Long-term outcome after aortic arch replacement with a trifurcated graft

Moritz S. Bischoff, MD,^a Robert M. Brenner, MS,^a Johannes Scheumann, MS,^a Carol A. Bodian, DrPH,^b Randall B. Griepp, MD,^a Steven L. Lansman, MD, PhD,^c and David Spielvogel, MD^c

Objective: We describe the long-term results of aortic arch replacement using a trifurcated graft, including an assessment of survival, neurologic complications, and graft patency.

Methods: A retrospective review was conducted on data from 206 consecutive patients (125 male; median age, 67 years; range, 20–87 years) who had a trifurcated graft used for aortic arch replacement between September 1999 and September 2009. Seventy-four patients (35.9%) had chronic dissection, 68 patients (33.0%) had atherosclerotic aneurysms, and 39 patients (18.9%) had degenerative disease. Ninety-one patients (44.2%) had undergone previous cardiac surgery.

Results: An elephant trunk was placed in 190 patients (92.2%) and completed in 101 patients (53.1%), with an interval of less than 365 days between stages in 94 of 101 patients. Hospital mortality was 6.8% (14/206). Adverse outcome (death/stroke within the first year postoperatively) occurred in 27.7% of patients (57/206; 50 deaths/7 strokes). Among 152 1-year survivors, the annual rates of transient ischemic attack and stroke were 0.85% and 1.1%, respectively. At 6 years, 75% of patients were still alive, compared with 92% in a matched New York State control population ($P < .001$). Follow-up computed tomography scans (189 studies in 176/206 patients [85.4%]) revealed 100% patency of the trifurcated graft limbs at a mean of 2.3 years.

Conclusions: Aortic arch replacement using a trifurcated graft is highly durable, with excellent patency in the branch grafts, and is associated with a low incidence of cerebral embolization. However, the long-term outcome in these patients is compromised by extensive comorbidities. (J Thorac Cardiovasc Surg 2010;140:S71-6)

Cerebral injury is a devastating complication of aortic arch replacement, with an enormous impact on quality of life and long-term survival. Mounting evidence suggests that the best method for cerebral protection in aortic arch surgery is selective cerebral perfusion (SCP) combined with deep or moderate hypothermic circulatory arrest (HCA).¹⁻³

Especially in procedures requiring circulatory arrest exceeding 30 minutes, antegrade SCP has been shown to preserve cerebral oxygenation and attenuate derangements in cerebral metabolism.⁴⁻⁶ Various methods for delivering SCP have been developed, yielding low mortality rates and neurologic injury.⁷⁻¹¹ Nevertheless, cerebral embolism and malperfusion during SCP remain problematic, highlighting the importance of designing a technique to minimize these complications.¹²

Spielvogel and coworkers¹³⁻¹⁵ have published several reports describing the use of a trifurcated graft (TG) to

replace the aortic arch. The technique has proven simple, permitting expeditious arch reconstruction, yet versatile, easily accommodating different anatomic situations.¹³⁻¹⁵ Moreover, the TG technique reduces the potential for cerebral injury. First, administration of SCP via the right axillary artery shortens the duration of HCA. Second, excluding diseased portions of the arch and minimizing manipulation of the brachiocephalic vessels both reduce the potential for cerebral embolization. Short-term studies of the TG technique have yielded low neurologic complication and in-hospital mortality rates.¹⁶ The current study focuses on long-term outcome, highlighting neurologic events and the durability of the procedure.

MATERIALS AND METHODS

Patient Data Abstraction

From September 1999 to September 2009, 206 consecutive patients (125 male, 81 female) underwent aortic arch replacement using a TG and hypothermic SCP via direct axillary artery cannulation.¹⁷ This retrospective analysis, using review of medical records and telephone follow-up, was approved by an institutional review board and did not require individual patient consent.

All patients who underwent the TG operation at our institutions during this 10-year interval were included. The focus is on their long-term outcome, regardless of whether the TG procedure was intended as a stand-alone procedure or part of a planned 2-stage approach.

The median patient age was 67 years (range, 20–87 years). The most frequent underlying causes for operation were chronic dissection (74; 37.3%), atherosclerosis (68; 32%), and degenerative disease (39; 19.3%); other causes are detailed in Table 1. Ninety-one patients (44.2%) had undergone previous cardiac surgery (Table 2).

From the Departments of Cardiothoracic Surgery^a and Anesthesiology,^b Mount Sinai School of Medicine, New York, NY; and the Department of Cardiothoracic Surgery,^c Westchester Medical Center, Valhalla, NY.

Disclosures: David Spielvogel is a consultant for Magurt and is a member of the speakers bureau for Vascutek Terumo. Moritz S. Bischoff, Robert M. Brenner, Johannes Scheumann, Carol A. Bodian, Randall B. Griepp, and Steven L. Lansman have nothing to disclose with regard to commercial support.

Received for publication April 28, 2010; accepted for publication July 12, 2010.

Address for reprints: Moritz S. Bischoff, MD, Mount Sinai School of Medicine, Department of Cardiothoracic Surgery, One Gustave L. Levy Place, PO Box 1028, New York, NY 10029 (E-mail: moritz.bischoff@mountsinai.org).

0022-5223/\$36.00

Copyright © 2010 by The American Association for Thoracic Surgery

doi:10.1016/j.jtcvs.2010.07.034

Abbreviations and Acronyms

AO	= adverse outcome
CT	= computed tomography
ET	= elephant trunk
HCA	= hypothermic circulatory arrest
SCP	= selective cerebral perfusion
TG	= trifurcated graft

Risk factors for adverse outcome (AO) included smoking (78 patients; 36 active smokers, 42 past smokers), chronic obstructive pulmonary disease (28 patients; 13.6%), neurologic events (24 patients; 19 with stroke, 5 with transient ischemic attack), coronary artery disease (16 patients; 7.8%), insulin-dependent diabetes mellitus (10 patients; 4.9%), and dialysis-dependent renal failure (10 patients; 4.9%).

The mean maximal diameter of the aorta was 6.0 ± 1.3 cm (range, 4.0–12.0 cm). The extent of aortic replacement varied depending on the underlying disease. Isolated arch replacement was undertaken in 49 patients (23.8%). Concomitant procedures included ascending aortic replacement (102; 49.5%), ascending and root replacement (26; 12.6%), descending aortic replacement (8; 3.9%), and simultaneous coronary artery bypass grafting (53; 25.7%).

An elephant trunk (ET) procedure was performed in 190 of 206 patients (92.2%); in 69 patients (33.5%), no further procedure was undertaken. A completion stage II ET was performed in 101 patients (53.2%), using an endograft in 5 patients. The median interval between stages I and II was 65 days (range, 0–4.3 years; 2 simultaneously); the interval was 30 days or less in 22 patients (21.8%), 30 to 100 days in 45 patients (44.6%), and more than 100 days in 32 patients (31.7%).

Operative Technique

Details of the TG technique have been described.^{13–16} A custom TG can be constructed or a commercially prepared graft can be used (MAQUET, Wayne, NJ). Briefly, the arch is approached via a median sternotomy or bilateral anterior thoracotomy. With the aorta crossclamped and perfusing via direct axillary artery cannulation, the proximal aortic reconstruction is performed while cooling toward 15°C. HCA is initiated when jugular bulb saturation is 95% or greater, indicating maximum cerebral metabolic suppression. During circulatory arrest, the brachiocephalic vessels are transected approximately 1 cm beyond their origins; the presence of macroscopic atherosclerotic disease may warrant further resection. The arch vessels are serially anastomosed with 5-0 polypropylene sutures. The left subclavian artery typically is attached first, followed by the left common carotid and innominate arteries. By clamping the main limb of the TG, axillary perfusion is resumed, providing hypothermic SCP to the head and upper extremities. The perfusate temperature is allowed to drift upward during the remaining arch repair, and active rewarming is not begun until full systemic flow is resumed. The ET anastomosis is constructed proximal to the left subclavian artery origin. A graft-to-graft anastomosis is constructed between the ET graft and the proximal repair, and the TG can be anastomosed to the neo-ascending aorta without interrupting cerebral circulation.

Follow-up

This retrospective review was conducted using contemporaneously gathered data and follow-up involving direct telephone interviews of the patient, a close relative, or the referring physician. A standardized questionnaire included queries about general health, cerebral vascular accidents, rehospitalization, reoperation, complications, and medications. Three patients (1.5%) were lost to follow-up after 63, 86, and 1099 days. Follow-up was 98.5%

TABLE 1. Causes

	n (%)
Chronic dissection	74 (35.9%)
Atherosclerosis	68 (33.0%)
Degenerative	39 (18.9%)
Ruptured atherosclerotic ulcer	8 (3.9%)
Marfan syndrome (non-dissected)	5 (2.4%)
Acute dissection	5 (2.4%)
Trauma	2 (1.0%)
Inflammatory aneurysm	2 (1.0%)
Other	2 (1.0%)
False aneurysm	1 (0.5%)

complete, and median follow-up time was 3.7 years (range, 63 days to 9.6 years).

Computed Tomography Scans

The latest contrast-enhanced computed tomography (CT) scans were reviewed for each patient, focusing on graft patency, change of caliber at the anastomotic site, and the presence of dissection.

Statistical Analysis

Risk factors for AO and long-term survival were estimated by Cox proportional hazards regression. Survival curves were estimated using a Kaplan–Meier curve, and Poisson regression was used to estimate the standardized mortality ratio, relative to the 2004 New York State mortality rates matched by gender and age. Linearized rates for permanent and temporary neurologic dysfunction were calculated by dividing the number of events by the corresponding person-years of exposure. In all of these analyses, follow-up was measured from the time of surgery, or from 1 year after surgery, to the earlier date of death or of last contact alive, as appropriate. For analyses regarding AO, follow-up was terminated at the earlier time of stroke, death, last contact alive, or end of observation period.

RESULTS

Analysis of Results

With the desire to focus on the true long-term outcome, AO was defined as death or occurrence of permanent stroke within 1 year of surgery. Neurologic impairment was categorized as stroke (whether hemorrhagic, ischemic, or of

TABLE 2. Spectrum of previous cardiothoracic procedures (n = 91)

	n (%)
Procedures for acute type A dissection	
Ascending interposition graft	36 (39.5%)
Ascending and aortic root replacement	13 (14.3%)
Ascending and aortic arch replacement	3 (3.3%)
Other aortic procedures	
Aortic root replacement	12 (13.2%)
Thoracoabdominal aneurysm repair	9 (9.9%)
Other cardiac procedures	
Coronary artery bypass grafts	8 (8.8%)
Aortic valve replacement	5 (5.5%)
AVR and CABG	4 (4.4%)
Triple-valve replacement	1 (1.1%)

AVR, Aortic valve replacement; CABG, coronary artery bypass grafting.

unknown nature) or transient neurologic dysfunction: postoperative confusion, agitation, delirium, prolonged obtundation, or Parkinson-like symptoms, with no focal deficit on CT or magnetic resonance imaging.

Operative Technique

A TG was used in 194 of 206 cases. In 12 patients, a bifurcated graft was used because of a specific anatomic condition or previous operation (ie, carotid-to-subclavian bypass). In total, these patients had 606 anastomoses, with a mean of 2.9 anastomoses per patient.

Postoperative Complications

Postoperative complications after aortic arch replacement using a TG occurred in 66 patients (32%). The most frequent complication was prolonged intubation (>48 hours) in 27 patients (13.1%). Postoperative transient neurologic dysfunction developed in 12 patients (5.8%). Bleeding requiring return to the operating room was reported in 11 patients (5.3%). Nine patients (4.4%) required dialysis: renal failure was permanent in 2 patients and transient in 7 patients. Cardiac complications occurred in 7 patients (3.4%): 3 patients had episodes of atrial fibrillation, and 4 patients developed pericardial effusions. Permanent stroke occurred in 7 patients (2 of them died, vide infra: hospital mortality).

The median hospital stay was 11 days (range, 1–108 days). The median intensive care unit stay was 3 days (range, 1–108 days).

Hospital Mortality

Overall hospital mortality (death in the hospital or within 30 days postoperatively) was 6.8% (14/206). Congestive heart failure ($n = 3$), stroke ($n = 2$, ischemic = 1, hemorrhagic = 1), aortic rupture ($n = 2$), and bleeding ($n = 2$) were the most common causes of death. Respiratory failure, myocardial infarction, gastric ulceration, uncontrollable acidosis, and multiorgan failure each occurred in 1 patient.

Adverse Outcome in the First Year

AO, defined as stroke or death within the first year postoperatively, occurred in 27.7% of patients (57/206). There were 50 deaths (including 7 fatal strokes) and 7 stroke survivors (Table 3; Figure 1).

Nineteen patients had AO after planned stage II completion (completion group); AO also occurred in 15 patients in whom stage II was planned but had not yet been performed (intermediate group). In 11 patients with AO, no stage II completion was considered (prophylactic group) and in 5 patients no ET was placed (non-ET group). The relationship between AO and the operative grouping described is shown in Figure 1.

TABLE 3. Adverse outcome: Causes of death ($n = 50$)

Cause of death	n (%)
Aortic rupture	9 (18%)
Cardiac failure	7 (14%)
Stroke	7 (14%, h = 5; i = 2)
Multiorgan failure	6 (12%)
Bleeding	3 (6%)
Infection	4 (8%)
Other	6 (12%)
Unknown	8 (16%)

h, Hemorrhagic stroke; i, ischemic stroke.

The probability of 1-year survival without AO was 76%. Risk factor analysis by multiple logistic regression analysis of all 206 patients identified only age as a significant risk factor for AO ($P = .0015$ /hazard ratio = 1.038).

Permanent Stroke

Within the first year after the TG operation, 14 strokes were reported: 7 within the first 30 days and 7 between 30 days and 1 year postoperatively. Six strokes were ischemic, 6 strokes were hemorrhagic, and 2 strokes were of unknown cause. The linearized rate of stroke between 30 days and 1 year was 4.8 per 100 patient-years (7 strokes/147.0 patient-years).

In the first 30 days after the operation, the ratio of ischemic/hemorrhagic strokes was 2.5 (ischemic = 5, hemorrhagic = 2). The median interval between operation and stroke was 2 days (range, 0–12 days).

After 30 days, strokes were predominantly hemorrhagic, with a ratio of 0.25 (ischemic = 1, hemorrhagic = 4, unknown cause = 2). Six of 7 patients with late stroke had undergone reoperation after a median interval of 93 days (range, 41–173 days) after the TG surgery and had their event after the second operation.

Other Causes of Death

Between 30 days and 1 year after TG aortic arch repair, aortic rupture occurred in 7 cases. Three patients had undergone ET stage II after an interval of 31, 76, and 164 days, and had aortic rupture subsequently: 1 patient had a thoracoabdominal aneurysm, and 1 patient had residual arch disease. Four patients died of cardiac failure; 2 of them had undergone ET stage II completion 36 days and 173 days after the TG operation. One patient died of bleeding 199 days after stage II repair, which was performed 144 days after the TG operation. In 8 patients, the cause of death remains unknown: 5 patients (62.5%) had undergone subsequent surgery for aortic aneurysm disease.

Long-Term Outcome and Survival

Reoperation at the arch vessels. Reoperation at the site of the arch vessels was reported in 1 patient with bilateral subclavian aneurysms caused by Marfan syndrome.

FIGURE 1. Flow chart of AO ([stroke]/death within first year) in relation to the first and second stage of aortic arch and descending/thoracoabdominal aortic aneurysm repair with the ET technique. No ET was placed in the non-ET group; completion was not planned in the prophylactic group; the adverse events occurred between the stages in the intermediate group; and the adverse events in the completion group occurred after stage II ET. ET, Elephant trunk.

Long-term survival. Calculations of long-term survival are based on data from 152 patients who were alive 1 year after the procedure. A total of 29 patients died during follow-up after having survived the first year after the TG procedure. Cause of death is unknown in 18 patients; among those patients, 9 (50%) required subsequent surgery.

Multiple logistic regression analysis of the 152 1-year survivors identified only age as a significant risk factor for long-term survival ($P = .018$ /hazard ratio = 1.037).

Long-term survival was 94% and 78% 3 and 5 years postoperatively, respectively. Comparison of the patient population with an age- and gender-matched New York State control group revealed a significantly lower survival of the patients than of the control population ($P < .001$, Figure 2). Calculated survival probabilities were .75 and .92, respectively. Among the 152 1-year survivors, there were 584 person-years of follow-up beyond the first year, with 29 observed deaths and 14.6 expected deaths, yielding an observed/expected ratio of 1.99 ($P = .0002$, per Poisson regression).

Long-term cerebral events. Among the 152 1-year survivors, the linearized rate of stroke was calculated as 1.1 per 100 patient-years (6 strokes/707 patient-years). The strokes occurred after a median interval of 2.7 years (range, 1.6–3.6 years). The nature of the stroke could not be determined in 4 cases; 2 were hemorrhagic. Three patients had undergone reoperation and had strokes after the second operation. The rate of transient ischemic attack was calculated as 0.85 per 100 patient-years (6 transient ischemic attacks in 721.8 patient-years).

A total of 98 of 124 contacted patients were taking anticoagulants at the time of follow-up. Most patients were taking aspirin (51/98; 52.0%) or warfarin (Coumadin, Bristol-Myers Squibb Co, Princeton, NJ [47/98; 48.0%]). Follow-up revealed no episodes of bleeding or myocardial infarction.

Patency of the trifurcated graft. To assess long-term durability and arch graft patency, the latest available CT studies were reviewed: 189 studies in 176 patients (85.4%). The median interval between the operation and the CT angiogram was 1.6 years (range, 4 days to 7.9 years). All reviewed scans showed widely patent TG limbs (Figure 3).

A CT angiogram was available in 122 of 127 surviving patients (96.0%). The median interval between the TG operation and the last scan in which graft patency was demonstrated was 2.8 years (range, 4 days to 8.0 years). The median interval between the scan and the date of last follow-up was 1.1 years (12 days to 9.7 years).

Of the patients who died, 55 of 79 (69.6%) had a reviewable CT scan. The median interval between the TG operation and the latest scan showing graft patency was 76 days (range, 4 days to 4.4 years), whereas the median interval between the last scan and the date of death was 186 days (range, 2 days to

FIGURE 2. Aortic arch replacement with a TG: Kaplan-Meier curve of 152 1-year survivors versus New York State population.

FIGURE 3. Postoperative angiogram (A) and 3-dimensional reconstruction (B) of arch replacement with a trifurcated graft. Displayed are the left carotid limb (1), left subclavian limb (2), and innominate limb (3).

6.0 years). The median interval between the TG operation and the date of death was 217 days (range, 17 days to 6.2 years).

DISCUSSION

Cerebral protection during aortic arch surgery is multifaceted. The basic technique of deep HCA has been used for more than 20 years.¹⁸ However, episodes of deep HCA exceeding 30 minutes have been shown to lead to memory and fine motor deficits, resulting in temporary neurologic dysfunction, with some evidence of subtle long-term sequelae.¹⁹

Antegrade SCP extends the safe threshold of HCA^{20,21}; however, when administered directly into the arch vessels, it carries a risk of dislodging atherosclerotic debris. Several surgical techniques have been developed to overcome this problem. Kazui and colleagues¹² introduced a 4-branched graft in which the brachiocephalic vessels are implanted distal to their origins. This technique quickly led to impressive results, with permanent and temporary neurologic dysfunction rates of 4% in 50 consecutive patients with atherosclerotic arch aneurysms.

In 2002, Spielvogel and colleagues¹⁵ introduced the TG technique, which not only uses SCP to minimize cerebral ischemia but also (in contrast with the Kazui technique) avoids manipulation and direct cannulation of diseased or atherosclerotic cephalic vessels because these vessels are anastomosed during a brief interval of HC. In 2007, Spielvogel²² presented 150 TG cases, with a stroke rate of 4.1% and temporary neurologic deficit in 4.7%.

The current 30-day results are similar, with a rate of 3.4% (7/206) for permanent neurologic injury and 5.8% (12/206) for transient neurologic dysfunction. Although the TG technique yielded satisfactory early results, the need for further procedures led to 21 adverse events during the first year after surgery, including 15 deaths and 6 strokes (Figure 1). More than 60% of this cohort underwent further surgery for aneurysm repair after arch replacement. ET completion was the most common reoperation: 69 of 101 ET stage II procedures were carried out within 100 days of the TG operation. The

presence of extensive aortic disease requiring staged procedures is a major factor contributing to AO after the TG procedure.

The study population has a high prevalence of comorbidities and cardiovascular risk factors, including hypertension, smoking, and older age. Notably, age was the only factor that significantly influenced AO or long-term survival in our cohort (AO: $P = .0015$; long term survival: $P = .018$; Cox proportional hazards regression). Age, however, is an important factor because the aging process modifies other risk factors.²³

Survival in our patients is significantly lower than in the age- and gender-matched New York State control group ($P = .0002$, per Poisson regression). Although aortic rupture, stroke, and heart disease played a significant part in mortality in this high-risk cohort, we could not clearly identify the cause of death in 18 patients who died more than 1 year after the operation, which limits our analysis.

Among the 20 stroke victims, 10 had subsequent operations. In these cases, stroke occurred in only 1 patient after the TG procedure; 9 of 10 patients had a stroke after a subsequent operation. The stroke pattern also changed over time, from ischemic to hemorrhagic. The early ischemic strokes were not unexpected, because postoperative stroke in aortic arch operations usually results from cerebral emboli.²⁴

Of 6 cases of stroke among the 152 1-year survivors, the nature of the event remains unknown in 4, but 2 were caused by intracranial bleeding. Eighty percent of strokes in the general population are caused by emboli rather than hemorrhage,²⁵ and 80% of our patients were taking Coumadin or aspirin, including all 5 patients with stroke who could be interviewed. It is therefore conceivable that the high prevalence of anticoagulation may have increased long-term freedom from stroke in this patient collective, mitigating their otherwise higher risk of cerebral embolization.

Review of the patients who died between 30 days and 1 year after TG surgery revealed that death resulting from cardiac failure, aortic rupture, and bleeding ($n = 12$) occurred in 50% of patients after a more recent reoperation, usually ET completion, which occurred at a median of 136 days after the

TG procedure. It seems reasonable to attribute these deaths to the consequences of extensive aortic disease rather than to a failure of the TG operation, but the cause of death remains unclear in 8 patients; thus, it is difficult to know whether the TG operation played any significant role.

Examination of follow-up CT scans of the TG was an approach to determine the long-term durability and patency of the graft. In lower-limb revascularization, long-term patency is often less than 70%,²⁶⁻²⁸ whereas studies of splanchnic and carotid subclavian bypass grafting show patency rates of approximately 85%.^{29,30} Hughes and colleagues³¹ evaluated TGs in hybrid aortic debranching, showing 100% graft patency after a follow-up of 7.5 ± 6.0 months and suggested that high flow through these grafts contributes to their long-term patency. Our review of available scans showed no graft occlusion in any living patient after a median interval of 2.9 years, but we cannot rule out the possibility of graft failure in some of the patients who died.

CONCLUSIONS

The use of a TG for aortic arch replacement is characterized by a low incidence of cerebral injury, morbidity, and mortality. Late strokes do not seem to be a direct consequence of the TG operation. Our evaluation of graft patency suggests that reimplantation of the cephalic vessels with a TG can be performed with excellent long-term patency. Although significant attrition occurs during the first postoperative year, it is a consequence of the underlying disease and the need for subsequent treatment.

References

- Soeda M. Antegrade selective cerebral perfusion combined with deep hypothermic circulatory arrest on cerebral circulation: comparison between pulsatile and nonpulsatile blood flows. *Ann Thorac Cardiovasc Surg.* 2007;13:93-101.
- Kazui T, Yamashita K, Washiyama N, Terada H, Bashar AH, Suzuki K, et al. Aortic arch replacement using selective cerebral perfusion. *Ann Thorac Surg.* 2007;83:S796-8; discussion S824-31.
- Di Eusanio M, Wesselink RM, Morshuis WJ, Dossche KM, Schepens MA. Deep hypothermic circulatory arrest and antegrade selective cerebral perfusion during ascending aorta-hemiarch replacement: a retrospective comparative study. *J Thorac Cardiovasc Surg.* 2003;125:849-54.
- Salazar JD, Coleman RD, Griffith S, McNeil JD, Steigelman M, Young H, et al. Selective cerebral perfusion: real-time evidence of brain oxygen and energy metabolism preservation. *Ann Thorac Surg.* 2009;88:162-9.
- Yamashita K, Kazui T, Terada H, Washiyama N, Suzuki K, Bashar AH. Cerebral oxygenation monitoring for total arch replacement using selective cerebral perfusion. *Ann Thorac Surg.* 2001;72:503-8.
- Sakurada T, Kazui T, Tanaka H, Komatsu S. Comparative experimental study of cerebral protection during aortic arch reconstruction. *Ann Thorac Surg.* 1996;61:1348-54.
- Griep RB. Cerebral protection during aortic arch surgery. *J Thorac Cardiovasc Surg.* 2001;121:425-7.
- Hagl C, Ergin MA, Galla JD, Lansman SL, McCullough JN, Spielvogel D, et al. Neurologic outcome after ascending aorta-aortic arch operations: effect of brain protection technique in high-risk patients. *J Thorac Cardiovasc Surg.* 2001;121:1107-21.
- Numata S, Ogino H, Sasaki H, Hanafusa Y, Hirata M, Ando M, et al. Total arch replacement using antegrade selective cerebral perfusion with right axillary artery perfusion. *Eur J Cardiothorac Surg.* 2003;23:771-5.
- Kazui T, Yamashita K, Washiyama N, Terada H, Bashar AH, Suzuki T, et al. Usefulness of antegrade selective cerebral perfusion during aortic arch operations. *Ann Thorac Surg.* 2002;74:S1806-9; discussion S1825-32.
- Di Eusanio M, Schepens MA, Morshuis WJ, Dossche KM, Di Bartolomeo R, Pacini D, et al. Brain protection using antegrade selective cerebral perfusion: a multicenter study. *Ann Thorac Surg.* 2003;76:1181-9.
- Kazui T, Washiyama N, Muhammad BA, Terada H, Yamashita K, Takinami M, et al. Total arch replacement using aortic arch branched grafts with the aid of antegrade selective cerebral perfusion. *Ann Thorac Surg.* 2000;70:3-9.
- Spielvogel D, Halstead JC, Meier M, Kadir I, Lansman SL, Shahani R, et al. Aortic arch replacement using a trifurcated graft: simple, versatile, and safe. *Ann Thorac Surg.* 2005;80:90-5.
- Spielvogel D, Mathur MN, Lansman SL, Griep RB. Aortic arch reconstruction using a trifurcated graft. *Ann Thorac Surg.* 2003;75:1034-6.
- Spielvogel D, Strauch JT, Minanov OP, Lansman SL, Griep RB. Aortic arch replacement using a trifurcated graft and selective cerebral antegrade perfusion. *Ann Thorac Surg.* 2002;74:S1810-4; discussion S1825-32.
- Strauch JT, Spielvogel D, Lauten A, Galla JD, Lansman SL, McMurtry K, et al. Technical advances in total aortic arch replacement. *Ann Thorac Surg.* 2004;77:581-90.
- Etz CD, Plestis KA, Kari FA, Silovitz D, Bodian CA, Spielvogel D, et al. Axillary cannulation significantly improves survival and neurologic outcome after atherosclerotic aneurysm repair of the aortic root and ascending aorta. *Ann Thorac Surg.* 2008;86:441-7.
- Griep RB, Stinson EB, Hollingsworth JF, Buehler D. Prosthetic replacement of the aortic arch. *J Thorac Cardiovasc Surg.* 1975;70:1051-63.
- Ergin MA, Galla JD, Lansman L, Quintana C, Bodian C, Griep RB. Hypothermic circulatory arrest in operations on the thoracic aorta. Determinants of operative mortality and neurologic outcome. *J Thorac Cardiovasc Surg.* 1994;107:788-99.
- Kazui T, Kimura N, Yamada O, Komatsu S. Surgical outcome of aortic arch aneurysms using selective cerebral perfusion. *Ann Thorac Surg.* 1994;57:904-11.
- McCullough JN, Zhang N, Reich DL, Juvonen TS, Klein JJ, Spielvogel D, et al. Cerebral metabolic suppression during hypothermic circulatory arrest in humans. *Ann Thorac Surg.* 1999;67:1895-21.
- Spielvogel D, Etz CD, Silovitz D, Lansman SL, Griep RB. Aortic arch replacement with a trifurcated graft. *Ann Thorac Surg.* 2007;83:S791-5.
- Lakatta EG, Levy D. Arterial and cardiac aging: major shareholders in cardiovascular disease enterprises: Part I: aging arteries: a "set up" for vascular disease. *Circulation.* 2003;107:139-46.
- Kazui T, Washiyama N, Muhammad BA, Terada H, Yamashita K, Takinami M. Improved results of atherosclerotic arch aneurysm operations with a refined technique. *J Thorac Cardiovasc Surg.* 2001;121:491-9.
- Feigin VL, Lawes CM, Bennett DA, Anderson CS. Stroke epidemiology: a review of population-based studies of incidence, prevalence, and case-fatality in the late 20th century. *Lancet Neurol.* 2003;2:43-53.
- Post S, Kraus T, Muller-Reinartz U, Weiss C, Kortmann H, Quentmeier A, et al. Dacron vs. polytetrafluoroethylene grafts for femoropopliteal bypass: a prospective randomised multicentre trial. *Eur J Vasc Endovasc Surg.* 2001;22:226-31.
- Reul GJ, Jacobs MJ, Gregoric ID, Calderon M, Duncan JM, Ott DA, et al. Innominate artery occlusive disease: surgical approach and long-term results. *J Vasc Surg.* 1991;14:405-12.
- van Det RJ, Vriens BH, van der Palen J, Geelkerken RH. Dacron or ePTFE for femoro-popliteal above-knee bypass grafting: short- and long-term results of a multicentre randomised trial. *Eur J Vasc Endovasc Surg.* 2009;37:457-63.
- Law MM, Colburn MD, Moore WS, Quinones-Baldrich WJ, Machleder HI, Gelabert HA. Carotid-subclavian bypass for brachiocephalic occlusive disease. Choice of conduit and long-term follow-up. *Stroke.* 1995;26:1565-71.
- Milite D, Campanile F, Tosato F, Pilon F, Zaramella M. Hypogastric artery bypass in open repair of abdominal aortoiliac aneurysm: a safe procedure. *Interact Cardiovasc Thorac Surg.* 2010;10:749-52. Epub 2010 Feb 19.
- 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.