus extend the known prognostic value of ASA class to 1-year mortality in patients undergoing TEVAR.

Our finding of increased mortality in patients more than 75 years old was expected. Czerny and colleagues¹⁸ found a near doubling of mortality (35% vs 18%) in patients older than 75 years after TEVAR during a median follow-up of 36 months. Numerous other studies have shown that increasing age is a risk factor for mortality after TEVAR.³¹⁻³³

Cardiopulmonary pathologies were the most common cause of nonperioperative 1-year mortality in the present study (22%). This appears consistent with the available data on early and late causes of post-TEVAR mortality. For example, in the series by Chung and colleagues,¹¹ cardiopulmonary causes were responsible for 43% of the 30-day mortality and 24% of the mortality more than 30 days after TEVAR. In the cohort reported on by Khoynzhad and colleagues,¹² 39% of early deaths were from myocardial infarction and 47% of late (>30-day) deaths were from myocardial infarction or pneumonia. This high incidence of cardiopulmonary causes of mortality was not unexpected, given the similar risk factors for cardiac, pulmonary, and many aortic diseases.

Recent data from the EVAR 1 trial⁹ examining the long-term outcomes of endovascular versus open abdominal aortic aneurysm repair showed that secondary aortic rupture after endovascular repair was likely responsible for much of the long-term increased aneurysm-related mortality with this treatment strategy. These findings contrast with the present TEVAR report in which aortic-related 1-year mortality was modest, accounting for 9% of nonperioperative 1-year deaths. The present results are more similar to those from the Dutch Randomised Endovascular Aneurysm Management (DREAM) trial³⁴ of EVAR, in which aneurysm rupture and graft-related complications were infrequent causes of longer term mortality.

The present study has several limitations. First, the study did not include a control group of nonoperative or open surgical management with which to compare the TEVAR 1-year survival data. Second, the cause of death was unknown for 4 patients, although the follow-up data were 100% complete. These deaths were generally unwitnessed sudden deaths at home. Finally, although the 5 variables in the multivariable model explain the large proportion (C statistic = 0.74) of risk for 1-year mortality after TEVAR, they do not explain all the risk, and other, as yet unknown, variables could also be important predictors. Furthermore, the ability to use the model as a meaningful predictor of risk for any given patient requires validation, although the present study represents the largest series to date reporting the risk factors for 1-year mortality after TEVAR, has more than 10 events per model variable, and

has confirmed many risk factors for mortality previously identified by other TEVAR studies. Finally, there are likely postoperative variables that also affect 1-year mortality that the present study did not attempt to identify.

CONCLUSIONS

In the present single-institution series, age older than 75 years, aortic diameter greater than 6.5 cm, and ASA class 4 were associated with increased mortality within 1 year of TEVAR. These clinical factors should be taken into account when weighing the risks and benefits of pursuing TEVAR as a treatment option and when providing patients with prognostic information. The results may help better risk stratify patients and identify those less likely to derive a long-term survival benefit from TEVAR.

References

- Scali ST, Goodney PP, Walsh DB, Travis LL, Nolan BW, Goodman DC, et al. National trends and regional variation of open and endovascular repair of thoracic and thoracoabdominal aneurysms in contemporary practice. *J Vasc Surg.* 2011;53:1499-505.
- Walsh SR, Tang TY, Sadat U, Naik J, Gaunt ME, Boyle JR, et al. Endovascular stenting versus open surgery for thoracic aortic disease: systematic review and meta-analysis of perioperative results. *J Vasc Surg.* 2008;47:1094-8.
- Jonker FH, Trimarchi S, Verhagen HJ, Moll FL, Sumpio BE, Muhs BE. Meta-analysis of open versus endovascular repair for ruptured descending thoracic aortic aneurysm. *J Vasc Surg.* 2010;51:1026-32. 1032.e1-2.
- Xenos ES, Minion DJ, Davenport DL, Hamdallah O, Abedi NN, Sorial EE, Endean ED. Endovascular versus open repair for descending thoracic aortic rupture: institutional experience and meta-analysis. *Eur J Cardiothorac Surg.* 2009;35:282-6.
- Makaroun MS, Dillavou ED, Wheatley GH, Cambria RP, Gore TAG Investigators. Five-year results of endovascular treatment with the Gore TAG device compared with open repair of thoracic aortic aneurysms. *J Vasc Surg.* 2008;47:912-8.
- Gopaldas RR, Huh J, Dao TK, LeMaire SA, Chu D, Bakaeen FG, Coselli JS. Superior nationwide outcomes of endovascular versus open repair for isolated descending thoracic aortic aneurysm in 11,669 patients. *J Thorac Cardiovasc Surg.* 2010;140:1001-10.
- Patel HJ, Shillingford MS, Williams DM, Upchurch GR Jr, Dasika NL, Prager RL, Deeb GM. Survival benefit of endovascular descending thoracic aortic repair for the high-risk patient. *Ann Thorac Surg.* 2007;83:1628-34.
- Mosquera VX, Herrera JM, Marini M, Estevez F, Cao I, Gullas D, et al. Mid-term results of thoracic endovascular aortic repair in surgical high-risk patients. *Interact Cardiovasc Thorac Surg.* 2009;9:61-5.
- United Kingdom EVAR Trial Investigators, Greenhalgh RM, Brown LC, Powell JT, Thompson SG, Epstein D, Schulpher MJ. Endovascular versus open repair of abdominal aortic aneurysm. *N Engl J Med.* 2010;362:1863-71.
- Leurs LJ, Bell R, Degrieck Y, Thomas S, Hobo R, Lundbom J, et al. Endovascular treatment of thoracic aortic diseases: combined experience from the EUROSTAR and United Kingdom Thoracic Endograft registries. *J Vasc Surg.* 2004;40:670-80.
- Chung J, Corriere MA, Veeraswamy RK, Kasirajan K, Milner R, Dodson TF, et al. Risk factors for late mortality after endovascular repair of the thoracic aorta. *J Vasc Surg.* 2010;52:549-55.
- Khoynezhad A, Donayre CE, Smith J, Kopchok GE, Walot I, White RA. Risk factors for early and late mortality after thoracic endovascular aortic repair. *J Thorac Cardiovasc Surg.* 2008;135:1103-9. 1109.e1-4.
- Hughes GC, Daneshmand MA, Balsara KR, Achneck HA, Sileshi B, Lee SM, McCann RL. "Hybrid" repair of aneurysms of the transverse aortic arch: mid-term results. *Ann Thorac Surg.* 2009;88:1882-8.
- Hughes GC, Nienaber JJ, Bush EL, Daneshmand MA, McCann RL. Use of custom Dacron branch grafts for "hybrid" aortic debranching during endovascular repair of thoracic and thoracoabdominal aortic aneurysms. *J Thorac Cardiovasc Surg.* 2008;136:21-8. 28.e1-6.
- Hughes GC, Daneshmand MA, Swaminathan M, Nienaber JJ, Bush EL, Husain AH, et al. "Real world" thoracic endografting: results with the Gore TAG device 2 years following U.S. FDA approval. *Ann Thorac Surg.* 2008;86:1530-8.
- Hughes GC, Lee SM, Daneshmand MA, Bhattacharya SD, Williams JB, Tucker SW Jr, McCann RL. Endovascular repair of descending thoracic aneurysms: results with "on-label" application in the post Food and Drug Administration approval era. *Ann Thorac Surg.* 2010;90:83-9.
- Hughes GC, McCann RL. Hybrid thoracoabdominal aortic aneurysm repair: concomitant visceral revascularization and endovascular aneurysm exclusion. *Semin Thorac Cardiovasc Surg.* 2009;21:355-62.
- Czerny M, Funovics M, Ehrlich M, Hoebartner M, Sodeck G, Dumfarth J, et al. Risk factors of mortality in different age groups after thoracic endovascular aortic repair. *Ann Thorac Surg.* 2010;90:534-8.
- Dillavou ED, Makaroun MS. Predictors of morbidity and mortality with endovascular and open thoracic aneurysm repair. *J Vasc Surg.* 2008;48:1114-20.
- Goodney PP, Travis L, Lucas FL, Fillingim MF, Goodman DC, Cronenwett JL, Stone DH. Survival after open versus endovascular thoracic aortic aneurysm repair in an observational study of the Medicare population. *Circulation.* 2011;124:2661-9.
- Rigberg DA, McGory ML, Zingmond DS, Maggard MA, Agustin M, Lawrence PF, Ko CY. Thirty-day mortality statistics underestimate the risk of repair of thoracoabdominal aortic aneurysms: a statewide experience. *J Vasc Surg.* 2006;43:217-23.
- Kouchoukos NT, Dougenis D. Surgery of the thoracic aorta. *N Engl J Med.* 1997;336:1876-88.
- Perler BA. Charles Dickens, Coach K, Pogo, and the recent history and future of vascular surgery. *J Vasc Surg.* 2010;51:1286-92.
- Patel ST, Haser PB, Bush HL, Kent KC. The cost-effectiveness of endovascular repair versus open surgical repair of abdominal aortic aneurysms: a decision analysis model. *J Vasc Surg.* 1999;29:958-72.
- Hayes PD, Sadat U, Walsh SR, Noorani A, Tang TY, Bowden DJ, et al. Cost-effectiveness analysis of endovascular versus open surgical repair of acute abdominal aortic aneurysms based on worldwide experience. *J Endovasc Ther.* 2010;17:174-82.
- Elefteriades JA. Natural history of thoracic aortic aneurysms: indications for surgery, and surgical versus nonsurgical risks. *Ann Thorac Surg.* 2002;74:S1877-80. S1892-98.
- Sacks D, Marinelli DL, Martin LG, Spies JB. Reporting standards for clinical evaluation of new peripheral arterial revascularization devices: Technology Assessment Committee. *J Vasc Interv Radiol.* 1997;8(1 Pt 1):137-49.
- Agmon Y, Khandheria BK, Meissner I, Schwartz GL, Sicks JD, Fought AJ, et al. Is aortic dilatation an atherosclerosis-related process? Clinical, laboratory, and transesophageal echocardiographic correlates of thoracic aortic dimensions in the population with implications for thoracic aortic aneurysm formation. *J Am Coll Cardiol.* 2003;42:1076-83.
- Eggebrecht H, Herold U, Kuhn O, Schmermund A, Bartel T, Martini S, et al. Endovascular stent-graft treatment of aortic dissection: determinants of post-interventional outcome. *Eur Heart J.* 2005;26:489-97.
- Zannetti S, De Rango P, Parlani G, Verzini F, Maselli A, Cao P. Endovascular abdominal aortic aneurysm repair in high-risk patients: a single centre experience. *Eur J Vasc Endovasc Surg.* 2001;21:334-8.
- Bhamidipati CM, LaPar DJ, Mehta GS, Kern JA, Kron IL, Upchurch GR Jr, Ailawadi G. Have thoracic endografting outcomes improved since US Food and Drug Administration approval? *Ann Thorac Surg.* 2011;91:1314-22.
- Patel HJ, Hemmila MR, Williams DM, Diener AC, Deeb GM. Late outcomes following open and endovascular repair of blunt thoracic aortic injury. *J Vasc Surg.* 2011;53:615-21.
- Jonker FH, Verhagen HJ, Heijmen RH, Lin PH, Trimarchi S, Lee WA, et al. Endovascular treatment of ruptured thoracic aortic aneurysm in patients older than 75 years. *Eur J Vasc Endovasc Surg.* 2011;41:48-53.
- De Bruin JL, Baas AF, Buth J, Prinssen M, Verhoeven EL, Cuypers PW, et al. Long-term outcome of open or endovascular repair of abdominal aortic aneurysm. *N Engl J Med.* 2010;362:1881-9.