Present day cardiac and cardiovascular surgeons have experienced significant progress toward reducing complications during aortic and great vessel surgery. This can be attributed to enhanced preoperative imaging modalities, advances in graft materials and biologic glues, improved anesthetic techniques and strategies for cerebral and spinal cord protection, and the emergence of endovascular technology. While open aortic and great vessel procedures continue to be associated with a wide range of complications and a small but not insignificant mortality rate, endovascular procedures have been associated with a new set of complications. As technology evolves and new therapies are introduced, we must be creative in the prevention and management of previously unrecognized complications.

Aortic and great vessel operations are complex procedures that often require extensive surgical incisions and anatomic exposures, long operating times, transient end-organ ischemia, and occasionally the need for extracorporeal circulation and hypothermic circulatory arrest. In addition, the violation of major (and sometimes multiple) body cavities in association with blood loss, blood pressure fluctuations, and fluid shifts can significantly increase the risk of specific postoperative complications for patients who often enter the operating room with significant preexisting cardiopulmonary, renal, or cerebral vascular disease. As challenging as these patients may be to care for, intraoperative complications are usually not the greatest concern. Present day imaging and image reconstruction software usually allow for detailed preoperative anatomic surgical planning, and as a result unmanageable intraoperative technical complications should be exceedingly rare. Operations on the aorta and great vessels are indicated for a number of reasons, but aneurysmal and occlusive disease are the most common. Close communication between the surgeon and the entire operating team, particularly the anesthesiologist and perfusionist, is paramount to a successful surgical outcome.
Neurologic complications

Neurologic complications that occur during aortic surgery can range from transient dysfunction such as postoperative confusion or agitation to permanent damage with the associated lifelong physical and mental disabilities. Perfusion strategies developed to combat these morbidities during aortic operations include profound hypothermic circulatory arrest (PHCA), antegrade cerebral perfusion (ACP), and retrograde cerebral perfusion (RCP). PHCA was pioneered in London by Charles Drew in 1959 [1]. Since then, it has become a common strategy for cerebral protection in thoracic aortic repairs. Dr. Elefteriades’ group recently evaluated their experience of PHCA in 394 patients over a 10-year period [2]. With a mean circulatory arrest time of 31 minutes and only PHCA as a means of cerebral protection, their overall stroke rate was 4.8%. The stroke rate among the elective ascending and aortic arch patients was only 2.3%. Overall, approximately two-thirds of the strokes were attributed to embolic phenomena and one-third was attributed to hypoperfusion. In France, Dr. Bachet’s group has used an ACP strategy they initially developed in 1986 [3]. This technique involves selective antegrade perfusion of the cerebral vessels with 6–12°C blood and moderate systemic hypothermia (25–28°C) with brief circulatory arrest as needed, all while avoiding profound hypothermia and the associated longer cardiopulmonary bypass times required for cooling and rewarming. Over a 14-year period, this group evaluated 171 patients in whom this strategy was used and found an overall neurologic complication rate of 12.8% [4]. Advantages of this technique are that it does not limit the surgeon in terms of time to repair the aortic arch and great vessels, and it avoids the use of deep hypothermia and minimizes the associated risks of deep hypothermic perfusion and total circulatory arrest.

A third technique developed for cerebral protection involves RCP. Initially described to treat massive air embolisms during cardiopulmonary bypass, this technique involves selective cannulation of the superior vena cava and retrograde flow to maintain a predetermined central venous pressure [5]. Ehrlich et al. retrospectively evaluated their experience with this technique in 1999 [6]. A total of 109 patients were evaluated with 55 patients undergoing hypothermic circulatory arrest alone compared to 54 patients with hypothermic circulatory arrest with RCP. Circulatory arrest times were 30 and 33 minutes, respectively, and the stroke rate significantly favored RCP as a protective strategy (27% vs. 9%; p = 0.01). Further, on multivariate analysis, a lack of RCP was an independent predictor for a stroke. It is interesting that in this study, there was no difference in temporary neurologic dysfunction among the groups (17% vs. 18%; p = 0.9). Our method of cerebral protection is PHCA combined with the use of RCP. We ensure the central venous pressure stays less than 35–40 mm Hg during RCP. We do not routinely pretreat patients with barbiturates or steroids, but we do use cerebral oximetry, flood the field with carbon dioxide, maintain strict glycemic control during the operation, and pack the head in
ice. Although the data for these adjuvant techniques is not robust, we believe they do make some impact in protecting the brain during circulatory arrest.

Embolization is an unfortunate phenomenon that continues to challenge the field of aortic surgery and contributes significantly to the overall morbidity and mortality. To evaluate the contribution of atherosclerotic aortic disease to the risk of having a postoperative stroke, Jan van der Linden et al. prospectively used epiaortic ultrasound to assess the presence of calcification and the location of atheroma in 921 consecutive patients undergoing cardiac surgery [7]. In patients without atherosclerotic disease of the ascending aorta, the incidence of postoperative stroke was 1.8% compared with an 8.7% incidence in patients with atherosclerosis ($p < 0.0001$). Interestingly, atherosclerotic disease involving the middle-lateral segment of the ascending aorta was an independent predictor for having a postoperative stroke. Because of the increased incidence of emboli in patients with atherosclerotic plaques and diseased aortas, many strategies to avoid certain areas of these aortas have been attempted. Strategies such as routine epiaortic ultrasound and preoperative noncontrast CT scans have been utilized to help reduce the incidence of emboli. Das et al. selected 8 studies out of 179 to answer the question “Does epi-aortic ultrasound reduce the incidence of postoperative stroke during cardiac surgery?” [8]. Five of the eight studies showed a reduction of the stroke rate as a result of modifying the surgical technique from the results of the epiaortic ultrasound exam. The authors concluded that epiaortic ultrasound scanning is more accurate for detecting aortic atheroma than manual palpation.

A study by Lee et al. evaluated preoperative noncontrast CT scanning versus epiaortic ultrasound scanning, comparing a group of 230 consecutive patients who underwent selective epiaortic ultrasound to a group of 273 consecutive patients who received a preoperative noncontrast CT scan of the chest [9]. Of the 230 patients in the selective epiaortic ultrasound group, 7 patients underwent an ultrasound study and a deviation from the operative plan was noted in one patient. Of the 273 patients undergoing CT scanning, the scan identified 20 patients with significant aortic calcifications and resulted in a deviation from the operative plan in 19 patients. The overall stroke rate for the two groups was 3.04% in the epiaortic ultrasound group and 0.73% ($p = 0.05$) in the CT scan group. The authors concluded that preoperative CT scanning of the chest is superior to epiaortic ultrasound for preventing stroke in high-risk patients. Factors indicating those at high risk included a history of stroke or transient ischemic attack, peripheral vascular disease, end-stage renal disease, age greater than 70 years old, and aortic calcification noted on cardiac catheterization.

Protecting the spinal cord from ischemic injury during aortic surgery continues to be a major challenge for the aortic surgeon. Four types of thoracoabdominal aortic aneurysms have been described by Dr Crawford, and because of the length and location of aorta involved, Crawford type II aneurysms tend to have the highest risk for spinal cord ischemia. For type II thoracoabdominal
Aortic and Great Vessel Operations

Aortic aneurysms, the incidence of paraplegia ranges from 7% to 32% [10]. Many strategies have been developed to reduce the risk of spinal cord injury during thoracic aortic surgery. Left atrial to femoral artery bypass, intercostal artery reimplantation, cerebrospinal fluid cooling, cerebrospinal fluid drainage, intraoperative neuromonitoring, and postoperative blood pressure management have helped to decrease the rate of paraplegia and paraparesis following thoracic aortic surgery [11–13]. Safi et al. demonstrated a reduced risk of neurologic injury following type II thoracoabdominal aneurysm repair using cerebrospinal fluid drainage and distal aortic perfusion [11]. In this study, the additive effect of these modalities resulted in an increase in spinal cord perfusion pressure during the aortic cross-clamp period. The control group consisted of 42 patients who underwent thoracoabdominal aneurysm repair with only a cross-clamp and no additional modality to aid in spinal cord perfusion. For type II thoracoabdominal aneurysm repairs, the authors showed a reduction in spinal cord related neurologic complications from 19% in the control group (8 of 42 patients) to 9% in the experimental group (8 of 94 patients) ($p = 0.014$).

Another strategy used to help assess and limit spinal cord ischemia during thoracic aortic operations is the measurement of motor-evoked potentials (MEPs). When MEPs indicate ischemia, treatment options include increasing aortic perfusion pressure if using left heart bypass, increasing mean arterial pressure with vasopressor agents or volume, identifying critical intercostals or lumbar arteries, and reimplantation of the involved region with the goal being to revascularize any significant back-bleeding vessels. To evaluate the impact of MEP monitoring in thoracoabdominal aortic operations, Jacobs et al. devised a surgical protocol that included cerebrospinal fluid drainage, moderate hypothermia, left heart bypass with selective organ perfusion, and spinal cord ischemia assessment via monitoring of MEPs to 112 consecutive patients undergoing thoracoabdominal aortic operations [14]. They were able to monitor MEPs in all patients and by maintaining a mean distal aortic pressure of 60 mm Hg, 82% of the patients had adequate MEPs. In 19 patients, MEPs significantly decreased during aortic cross-clamping but returned to baseline once aortic flow was reestablished. Unfortunately in three patients, MEPs did not return after reestablishing aortic flow and this correlated with a neurologic deficit postoperatively. This study demonstrated that monitoring MEPs is a very reliable and accurate method to assess spinal cord ischemia and allows the potential to act upon ischemic events in hopes of eliminating neurologic injury during such procedures. Despite the overall success with this technique though, a small but not insignificant number of patients did develop paraplegia.

An additional technique described to help decrease the risk of spinal cord injury during thoracic aortic operations is epidural cooling. In 1993, Cambria et al. described a technique in which they infused normal saline at 4°C into the epidural space using an epidural catheter positioned at the T11–T12 vertebral body level [13]. A second catheter was placed intrathecally at the L3–L4 level...
to monitor both temperature and pressure of cerebrospinal fluid. In 2000, this group published their experience with this technique in 170 patients undergoing repair of thoracic aortic or thoracoabdominal aneurysms [15]. They used a clamp and sew technique with selective reimplantation of critical intercostal or lumbar vessels in the T9–L1 region. The overall operative mortality was 9.5% with postoperative cardiac complications and renal failure being independent predictors of death. Spinal cord injury occurred in 7% of the patients overall versus a predicted incidence of 18.5%. Of the patients with spinal cord injury, half were minor with good functional recovery and only 3 (2%) had long-term deficits. Multivariate analysis identified type I or II thoracoabdominal aneurysms, emergent operation, oversewn T9–L2 intercostal vessels, and postoperative renal failure as independent predictors of spinal cord injury.

At the University of Virginia, we prefer the use of RCP during hypothermic circulatory arrest for straightforward ascending aorta and aortic arch operations requiring less than 30 minutes of cerebral ischemia time. For complex aortic arch and great vessel operations, we are fully prepared to utilize antegrade cerebral perfusion through either the right axillary artery or the origin of the innominate or left carotid arteries. The use of both techniques in combination has also been helpful depending on the anatomy and complexity of the condition being treated. For extensive descending thoracic and thoracoabdominal aortic operations, we routinely utilize left heart bypass with passive systemic cooling in conjunction with cerebrospinal fluid drainage. We maintain CSF drainage for the first 48 hours after surgery in conjunction with optimal systemic blood pressure. We strive to maintain the CSF pressure less than 10 cm H₂O and a mean systemic arterial blood pressure of greater than 85 mm Hg. With present day small diameter cannulas that provide excellent flow characteristics in conjunction with axial flow pumps and heparinized circuits, complications related to the bypass circuit and excessive anticoagulation are minimal.

Cardiac complications

In general, patients with aortic pathology are at an increased risk of heart disease. This association reflects the high prevalence of coronary atherosclerosis in this group of patients. In a study in which patients with abdominal aortic aneurysms underwent cardiac catheterization for risk stratification, 31% had severe coronary artery disease [16]. Thus, a complete evaluation is required for every patient preoperatively to determine which patients are at increased risk and deserve further evaluation. How extensively one should evaluate a patient who is to undergo major aortic surgery is not clear. Routine, cardiac catheterization will result in a small number of patients that will undergo either percutaneous coronary intervention or surgical coronary revascularization with a less than ideal outcome resulting from the coronary intervention. Functional studies to identify silent coronary ischemia are available, and the specific study chosen varies from institution to institution.
A number of risk indices have been developed in the past to determine who warrants further evaluation. The Revised Cardiac Risk Index by Lee et al. identified six parameters that were independent predictors of major cardiac complications from a study of over 4000 patients undergoing major nonemergent noncardiac procedures [17]. These parameters include high-risk type surgery, history of ischemic heart disease, history of congestive heart failure, history of cerebrovascular disease, preoperative treatment with insulin, and preoperative serum creatinine greater than 2.0 mg/dL. Depending on the number of parameters present preoperatively, 0, 1, 2, 3, or greater, the rate of major cardiac complications in the derivation cohort was 0.5%, 1.3%, 4%, and 9%, respectively. In the validation cohort from the study, a similar percentage of cardiac complications were found: 0.4%, 0.9%, 7%, and 11%, respectively. This study provides us the opportunity to identify high-risk patients who may benefit from further cardiac evaluation.

After identifying those patients with an increased risk for perioperative cardiac events, the next step is to decide which study to utilize to further characterize and quantify their cardiac risk. Several noninvasive studies are available to evaluate cardiac risk including: exercise electrocardiography, dipyridamole myocardial perfusion scintigraphy, and dobutamine stress echocardiography. Although all of these tests do a reasonable job in providing data to stratify cardiac risk, in a recent meta-analysis dobutamine stress echocardiography performed best [18]. Recently, newer techniques such as cardiac magnetic resonance imaging and cardiac computed tomography have been developed to further predict patients’ cardiac risk [19]. The overall utility of these tests for preoperative evaluation remains to be determined. While exercise treadmill stress testing is often regarded as a sensitive test to rule out significant coronary disease, few patients facing major aortic or great vessel surgery are able to undergo this sort of evaluation. The functional test chosen depends on the local expertise of the institution and those involved in the evaluation of the study. In the end, the operating surgeon needs to be involved in the decision making process as to which, if any, functional test to order and how to act on the results of that study.

Beta-blockers, statins, and alpha-2 adrenergic blockers have shown some promise in decreasing perioperative cardiac risk. Bisoprolol was studied in a randomized fashion in 112 patients undergoing noncardiac vascular surgery with one or more cardiac risk factors and a positive dobutamine stress echocardiographic study. This study showed a significantly lower end point of cardiac death and myocardial infarction within 30 days after surgery in patients randomly assigned to bisoprolol (3.4% bisoprolol group vs. 34% in the control group \((p < 0.001)\)) [20]. Statins also are believed to have beneficial effects on cardiac morbidity in the perioperative setting. Durazzo et al. evaluated 20 mg atorvastatin in a randomized placebo-controlled trial with 100 patients for 45 days irrespective of their serum cholesterol level [21]. Vascular surgical procedures were then performed at about 30 days from the start of the drug, and 6-month end points included death from cardiac cause, nonfatal
myocardial infarction, unstable angina, and stroke. Patients taking atorvas-
tatin had a significantly lower rate of cardiac events at 6 months ($p = 0.018$).
Although the data on alpha-2 adrenergic blockers are not as clear, a meta-
alysis in 2003 of 23 trials by Wijeysundera et al. showed a reduced mortality
(RR = 0.47, $p = 0.02$) and myocardial infarction rate (RR = 0.66, $p = 0.02$)
following vascular surgery [22]. This group concluded, however, that larger
randomized studies were necessary to fully evaluate these findings.

Many patients requiring aortic and great vessel surgery have undergone
recent or remote coronary intervention with either bare metal or drug elut-
ing coronary stents. The use of Plavix in these patients is often critical for
the patency of their stents, yet significantly increases the risk of periopera-
tive bleeding. Patients with bare metal stents experience an early risk of stent
thrombosis if Plavix is withheld, but only within the first 6 weeks after stent
placement. For patients receiving bare metal coronary stents, surgery should
be delayed 6 weeks if possible, at which time Plavix can safely be held for
at least 3–5 days prior to surgery. After the initial 6-week period, treatment
with aspirin alone is sufficient. Patients with drug eluting stents have a small
but not insignificant lifetime risk of stent thrombosis upon discontinuation
of Plavix. As a result, patients with drug eluting coronary stents who require
major aortic or great vessel surgery should have their Plavix discontinued for
only 3–5 days prior to surgery, and then have Plavix restarted within 48 hours
of surgery to minimize the chance of acute stent thrombosis.

**Pulmonary complications**

The ability to predict a patient’s postoperative risk of pulmonary complica-
tions inherently seems simple. With an adequate history, and basic studies
including spirometry, an arterial blood gas, and a chest x-ray, one should be
able to stratify a patient’s risk. Postoperative pulmonary complications sig-
nificantly increase the mortality rate for patients undergoing surgery [23, 24].
These complications include pneumonia, atelectasis, diaphragm dysfunction,
prolonged mechanical ventilation, bronchospasm, and ventilation perfusion
mismatch. Unfortunately, the ability to predict pulmonary complications is
not as straightforward and precise for a number of reasons. For one, stud-
ies vary on the definition of postoperative respiratory failure. In two separate
studies evaluating postoperative respiratory failure, the length of postopera-
tive days on the ventilator equating to respiratory failure varied between 2
and 5 days [23, 25]. Second, anesthesia alone can increase the risk of respira-
tory failure. The mechanism is believed to be multifactorial. Factors such as
decreasing the mucociliary clearance of the tracheobronchial tree, decreasing
the number of alveolar macrophages and increasing the permeability of the
alveolar capillary membrane can contribute to pulmonary complications [26–
28]. Also, general anesthesia reduces the FRC (functional residual capacity)
leading to ventilation perfusion mismatch, further contributing to postopera-
tive complications [29].
Table 23.1 Respiratory failure risk index.

<table>
<thead>
<tr>
<th>Preoperative predictor</th>
<th>Point value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of surgery</td>
<td></td>
</tr>
<tr>
<td>Abdominal aortic aneurysm</td>
<td>27</td>
</tr>
<tr>
<td>Thoracic</td>
<td>21</td>
</tr>
<tr>
<td>Neurosurgery, upper abdominal, or peripheral vascular</td>
<td>14</td>
</tr>
<tr>
<td>Neck</td>
<td>11</td>
</tr>
<tr>
<td>Emergency surgery</td>
<td>11</td>
</tr>
<tr>
<td>Albumin (&lt;30 g/L)</td>
<td>9</td>
</tr>
<tr>
<td>Blood urea nitrogen (&gt;30 mg/dL)</td>
<td>8</td>
</tr>
<tr>
<td>Partially or fully dependent functional status</td>
<td>7</td>
</tr>
<tr>
<td>History of chronic obstructive pulmonary disease</td>
<td>6</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
</tr>
<tr>
<td>≥70</td>
<td>6</td>
</tr>
<tr>
<td>60–69</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: From Ref. [24]. Permission request submitted to Lippincott Williams and Wilkins.

To help better predict postoperative respiratory failure, Arozullah et al. used a prospective cohort study and evaluated cases from 44 Veterans Affairs Medical Centers to develop a respiratory failure risk index [24]. A total of 81719 cases were used from various surgical procedures including upper abdominal surgery, neurosurgery, abdominal aortic aneurysms, peripheral vascular surgery and orthopedic surgery to develop the model (phase I). The model was then validated from 132 Veterans Affairs Medical Centers using 99390 cases (phase II). The respiratory risk failure index was based on a point system using the following categories: type of surgery, emergency surgery, albumin, blood urea nitrogen, functional status, history of chronic obstructive pulmonary disease, and age (Table 23.1). Based upon the total number of points, five classes were created with an increasing predicted risk of respiratory failure as classes advance. Table 23.2 demonstrates the high correlation between the phase I and phase II studies among the different classes of patients. The strength of this study was that patient characteristics and outcomes were prospectively obtained, and overall, this provides a useful guideline to help assess respiratory risk preoperatively.

While few studies present data of prospective risk analysis of pulmonary complications in patients undergoing aortic or great vessel surgery, Money et al. retrospectively evaluated 100 consecutive patients undergoing thoracoabdominal aortic aneurysm repairs [23]. In addition to showing that patients who developed respiratory failure had a significantly higher mortality rate compared to those without respiratory failure (42% vs. 6%; p < 0.001), they also found that age, type of aneurysm, excessive intraoperative blood transfusion, creatinine elevation, and postoperative pneumonia were independent factors predicting respiratory failure. Of the patients who underwent preoperative pulmonary function testing, the forced vital capacity and forced
Table 23.2  Respiratory failure risk index scores for phase I and phase II patients.

<table>
<thead>
<tr>
<th>Class</th>
<th>Point total</th>
<th>n(%)&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Predicted probability of PRF (%)</th>
<th>Phase I (% RF)</th>
<th>Phase II (% RF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>≤10</td>
<td>39 567 (48%)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>11–19</td>
<td>18 809 (23%)</td>
<td>2.2</td>
<td>2.1</td>
<td>1.8</td>
</tr>
<tr>
<td>3</td>
<td>20–27</td>
<td>13 865 (17%)</td>
<td>5.0</td>
<td>5.3</td>
<td>4.2</td>
</tr>
<tr>
<td>4</td>
<td>28–40</td>
<td>7 976 (10%)</td>
<td>11.6</td>
<td>11.9</td>
<td>10.1</td>
</tr>
<tr>
<td>5</td>
<td>&gt;40</td>
<td>1 502 (2%)</td>
<td>30.5</td>
<td>30.9</td>
<td>26.6</td>
</tr>
</tbody>
</table>

Source: From Ref. [24]. Permission request submitted to Lippincott Williams and Wilkins.

PAF, postoperative respiratory failure.

<sup>a</sup>Number of phase I subjects in each risk class.

expiratory volume in 1 second were significantly lower in the patients with postoperative pulmonary complications.

Patients undergoing aortic surgery who have a history of chronic obstructive pulmonary disease (COPD) can experience significant postoperative morbidity. Prolonged ventilator dependency, the need for a tracheostomy, and pneumonia are not infrequent events in this patient population. However, overutilization of antibiotics preoperatively to treat tracheobronchial colonization can increase the risk of drug-resistant bacterial strains that can lead to significant life-threatening infectious complications postoperatively. We recommend placing COPD patients on antibiotics preoperatively only if they have a recent history of increased sputum production or a productive cough. For those patients who are actively wheezing, a short course of oral steroids can be considered. Beyond these specific measures, we ensure that all of our COPD patients are on a standard regimen of bronchodilators preoperatively. For those patients who are failing to wean from the ventilator in a routine fashion postoperatively, and particularly if they are wheezing and have no obvious pneumonia or other treatable cause of pulmonary failure such as pleural effusions or pulmonary edema, we again consider the use of steroids. Once these patients are extubated, we recommend an aggressive regimen of incentive spirometry and airway clearance maneuvers, and careful attention to proper fluid balance and diuresis.

**Renal complications**

Because of various definitions used to diagnosis postoperative renal failure, the exact incidence in aortic surgery is difficult to determine. Studies have used such definitions as a 25% reduction in the creatinine clearance, postoperative serum creatinine exceeding 3 mg/dL in patients with normal
baseline levels, increase in serum creatinine to 50% above baseline, the need for hemodialysis, and most recently the RIFLE criteria [30–34]. RIFLE is an acronym that stands for Risk of renal dysfunction, Injury to the kidney, Failure of kidney function, Loss of kidney function, and End-stage kidney disease. This is a renal failure classification model developed during a 2-day international conference with a goal of standardizing the definition of acute renal failure [34]. See Figure 23.1.

Using RIFLE criteria, Arnaoutakis et al. performed a retrospective cohort study to assess acute renal failure in aortic arch operations [35]. A total of 267 patients undergoing hypothermic circulatory arrest for aortic arch operations were assessed over a 5-year period. They found an incidence of postoperative acute renal failure of 48%. Independent risk factors for renal failure included hypertension, chronic kidney disease, transfusion requirement of greater than 5 units of packed red blood cells, and ratio of admission creatinine/MDRD (Modification of Diet in Renal Disease) predicted creatinine greater than 1. Although the incidence of acute postoperative renal failure was quite high in the study, all patients had aortic operations under circulatory arrest and 89% had aprotinin (Trasylol, Bayer Healthcare, Pittsburgh, PA, USA) used during the case.

To identify risk factors associated with postoperative renal failure in vascular surgery patients, Godet et al. prospectively studied 475 consecutive patients undergoing thoracoabdominal surgery over a 12-year period [36]. Their definition for development of acute renal failure was a postoperative
serum creatinine concentration greater than 150 µmol/L with normal preoperative renal function (approximately 1.7 mg/dL) or an increase in postoperative serum creatinine greater than 30% of preoperative level in patients with chronic renal dysfunction. Overall, 25% of patients developed postoperative renal failure and 8% required hemodialysis. From multivariate analysis, age greater than 50 years old, preoperative serum creatinine greater than 120 µmol/L (1.36 mg/dL), left kidney ischemia greater than 30 minutes, and a transfusion requirement greater than 5 units of packed red blood cells or greater than 5 units of cell-saver volume were predictive of postoperative renal failure. Predictive factors for postoperative hemodialysis included the following: age greater than 50, transfusion greater than 5 units, packed red blood cells, and preoperative serum creatinine greater than 120 µmol/L.

Patients with aortic pathology, including aneurysmal disease, are believed to have a higher incidence of renal failure. Hagiwara et al. retrospectively reviewed 350 patients with aortic aneurysms to examine the incidence of renal failure and found that 90 patients (25.7%) had chronic renal failure as defined by a GFR of less than 60 mL/min for at least a 6-month duration [30]. After a 30-month follow-up, 117 patients (33.4%) had developed renal failure. Independent risk factors for chronic renal failure included age greater than 64, hypertension, and multiple aneurysms. Of the 350 patients studied, 160 patients underwent an aortic surgical procedure. From this group of patients, 44 patients (27.5%) developed postoperative renal failure, with postoperative renal failure being defined as a serum creatinine level increase of greater than 1.5 times or a postoperative glomerular filtration rate (GFR) decrease greater than 25%. Independent risk factors for acute renal failure included dissecting aneurysms, elevated preoperative serum creatinine levels, and duration of operation.

Although endovascular procedures in theory have less cardiac and pulmonary morbidity than traditional open aortic procedures, there is, however, a significant risk of renal complications resulting from endovascular aortic procedures that is most often due to contrast-enhanced nephropathy. To better assess this association, Eggebrecht et al. retrospectively evaluated 97 patients who underwent thoracic aortic stent grafts from July 1999 to October 2005 [37]. Of this group, 45% had preoperative chronic kidney dysfunction as defined by a GFR less than or equal to 60 mL/min/1.73 m². They defined postoperative renal failure as an increase greater than or equal to 25% and/or greater than or equal to 0.5 mg/dL rise in preprocedure serum creatinine at 48 hours postprocedure. The contrast agent for the procedure was a nonionic, low-osmolar contrast medium (Ultravist 350, Schering, Berlin, Germany) and patients received approximately 307 ± 188 mL. The incidence of renal failure postoperatively was 34% (33 patients), with 3 requiring hemodialysis. From multivariate analysis, ASA (American Society of Anesthesiologists) class greater than three and duration of the procedure were found to be independent predictors of postoperative renal failure. Patients developing renal failure postoperatively had a significantly higher 30-day and 1-year mortality.
Endovascular approaches

Endovascular approaches to thoracic aortic pathology are rapidly evolving. Follow-up data from the initial multicenter trials continue to lengthen, and the results thus far show endovascular aortic repair to be a safe alternative to open repairs [38, 39]. With this new technology for aortic intervention comes a new set of previously unrecognized complications. These complications range from poor preprocedural planning to technical misadventures that can occur during the procedure, to failure of the devices remotely after the procedure. Although experience with endovascular aortic repair is still in its infancy, we continue to find innovative ways to treat and/or prevent these new and unusual complications.

During this new era of endovascular aortic intervention, strokes unfortunately, are not an uncommon complication. From the initial series of thoracic aortic stents, stroke rates ranged from 2% to 8% [38–41]. Gutsche et al. recently reviewed University of Pennsylvania data on strokes during thoracic stent graft trials occurring between 1999 and 2006 [42]. A total of 171 patients had thoracic aortic stent grafts placed during this time. This group was subdivided into three groups depending on the location of the thoracic aorta that was treated: extent A group required coverage of the proximal descending thoracic aorta (n = 52), extent B group underwent coverage of the distal descending thoracic aorta, and extent C group had the entire descending thoracic aorta treated. A total of 9 (5.8%) strokes were encountered in this series, and eight of these occurred within 24 hours of the operation. The mortality rate associated with a stroke was significant at 33%. Extent A or C coverage, a history of a prior stroke and CT scan revealing severe atheromatous disease of the aortic arch was associated with a postoperative stroke. In addition, combining a prior history of a stroke with extent A aortic coverage resulted in a 60% incidence of a stroke. Importantly though, those requiring coverage of the left subclavian artery, regardless of a carotid to subclavian bypass, was not associated with an increased risk of perioperative stroke.

Tommaso et al. evaluated their experience with endovascular repair of the descending thoracic aorta in 51 patients over a 4-year period (2001–2005) [43]. In 20 patients (39%), the entire descending thoracic aorta (from the left subclavian artery to the celiac axis) was stent grafted. In this series, there were no deaths, surgical conversions, or paraplegia. Procedure-related complications occurred in four patients and included three peripheral vascular complications requiring iliac to femoral artery bypass, and one type I endoleak. Interestingly, this type I endoleak spontaneously resolved after 9 months.

One of the more rare yet serious complications seen with thoracic aortic stent grafting is collapse of the device. This is most commonly a result of placing a slightly oversized device in a tightly curved arch, allowing a small portion of the device to extend out from the lesser curvature into the lumen of the aorta. This creates a protruding leading flap of the device, and with enough aortic pressure and lack of radial hoop strength of the device, the device
collapses or “in-folds.” Although most commonly a problem with stent grafts deployed in the aortic arch, this is not the only location where we have seen stent graft collapse. Recently, we have encountered an asymptomatic stent graft collapse in the mid-descending thoracic aorta diagnosed on routine surveillance CT scan 48 hours postprocedure. This patient, as all patients we have encountered with stent graft collapse, was successfully treated with a Palmaz (Cordis Endovascular, Warren, NJ, USA) stent. Hinchliffe et al. recently reported on a multicenter European case series of thoracic aortic stent graft collapse between 2003 and 2006 [44]. A total of seven stent grafts were found to be collapsed, or “in-folded” over this 3-year period from five experienced endovascular centers. All seven cases involved stents in the aortic arch, and all were diagnosed within 3 months of the index procedure. Six patients had a Gore TAG device (W.L. Gore and Associates, Evry, France) and one patient had a Zenith (Cook Medical Incorporated, Bjaeverskov, Denmark) stent graft. Interestingly, four of the seven patients had at least one postoperative CT scan that showed an intact stent without evidence of an endoleak, migration, or stent graft collapse. The one common variable to these seven cases was the presence of poor position of the stent in terms of position along the lesser curvature of the arch. Six of these cases were treated using endovascular technology, one with a second stent, and five with angioplasty and a balloon expandable stent placed in the proximal stent graft. There was one patient who underwent an axillary-bi-femoral bypass because of the inability to access the device with wires and catheters, and who was otherwise not medically fit to undergo an open thoracic aortic repair.

Endoleaks represent another difficulty of unknown significance encountered with current stent graft technology. Five types of endoleaks have been described (Figure 23.2) [45]. A primary endoleak refers to an endoleak identified within the first 30 days of implantation and anything thereafter is referred to as a secondary endoleak. The incidence of endoleaks appears to be improving with time as experience is gained, with first-generation stent grafts having a primary and secondary endoleak rate of 20% and 21%, respectively [46], and second-generation stent grafts having an incidence of 7% and 7%, respectively [46, 47]. Fortunately, the majority of these leaks can be repaired with additional endovascular procedures, sparing the patient from a conversion to an open operation. Riesenman et al. reported on their experience of 50 consecutive stent grafts of the descending thoracic aorta from October 2000 to May 2004 [48]. The overall endoleak rate was 20%, with half being primary and half secondary endoleaks. Of the five primary endoleaks (one type Ia, two type Ib, and two type III), four were treated with a second endovascular procedure, with the type III endoleak patients receiving additional stents and the type Ia and one of the type Ib patients being treated with balloon angioplasty to remold the end of the stent graft. Of the five secondary endoleaks (three type Ib, one type II, and one type III), three patients underwent a second endovascular procedure and all three required an additional stent graft component. Direct aneurysm sac puncture with embolization of branch
vessels, or infusion of fibrin glue or similar compounds, is another means for treating type II endoleaks that is being employed more commonly. However, large series reporting the results of these techniques and long-term outcomes data are not available.

The utility of debranching procedures to facilitate the creation of landing zones for stent grafting is being done more frequently as a means to avoid more extensive direct aortic operations. Such debranching procedures are often major operations in and of themselves, and the long-term durability of these procedures is not known. Long-term surveillance is not ameliorated with debranching procedures, and the ability to provide secondary percutaneous interventions may be severely compromised. It is our position to limit the use of debranching procedures at the present time, and we prefer to perform direct aortic reconstruction for those patients with truly inadequate landing zones for present stent graft technology.

**Conclusions**

Aortic and great vessel operations are associated with significant morbidity and mortality. Although we continue to make therapeutic advances utilizing improved technology, there remains a wide range of complications that occur with such invasive procedures. As new techniques are developed to minimize the impact and frequency of these complications, results are improving. Recently, endovascular approaches to aortic pathology have changed the way we approach aortic disease. Endovascular procedures are associated with a different set of complications, and as we encounter these complications, we must develop new and creative ways to treat and prevent them from occurring. Fortunately, most technical complications of endovascular aortic procedures are treatable with secondary percutaneous interventions. While open aortic operations are still required for many patients with aortic diseases, endovascular approaches may soon become the gold standard to treat aortic and great vessel pathology. It is imperative for all of us to maintain our skill set and knowledge at an appropriate level to allow optimal treatment of these very ill patients.
Chapter 23

References


