REVIEW

The Endovascular Management of Ruptured Abdominal Aortic Aneurysms

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Endovascular aneurysm repair (EVAR) is a controversial technique, which remains the subject of a number of prospective randomised trials. Although questions remain regarding its long-term durability objective evidence exists which demonstrates its reduced physiological impact compared with conventional open repair. If this technique could be used in patients with ruptured abdominal aortic aneurysm (AAA) it may reduce the high peri-operative mortality.

A review of the literature identified a limited experience with EVAR of ruptured AAA. Only a small number of case series with selected patients exist. The majority of patients were haemodynamically stable. However, the selective use of aortic occlusion balloons allowed successful endovascular management in a small number of unstable cases. All investigators had access to an “off the shelf” endovascular stent-graft (EVG).

Per-operative mortality ranged from 9 to 45% and may reflect increasing experience and patient selection. A number of patients who underwent successful EVAR were turned down for open repair.

A number of important lessons have been learned from these studies but questions remain regarding patient suitability and staffing issues. If these difficulties can be surmounted then the technique may offer an alternative to open repair.

Key Words: Ruptured abdominal aortic aneurysm; Endovascular aneurysm repair.

Introduction

In recent years major improvements have been made to make elective repair of abdominal aortic aneurysms (AAA) a safe procedure. In selected series mortality rates are less than 5%. Many of the patients with abdominal aortic aneurysm (AAA), however, remain asymptomatic until they present with rupture. Once rupture has occurred the overall mortality approaches 90%. The incidence of ruptured AAA is of the order of 8 per 100,000. In the U.K. there are 10,000 deaths from ruptured AAA every year. In a Welsh study only 36% of patients reaching hospital alive underwent attempted open repair of their ruptured AAA by general surgeons. Sixty-four percent of those who were operated on died. In single institutions the peri-operative mortality rate has remained constant at 50%. A recent meta-analysis of 50 years of the reported outcome of surgical repair of ruptured AAA has demonstrated a gradual reduction in peri-operative mortality. The gradual improvement in the literature may reflect reporting bias and patient selection. These results have, in the past led to conclusions that the outcome of ruptured AAA is out of the hands of the surgeon. Some studies show a greater mortality in the first 6 months after rupture repair when compared with elective surgery. After this, the mortality of those patients who had undergone ruptured AAA repair was equal to the elective aneurysm group. To improve the outcome of ruptured AAA new techniques should be directed at increasing the number of patients offered an operation as well as reducing early post-operative mortality. Only operating on good risk patients and rejecting poor risk ones should improve the individual series figures but is not much help to those rejected who are condemned to almost certain death.

Open repair, is the established method of treating ruptured AAA. Over the last decade endovascular techniques have been used increasingly to repair elective AAA and could offer another option to patients with a ruptured AAA.

Methods

A review of all the available literature on endovascular repair of ruptured abdominal aortic aneurysm

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was performed. Specifically, a medline search of all English language papers using the key words of endovascular aneurysm repair and ruptured abdominal aortic aneurysm was undertaken. In addition data was obtained from the proceeding of international vascular or endovascular meetings where there was an associated published abstract.

The feasibility of endovascular repair (EVAR) of ruptured AAA was proven in a case report from Nottingham in 1994. Since then there have been reports from specialized vascular units limited to selected and stable patients. Included were a variety of aortic ruptures including aorto-caval, aorto-renal vein and enteric fistula, ruptured false aneurysms and true aneurysms following open repair. Recently larger case series and two prospective studies have been reported. This review discusses the current status of endovascular repair of ruptured AAA.

The Effects of Ruptured EVAR on Patient Physiology

There are sound reasons why EVAR may be better for critically ill patients with ruptured AAA. Early studies of the potential physiological impact of EVAR compared with open repair in intact aneurysms have been well documented. EVAR has been shown to have less adverse effects on the cardiac, respiratory and renal systems. Specifically of interest in ruptured AAA is a reduced inflammatory (cytokine) response during EVAR. Cytokines are implicated in the development of multiple organ failure (MOF) following aortic surgery. MOF is the leading cause of peri-operative mortality following surgery for ruptured AAA.

Endovascular repair avoids the collateral damage associated with dissection of the aortic neck in the presence of free intra-peritoneal blood or a large retroperitoneal haematoma. Up to 68% of patients who die in the peri-operative period have an associated iatrogenic injury, these injuries being more common in those presenting with hypotension. Laparotomy is associated with hypothermia and consequent coagulopathy. There is evidence that the reduced physiological insult in elective EVAR will translate into improved outcome in patients with ruptured AAA.

Patient Selection

Currently there is no consensus among surgeons in the U.K. on which patients with ruptured AAA should be offered an operation. The majority of surgeons operate selectively. As few as 36% of patients who reach hospital alive receive an operation. Scoring systems exist which predict futility. One of these has been validated retrospectively. The results of scoring systems are, in general, available only after the operation has been performed. EVAR has been performed successfully in patients turned down for open repair on the basis of medical co-morbidity and likelihood of survival. A significant proportion of patients who had EVAR of ruptured AAA have done so on compassionate grounds. Whether these scoring systems are valid for patients undergoing EVAR is yet to be established.

Urgency of Operation

Cardiovascular instability does not prevent the use of the endovascular technique. A study on the blood pressure of patients who presented with ruptured AAA found 28% to be hypotensive on admission (systolic blood pressure < 100 mmHg), which increased to 44% on reaching the operating theatre for open repair. Permissive hypotension may reduce haemorrhage and mortality. The majority of U.K. surgeons do not rush patients to theatre and prefer a period of observation prior to performing open repair. In a study from Eindhoven the majority of patients were unstable (systolic blood pressure < 100 mmHg and signs of hypovolaemic shock) and one-third of those treated in Ulm had a systolic blood pressure < 80 mmHg. The Zurich group was able to demonstrate a free rupture on CT scanning in several patients who subsequently had successful EVAR.

Assessment of Patient Morphology

In the assessment of elective aneurysms contrast-enhanced spiral computed tomography (spiral CTA) has become the investigation of choice in many institutions. It is sufficiently reliable as a single imaging tool to assess aneurysm suitability and predict the required endograft size. There has been a trend in the U.K. to avoid radiological investigation of ruptured AAA in patients in whom a clinical diagnosis of rupture has been made. A report by Adam suggested clinical diagnosis in experienced hands provided sufficient grounds to take patients to the operating theatre. This practice facilitates rapid transfer of patients to theatre. Spiral CTA may add valuable information that alters management. Confirmation of the presence of an AAA and rupture on pre-operative spiral CTA is important to establish the diagnosis during endovascular management, and exclude alternative intra-abdominal pathology.
Willmann and colleagues have established that 3D reconstructions from spiral CTA can provide the necessary data for endograft planning in patients with ruptured AAA. Most centres that perform EVAR of ruptured AAA use spiral CTA for pre-operative planning. The Nottingham and Eindhoven groups specifically relied on thin slice axial CT without reconstructions.

Alternative techniques such as magnetic resonance angiography (MRA), which have been used electively have not been pursued in ruptured AAA. MRA is currently hampered by its availability, scan and image processing times and the requirement for specialist processing and interpretation of images. Ultrasound is unreliable for the detection of extravascular blood (and therefore diagnosis of rupture) and has not been validated in the pre-operative assessment of intact aortic morphology (particularly of neck length and diameter). The use of intra-operative investigations such as intravascular ultrasound (IVUS) or calibration digital subtraction angiography (DSA) are an attractive prospect that would avoid pre-operative delay. Both IVUS and DSA have been used as adjunctive investigations to confirm the measurements taken from pre-operative spiral CTA or MRA. IVUS has additionally been used as a quality control for graft deployment.

Unlike spiral CTA, DSA cannot establish the integrity of the aneurysm sac nor exclude other causes of the acute abdomen. Veith’s experience suggests that DSA alone may provide sufficiently accurate data about aneurysm morphology to successfully treat ruptures. In several patients the Montefiore group used DSA alone to successfully deploy their balloon expandable customisuble aortouniiliac stent-graft system. Whether DSA can be used reliably to predict aneurysm suitability and stent-graft size for other systems that are not customisable intra-operatively remains uncertain. The Malmo group reported three patients in whom pre-operative radiological investigations were not performed but in whom EVAR was subsequently performed. Specific details were not given but successful aneurysm exclusion was achieved in all three.

Anatomical Considerations

Endovascular repair relies on certain anatomical constraints for complete aneurysm exclusion. Aneurysms which rupture, are associated with larger diameters than their intact counterparts. Although absolute aneurysm diameter bears no relationship to the likelihood of successful aneurysm exclusion, it has been suggested that larger aneurysms tend to have more adverse morphological features, which increase the technical difficulty and reduce the applicability of the endovascular technique. The implications are that fewer ruptured AAA will be treatable by EVAR. The Zurich, Ulm and Eindhoven reports suggested an applicability of 58%, 67% and 81% respectively from their prospective intention-to-treat experience. The latter two centres included all abdominal and thoracic aortic ruptures and “acute symptomatic” AAAs respectively in their calculation of suitability. Consequently the proportion of patients suitable in Ulm and Eindhoven were higher. The overall values are much higher than the 30% suggested by some other authors for unselected populations of intact
aneurysms, but similar to the commonly quoted 60% by other authors.64±66

More liberal application of morphological criteria in patients with ruptured AAA are likely to account for some of the discrepancy, as well as the use of second generation devices which are now able to accommodate more difficult anatomy. In order to manage a higher proportion of aneurysms a change in the criteria will be required to incorporate morphology not normally considered suitable for elective repair. Morphological constraints centre on the suitability for creating a seal in the infra-renal aortic neck. The introduction of devices with supra-renal fixation has allowed shorter necks to be treated.67 Neck lengths of at least 15 mm and less than 30 mm width are generally required, but an adequate haemostatic seal has been achieved in patients with more adverse features, particular in necks which are shorter and wider.68,69 Examining the data from each of the studies (in particular those from Nottingham and Zurich) it becomes apparent that a number of patients underwent successful aneurysm exclusion where the morphology was not ideal for endovascular repair. Adverse anatomy was encountered in half of patients in the Nottingham study. However, deviations from the recommended criteria may increase the number of complications,70,71 which probably accounted for the high number (35% of patients at a median follow-up of 19 months) of secondary endovascular and trans-abdominal interventions reported from Zurich.34

Whilst the neck forms an important zone to create a seal other aspects of aortic morphology must not be overlooked. Ulm found that whilst they used neck dimensions as a sole criterion for exclusion (other than the presence of internal iliac artery aneurysms) they did not appreciate access difficulties posed by tortuous iliac arteries. In one patient, graft delivery was prevented by tortuous iliac morphology that required conversion to open repair, resulting in death of the patient. Similar access problems were

Table 1. Studies of patients undergoing endovascular repair of ruptured AAA.

<table>
<thead>
<tr>
<th>Study</th>
<th>Numbers treated</th>
<th>Time period</th>
<th>Type of study</th>
<th>Mean/median duration of symptoms (hours)</th>
<th>Transfer/unfit for open repair</th>
<th>Hypotension Investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montefiore</td>
<td>12</td>
<td>1993–1998</td>
<td>Retrospective non-comparative</td>
<td>29 (2–96)</td>
<td>9 and 12</td>
<td>Spiral CTA</td>
</tr>
<tr>
<td>Nottingham</td>
<td>20</td>
<td>1994–2000</td>
<td>Retrospective non-comparative</td>
<td>12 (3–48)</td>
<td>7 and 8</td>
<td>Spiral CTA</td>
</tr>
<tr>
<td>Ulm</td>
<td>21</td>
<td>1995–2000</td>
<td>Prospective non-randomised consecutive series of patients with ruptured AAA</td>
<td>8 (3–36)</td>
<td>n/a</td>
<td>Spiral CTA</td>
</tr>
<tr>
<td>Zurich</td>
<td>21</td>
<td>1998–2001</td>
<td>Spiral CTA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eindhoven (includes data on symptomatic)</td>
<td>17 (+7 with symptomatic)</td>
<td>1999–2001</td>
<td>Retrospective comparative with last 6 months data acquired prospectively (with management protocol)</td>
<td>n/a</td>
<td>Nil</td>
<td>Spiral CTA (1 USS)</td>
</tr>
</tbody>
</table>

Table 2. Intra-operative data.

<table>
<thead>
<tr>
<th>Study</th>
<th>Anaesthesia</th>
<th>Graft used</th>
<th>Operating time (mins)</th>
<th>Blood loss (ml)</th>
<th>Technical intra-op complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montefiore</td>
<td>1LA, 4E, 7GA (unitary)</td>
<td>3 straight, 9 aortouniiliac</td>
<td>263 (110–465)</td>
<td>715 (100–2500)</td>
<td>Nil</td>
</tr>
<tr>
<td>Nottingham</td>
<td>20GA (3 started with LA)</td>
<td>18 AUI, 2 modular AUI</td>
<td>180 (120–480)</td>
<td>1200 (750–2000)</td>
<td>3 conv to open repair, 4 renal artery occl, 1 popliteal embolectomy, 1 repair of EIA dissection</td>
</tr>
<tr>
<td>Ulm</td>
<td>At least 12 GA (intubated)</td>
<td>Bifurcated</td>
<td>105 (53–280)</td>
<td>1250 (500–3000)</td>
<td>1 conv to open repair, 1 renal art occl</td>
</tr>
<tr>
<td>Zurich</td>
<td>20LA (5 to GA)</td>
<td>1 straight, 20 bifurcated modular</td>
<td>120 (75–345)</td>
<td>2200 (800–3500)</td>
<td>3 reqd transfemoral balloons</td>
</tr>
<tr>
<td>Eindhoven (includes data on symptomatic) LA to GA in all</td>
<td>Modular AUI</td>
<td>173 (60–305)</td>
<td>660 (100–1300)</td>
<td>Peri-aortic ligatures for type Ia endoleak</td>
<td></td>
</tr>
</tbody>
</table>

LA = local anaesthesia; AUI = aortouniiliac; GA = general anaesthesia; modular = two-piece; E = epidural; unitary = one-piece; USS = ultrasound.
encountered with the first generation stent-grafts used by the Nottingham group, but newer commercially available designs are more trackable and able to deal with such problems. The Eindhoven group, using second generation devices exclusively were able to satisfactorily deploy endovascular stent-grafts using only neck and iliac dimensions.

**Graft Configuration and Sizing**

Aorto-aortic devices in the management of atherosclerotic AAA have largely been consigned to history. The majority of attention now focuses on grafts that extend to the common iliac arteries. Bifurcated stent-grafts are more “anatomical” than their aortouniiliac counterparts and avoid the need for a femoro-femoral bypass graft. During EVAR of ruptured AAA aorto-uniiliac devices may have some advantages. Uniliac devices can be used to exclude contralateral common iliac aneurysms, they are quick and easy to deploy, and produce rapid haemorrhage control. Though the need for a femoro-femoral bypass graft may prevent the use of local anaesthesia for the whole procedure.

Armon calculated a total of 750 one-piece aortouniliac stent-grafts would be required to accommodate all aneurysms. Clearly this is not a practical proposition. A variety of stent-graft designs have been used in ruptures. Some of the first operations for ruptured AAA used grafts manufactured in the operating theatre. These included the Montefiore endograft system and the Nottingham–Malmo system. Later, the Nottingham group used a two-piece uni-iliac design, which was sutured together in the operating theatre. Two of the centres (Nottingham and Eindhoven) have been involved in the development of commercially available devices specifically for use in ruptured AAA. These stent-grafts are of a modular uni-iliac configuration. The modular design used by the Nottingham and Eindhoven groups allows an array of “tops” and “bottoms” to be fitted together intra-operatively and tromboned to length. This configuration has reduced the number of grafts required in stock. As few as eight components (four proximal and four distal) are required to cover the full spectrum of aortic morphology. Furthermore, a modular design may mean that time consuming multiplanar reconstructions are not necessary. Calculation of aorto-iliac length from axial spiral CTA has proved sufficient in the planning of modular aorto-uniiliac endografts by both the Nottingham and Eindhoven groups. The Montefiore graft takes a different approach to length accommodation. The PTFE graft is cut to length as it emerges from the common femoral artery. The Montefiore device requires occlusion of the ipsilateral internal iliac artery. This manoeuvre requires a degree of endovascular manipulation and potentially contributes a delay to definitive haemorrhage control (back bleeding via a patent IIA). Newer modular bifurcated designs have almost as much versatility and were used exclusively in Zurich (through the use of large iliac limbs for ectatic common iliac arteries). Although an iliac limb may be required to be deployed in an external iliac artery to accommodate a CIA aneurysm. Prolonged cannulation or difficult deployment of the contralateral iliac limb may result in further blood loss. It took an average of 120 min to complete a bifurcated endovascular repair in Zurich. Whereas, in the Montefiore experience an average of 33 min was required to gain haemorrhage control using an occlusion balloon (although 263 min to complete the procedure). Comparative times to haemorrhage control and lower limb reperfusion are not stated. It is probable that haemorrhage control will be achieved earlier in patients with an aorto-uniiliac device deployed in the common iliac artery. Reperfusion times will vary and depend on a wide variety of intra-operative factors. In an attempt to achieve earlier control and reperfusion with bifurcated grafts, the group from Ulm used cross-bifurcation catheter techniques to facilitate catheterisation of the contralateral limb.

The majority of endovascular repairs of ruptured AAA have been performed with self-expanding stent-grafts. The balloon expandable (Palmaz stent) system used in the Montefiore unit allows intra-operative customisation of proximal diameter using calibration DSA. Palmaz stents have shown themselves to be a useful adjunct in the treatment of difficult proximal necks. In particular, they can achieve seal where a type I endoleak has occurred with a self-expanding stent-graft system. The PTFE graft used may be dilated to a diameter of 28 mm. With requirements for oversizing, a significant proportion of patients will have necks which are simply too wide. Inflation of the Palmaz stent requires a longer aortic occlusion time than does the self-expanding system, which may result in haemodynamic complications on deflation. There is also the possibility that balloon expandable systems are associated with marked peripheral embolization. In a report from Leicester, peripheral emboli occurred more commonly than during open repair and were not necessarily related to manipulation within the aneurysm sac.

Evolution of stent-graft designs have allowed more aneurysms to be treated. The early problems reported from Nottingham were frequently related to device
insertion and accuracy of deployment. Device related complications have been reduced with improved second generation grafts.76

Endovascular Control of Aortic Rupture

Some authors prefer to selectively use intra-aortic occlusion balloons placed via either the brachial or femoral routes to provide temporary haemostasis prior to definitive aneurysm exclusion (these techniques can even be a useful adjunct to open repair). In open repair, Foley urinary catheters have been used for haemorrhage control where direct clamping of the aorta has proven difficult. Intra-aortic occlusion balloons may be used to control haemorrhage from a number of causes.77 Access via both femoral and brachial routes have been described, both of which appear efficacious. Femoral access for the balloon has the advantage during EVAR of avoiding the need for further arterial puncture. The Montefiore group have had notable success using brachial access including patients with cardiac arrest. Other centres, such as the Nottingham and Eindhoven groups prefer swift deployment of the graft with definitive haemorrhage control and argue that occlusion balloons are not without their complications including renal and splanchnic ischaemia and embolization. Despite fears regarding sudden intra-operative patient deterioration/instability only three occlusion balloons (one urgently) were inflated by the Zurich group in their series of 21 patients. The Montefiore group used balloons in a minority of (unspecified) cases.

Anaesthetic Considerations

Open repair of ruptured AAA necessitates a general anaesthetic. Hypotension associated with the induction of general anaesthesia is a well recognized phenomenon during ruptured AAA surgery. The use of local anaesthetic techniques may avoid major haemodynamic disturbance. The ability to perform elective EVAR under local anaesthesia is well established.78 In a non-randomized retrospective study of elective EVAR, local anaesthesia was demonstrated to offer haemodynamic stability and shorten intensive care unit stay compared with either epidural or general anaesthesia.79 Using bilateral inguinal infiltration with lignocaine, conversion to general anaesthesia was only required in seven of 63 (11%) cases. Anaesthetic conversion was usually required because of the need for iliac artery access and therefore extended surgical exposure. Lachat and colleagues using a bifurcated stent-graft performed EVR of ruptured AAA completely under local anaesthesia in 15 of 21 patients. A further five of the procedures were commenced under local and converted to general anaesthesia. The Nottingham and Eindhoven groups did not have the same success with local anaesthesia. The former group found the patients to be restless and in considerable pain from the rupture, which appeared to be exacerbated by endovascular instrumentation of the aorta and iliac arteries. Later in the procedure lower limb ischaemia (due to the occlusion of common femoral artery blood flow) also contributed to patient restlessness. Inadequate analgesia may result in an adverse physiological response and movement artefact on imaging. The Nottingham and Eindhoven groups start the procedure under local anaesthesia and sedation and convert to general anaesthesia for deployment of the endovascular graft and placement of the femoro-femoral bypass graft.

Regional techniques such as epidural frequently used in elective repair, are not commonly undertaken because of the haemodynamic effects (autonomic sympathetic blockade) and potential for spinal complications in the presence of a coagulopathy. Totally percutaneous endovascular grafts would be an attractive development, with the potential to reduce the time involved in arterial exposure and reduce the analgesic requirement.80 However, the pain experienced by patients that requires conversion to general anaesthesia is caused by the rupture itself and instrumentation of the aorta rather than from the femoral artery exposure.

Staffing Considerations

An emergency endovascular service needs experienced nursing, surgical and radiological staff trained in endovascular procedures. Many of the early EVARs for ruptured AAA were performed only when sufficiently trained personnel were available. The procedures took place in institutions with considerable experience in elective endovascular aneurysm repair and many months were required to accrue suitable patients. One study specifically cited logistics as a major cause of the delay in the uptake of the procedure.31 An emergency endovascular service depends upon access to radiological and theatre suites. An emergency endovascular team will require personnel competent in both open and endovascular surgical techniques. One of the most significant obstructions to the introduction of EVAR for ruptures will be the provision of a 24-h emergency interventional radiology service. Elective peripheral endovascular
procedures can be performed safely in the operating theatre with no significant difference in outcome when compared to those performed in the interventional radiology suite. Whether endovascular aortic procedures are performed in the operating theatre or interventional radiology suite will depend on local resources and planning.

**Post-operative Complications**

Patients who have had endovascular ruptured AAA repair are prone to complications similar to those who have open repair and some unique to EVAR.

**Splanchnic Ischaemia**

Two of the four patients who died in the Eindhoven study did so as a result of colonic infarction. Patients with pre-operative hypotension are more likely to develop ischaemic colonic lesions following open aortic surgery. Elective EVAR is associated with less ischaemia of the sigmoid colon than open repair. Whether this difference is maintained following repair of ruptured AAA is less certain. Some authors have suggested that occlusion of one or both internal iliac arteries (IIA) during elective EVR may be achieved safely. However, these observations have been made in small numbers of patients after elective operations. In the former study six of the eight patients who had undergone bilateral IIA occlusion did so in a staged fashion. This allowed for the development of collateral vessels. Both patients in Eindhoven with colonic infarction had bilateral IIA occlusion to accommodate bilateral CIA aneurysms. Interestingly, the Montefiore endovascular stent-graft system requires occlusion of the ipsilateral IIA simultaneously in all cases to achieve AAA exclusion. No clinical evidence of colonic ischaemia has been reported despite unilateral IIA occlusion (the level of subclinical ischaemic injury was not recorded). The Leicester experience (in elective aneurysms) with a Montefiore system that causes ipsilateral internal iliac artery occlusion reported a 40% incidence of buttck claudication.

**Compartment Syndrome**

The abdominal compartment syndrome is an important cause of MOF, a leading cause of peri-operative death in those patients undergoing open repair of ruptured AAA. To prevent intra-abdominal compartment syndrome recent reports advocate delayed abdominal wound closure in patients who have undergone open repair of ruptured AAA. In “high risk” patients a mesh repair of the abdominal wall has been used, although no clear advice exists.

One of the concerns about the closed nature of endovascular techniques is that there may be an increase in intra-abdominal pressure secondary to the retroperitoneal haematoma. This might cause compartment syndrome. A recent report confirmed that a raised intra-abdominal pressure does not necessarily result in the compartment syndrome. Drainage of a retroperitoneal haematoma has been performed in three patients after EVAR of ruptured AAA. It is not routinely performed during open repair of ruptured AAA. On one occasion a large retroperitoneal haematoma was drained because it was considered to be impairing the patients respiratory function (Ulm). This is the only case in which an intra-abdominal compartment syndrome was treated by decompression. In a further two cases drainage was performed because the haematoma was large and thought to be at risk of becoming infected. There was no evidence of compartment syndrome or infection in either. Another two cases of the intraabdominal compartment syndrome developed in patients in Zurich but both responded well to supportive therapy and did not require laparotomy.

**Renal Failure**

Renal failure after open repair occurs in 29% of ruptured AAA. It is caused by hypoperfusion, hypotension, and embolization and can be exacerbated by supraceliac clamping. It has an associated mortality of 75%. In the Zurich study six out of 21 (28%) patients developed temporary deterioration of renal function but only two required temporary haemofiltration. The administration of radiographic contrast is an additional insult to renal function after EVAR. In a study of 400 patients who underwent aortography, there was an 11.3% incidence of acute renal dysfunction. Patients with pre-existing renal disease, hypoperfusion and large contrast volumes were at increased risk of dysfunction. The contrast volumes used during EVAR of ruptured AAA are large (in excess of 200 ml). Contrast is used in the bolus administration during pre-operative spiral CTA and excess use can occur with adverse anatomy of the aorta. The Montefiore group required an average of 160 ml of contrast intra-operatively and the Eindhoven CT protocol injected a 150 ml bolus. Strategies to reduce the contrast volume would include the use of dilute
contrast intra-operatively and possibly the use of carbon dioxide angiography or IVUS, the former of which has been used to good effect in three patients with ruptured AAA treated by the Malmo group.\textsuperscript{95,96}

**Endoleak**

Endoleak is a term that describes, “the inability to obtain or maintain a secure seal between the aortic wall and a transluminally implanted intra-aneurysmal graft.”\textsuperscript{97} Both type I (attachment site) and type III (modular limb dislocation or graft fabric failure) are significant risk factors for late aneurysm rupture.\textsuperscript{98} Their behaviour in the presence of a ruptured aneurysm sac is less well documented. The Nottingham experience suggested that proximal type I endoleak was associated with on-going haemorrhage. Both patients in Zurich with type I endoleak required in-hospital secondary endovascular intervention but one of the two in Eindhoven was managed expectantly and remained well at four months of follow-up. In contrast type II endoleak has generally been thought to be benign with only isolated cases of aneurysm expansion and rupture following elective repair.\textsuperscript{99} The natural history of type II endoleaks in the early post-operative period after EVAR of ruptured AAA is unknown. The Nottingham group reported an isolated case of type II endoleak due to a patent inferior mesenteric artery. That case was not associated with on-going bleeding or aneurysm expansion but was ligated at open operation.\textsuperscript{100} The ruptured aneurysm sac appears to behave no differently than its intact counterpart. Reports show successful resorption of the haematoma with reduction of sac size. The Zurich group experienced late type II endoleak in 20% of patients, all of which presented following resorption of the retroperitoneal haematoma. None of those endoleaks were associated with aneurysm expansion or rupture. Complications mandating conversion to open repair have, as expected resulted in high morbidity and mortality. In a series of intact aneurysms the mortality associated with conversion exceeded 20%.\textsuperscript{101} Conversions to open repair in these studies were required due to access failure or proximal endoleak not amenable to endovascular correction.

**Discussion**

The results reviewed here are those of pioneering centres with a great deal of experience in endovascular aneurysm surgery. They are encouraging but critics may argue that further investigation of the endovascular technique in ruptured AAA should not be conducted until the results of large multicentre randomized trials such as the U.K. EVAR trials and the Dutch DREAM trial are available. Some endovascular enthusiasts have suggested that the results from these preliminary studies are evidence enough, demonstrating the efficacy and improved outcome of the new technique. They argue that the outcome is so much better than open repair that randomised trials are unethical.

It is unlikely that EVR of ruptured AAA will be adopted without prospective trials to objectively compare it with open repair. Trials designed to demonstrate whether EVAR is associated with an improved outcome when compared with open repair of ruptured AAA face a number of significant challenges in order to gain meaningful results. The endpoints must primarily be peri-operative mortality with secondary endpoints to include major morbidity and resource issues such as ICU stay. A lesson learned from elective EVAR was the presence of a distinct learning curve.\textsuperscript{102} Lobato et al.\textsuperscript{103} and Lee et al.\textsuperscript{102} demonstrated reduced contrast volumes and fluoroscopy times respectively with increased experience and better technology. A learning curve will undoubtedly exist for ruptured

| Montefiore | 2 | Nil | Groin wound inf (2), A-E fistula | 7 (2-18) | Ax-bifem for graft occl at 2 months, groin wound drainage (2) | 18 |
| Nottingham | 9 | I, III | Renal failure (6) | n/a | 1 endovascular, 2 laparotomy | n/a |
| Ulm | 3 | Nil | Renal failure (3) | 23 (4-52) | 1 laparotomy | 19 |
| Zurich | 2 | Nil (4 late type II endoleaks) | Renal failure (6) | 6 (3-10) | 3 endovascular, 1 cross-over bypass, 1 open repair | 19 |
| Eindhoven (includes data on symptomatic) | 4 (no deaths in 7 with symptomatic) | 1 type I endoleak which was not treated intra-operatively | Ischaemia colon (2), Cholecystitis (1) | 15 (2-70) | 1 laparotomy (cholecystectomy) | 4 |

<table>
<thead>
<tr>
<th>Peri-operative mortality</th>
<th>Peri-operative endoleak</th>
<th>Peri-operative complications</th>
<th>Hospital stay</th>
<th>Secondary interventions</th>
<th>Mean/median follow-up (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montefiore</td>
<td>2</td>
<td>Nil</td>
<td>Groin wound inf (2), A-E fistula</td>
<td>7 (2-18)</td>
<td>Ax-bifem for graft occl at 2 months, groin wound drainage (2)</td>
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</tr>
<tr>
<td>Ulm</td>
<td>3</td>
<td>Nil</td>
<td>Renal failure (3)</td>
<td>23 (4-52)</td>
<td>1 laparotomy</td>
</tr>
<tr>
<td>Zurich</td>
<td>2</td>
<td>Nil (4 late type II endoleaks)</td>
<td>Renal failure (6)</td>
<td>6 (3-10)</td>
<td>3 endovascular, 1 cross-over bypass, 1 open repair</td>
</tr>
<tr>
<td>Eindhoven (includes data on symptomatic)</td>
<td>4 (no deaths in 7 with symptomatic)</td>
<td>1 type I endoleak which was not treated intra-operatively</td>
<td>Ischaemia colon (2), Cholecystitis (1)</td>
<td>15 (2-70)</td>
<td>1 laparotomy (cholecystectomy)</td>
</tr>
</tbody>
</table>
EVAR. The early experience in Montefiore recorded a mean operating time of 263 min, which was reduced to 173 min in the more recent Eindhoven study. Organizational issues are also likely to impact on the learning curve. One way to gain experience and address these organizational issues may be to include patients with acute symptomatic aneurysms. Patients with acutely expanding aneurysms, which are operated on urgently by open repair, have a higher mortality than elective aneurysms and may be a group, which could equally benefit from urgent EVAR. This has been demonstrated prospectively.

In critically ill patients with rupture, issues regarding informed consent will arise. Long discussions and written consent may clearly be inappropriate in unstable patients. Consent will vary from country to country but similar problems have been encountered in patients undergoing research in coronary thrombolysis trials or neurosurgical trials for head injury where the patient may not be able to give informed consent.

Conclusions

Low peri-operative mortality rates can be achieved in selected patients with ruptured AAA using endovascular techniques. Patients turned down for open repair on the basis of medical co-morbidity can survive EVAR.

Some patients will not be suitable for endovascular repair because of unsuitable aneurysm morphology or severe haemodynamic instability. Pre-operative hypotension and free rupture are not absolute contraindications to EVAR in themselves if managed appropriately with fluid restriction and permissive hypotension.

The current “best-buy” imaging technique from which to plan endograft size is spiral CTA. Multiplanar reconstructions do not appear necessary as axial CT images provide sufficient information if modular devices are used to accommodate length. Sole reliance on intra-operative calibration DSA may be possible in selected patients but cannot currently be recommended in all.

Many of the early complications resulted from inadequate stent-graft technology. The availability of manufactured devices “off the shelf” has reduced complications such as endoleak and transabdominal secondary procedures, which are associated with high morbidity and mortality. Both uniliac and bifurcated grafts may be suitable. Operations can be performed under local anaesthesia.

Putting in place an emergency ruptured AAA endovascular service requires a great deal of organization and is only likely to be possible at major vascular centres. The preliminary evidence suggest that a major break through can be made in the management of ruptured AAA using EVAR. The time is right for carefully designed trials to answer the remaining questions.

References

technique in a patient with severe pulmonary disease: report of a case. 


