Update on endovascular repair of abdominal aortic aneurysm
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Abstract
Endovascular repair of abdominal aortic aneurysm was first introduced by Parodi in 1990. There has been tremendous development of the device and the procedure since the investigational stage. Also it has been over a decade of clinical experience of endovascular repair of abdominal aortic aneurysm worldwide. The purpose of this article is to review the application of the procedure related complications and overall outcomes.

Introduction
Abdominal aortic aneurysm is a silent killer. Most people are not aware of its presence until the patient presents with acute symptoms. Early detection and treatment is the key to the prevention of major morbidity and mortality. The incidence of abdominal aortic aneurysm (AAA) in the world is rising because of significant prolongation of longevity of the population, awareness of the disease in the medical community, and the ease of detecting an abdominal aortic aneurysm with a duplex scan. It is estimated that 3-5% of the western population over the age of 50 years have abdominal aortic aneurysm. Thirty percent (30%) of all patients with an abdominal aortic aneurysm have strong family history and there is high predilection to the male gender at a ratio of 4:1. Hypertension and atherosclerotic disease are major contributing risk factors of abdominal aortic aneurysms.

Clinical presentation
The vast majority of patients with abdominal aortic aneurysms are asymptomatic. These are diagnosed during routine physical examinations, during other diagnostic procedures, or with screening duplex scans for patients with high risk factors. 25-30% of patients with abdominal aneurysms present with chronic or acute symptoms. Acute symptoms include severe abdominal or back pain secondary to acute expansion or contained leak of an abdominal aortic aneurysm. Patients will present with symptoms of hypotension when the aneurysm is leaking or ruptured. They also may present with acute ischemic symptoms of the lower extremities, either with major embolic occlusion or as blue-toe syndrome secondary to microembolization.

Patients with abdominal aortic aneurysms frequently present with chronic back pain or abdominal pain. These symptoms can easily be confused with pain secondary to chronic lumbar degenerative disease or gastrointestinal diseases. Occasionally, the patient also presents with obstructive ureteric or gastrointestinal symptoms. Obstructive symptoms are proportionate to the size of the abdominal aortic aneurysm. A large abdominal aortic aneurysm can cause extrinsic compression of either ureter or gastrointestinal tract resulting in chronic symptoms from the obstructing organ. An inflammatory abdominal aortic aneurysm may also present with obstructing symptoms regardless of the size of the aneurysm. In this scenario, the severity of symptoms would depend on the extent and intensity of the inflammatory process around the aneurysm.

Epidemiology
It is estimated that 40-50% of all ruptured abdominal aneurysm patients succumb to the event before the patient is able to reach the emergency facility. Of those who survive, the morbidity and mortality amongst those even with surgical intervention approaches 40-50%. Mortality is directly related to the immediate availability of an operating room, the

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experience and skills of the operating surgeon, institutional experiences, and the availability of other supporting specialties in the facility.

**History & development of surgery**
In 1888, Matas introduced the procedure of epoch-making significance. Later in 1909, he designated it as endoaneurysmorrhaphy. This principle is still an applicable technique in certain situations. In 1952, Dubost first performed the successful resection of abdominal aneurysm with homo-grafting. Debakey and many others have developed and expanded the surgical procedure and radically improved the prognosis of the fatal condition. Although abdominal aneurysm resection is very effective, it nevertheless is quite invasive. The morbidity and mortality of the procedure remains between 5-10% and is significantly higher with co-morbidity of cardiac, pulmonary and renal diseases. In 1990, Parodi performed the first endovascular repair of abdominal aortic aneurysm with the goal of reducing the morbidity and mortality of abdominal aortic aneurysm repair, even in patients with significant co-morbidity.

Since the initial deployment of aneurysm endograft, there has been tremendous technological advancement of graft design, deployment technique and the understanding of application of the procedure. Many graft devices have been approved and are commercially available for the repair of abdominal aortic aneurysms. There are a multiple series of continued development and clinical investigations for treating complex aneurysms, including suprarenal aneurysms with a fenestrated endovascular graft.

**Endografts**
The approved devices could be categorized into two types:
A. Infra renal fixating devices
B. Supra renal fixating devices

**A. Infra renal fixation devices:** Infra renal fixation devices (Excluder, Aneurex, Endologix) are deployed distal to the lower most renal artery origin. All grafts have self expanding stents to a predetermined diameter that affixes the graft against vessel wall with the stent's radial force. Excluder has micro-hooks all around the proximal part of the graft to anchor the graft onto aortic wall and thus enhance the fixation of the device. Aneurex has no fixation device and solely depends on the radial force of the stent, however, with this device it is recommended to extend graft deployment to the iliac bifurcation to prevent migration. Endologix is a unibody bifurcated graft initially deployed at the aortic bifurcation and the graft is extended proximally with aortic cuff upto the lower most renal artery origin. Since the graft sits over the aortic bifurcation, the risk of migration of the graft is practically eliminated.

**B. Suprarenal fixation devices:** Suprarenal fixation devices (Zenith, Talant) have hooks or stents extending proximally from the upper most part of the graft. The graft is deployed below the lower most renal artery origin but the hooks and stents are placed above the renal artery origins. Zenith has multiple hooks at the proximal end of the graft and Talant has multiple stents for suprarenal fixation of the graft, thus preventing graft migration. All of the graft devices have stents of various configurations along the body and limb of the graft to achieve stability and apposition against the aortic and iliac arteries, thus preventing migration as well as leak around the graft (endoleaks). All of the grafts are bifurcated modular except Endologix, which is a unibody bifurcated graft.

During clinical investigational phase, only approximately 30-40% of patients with abdominal aneurysms were suitable candidates for endograft repair. With downsizing the diameter of the deploying device, upgrading the graft diameter and better understanding of application of the procedure, more and more patients with abdominal aneurysms are treated with endograft. At present, perhaps as high as 70% of patients with abdominal aneurysms are candidates for endograft repair. Before a patient is offered the option of endograft repair.
repair of an abdominal aortic aneurysm, a few detail anatomic assessments of the aneurysm are mandatory, not only for feasibility of the procedure but for the selection of the graft device. Proper selection of the patients and the graft device will ensure the success of the procedure and minimize the risks and complications. A good quality CT scan with contrast (preferably 3 mm or less slices) with 3D reconstruction is adequate for preoperative detailed assessment of the aneurysm. Occasionally an angiogram is necessary, particularly for the patient with complicated aneurysm anatomy or with occlusive disease.

Assessment of aneurysm anatomy

A. Proximal aortic neck length, diameter and angulation:
   i. Proximal aortic neck length: The aortic neck length needs to be at least 15 mm to avoid any major proximal endoleaks and migration. A 15 mm neck length is not an absolute requirement and many vascular surgeons have successfully treated AAA with a neck shorter than 15 mm in length. In the case of a neck shorter than 15 mm, the choice and sizing of the graft become critical.
   ii. Proximal aortic neck diameter: Most of the graft devices are designed to treat the aneurysm with a neck diameter of 26-28 mm or less. At present, Zenith graft is approved to treat aneurysms with a neck up to 32-33 mm. Other commercially available grafts are also in process of up-sizing the graft to treat aneurysms with a larger diameter aortic neck.
   iii. Angulation of aortic neck greater than 45 degrees: This is a relative contraindication of endograft repair of an abdominal aortic aneurysm. With the availability of choice graft devices and it's variable compliances, the angle of the aortic neck has become less problematic.

B. Characteristic of plaque at aortic neck: 40% or more of aortic neck diameter calcification or soft atheromatous plaque is a relative contraindication of endovascular repair of an abdominal aortic aneurysm because of increased risk of endoleaks or embolization. With the availability of a suprarenal fixating graft device or the graft placed at the aortic bifurcation, problems arising from partial circumference calcification or soft atheromatous plaque can be avoided. Patients with a significant amount soft atheromatous plaque at the aortic neck have a higher risk of embolization to the renal or mesenteric artery during deployment of the graft. However, patients with total circumferential calcification or soft plaque at the aortic neck are not candidates for endograft repair of an abdominal aortic aneurysm.

C. Evaluation of access artery: The larger the diameter of the femoral and external iliac arteries, the easier it is to advance the device. The smallest of all devices is 7 mm in diameter. Even with less than 7 mm in diameter, sometimes a non-calcified or minimally calcified artery can be dilated to an adequate lumen to advance the device. On the other hand, a heavily calcified artery, even with diameter larger than 7 mm, may result in intimal dissection or rupture of the artery during advancement of the sheath or the graft. It is critically important to assess the access artery before consideration of endograft repair of abdominal aneurysm. If access artery is too small for the graft device, an 8-10 mm graft can be anastomosed to the common iliac artery and brought down to the femoral artery, thus creating an adequate access conduit for the graft device.

Overall, 97-98% of endovascular repair of abdominal aneurysm procedures are technically, as well as clinically, successful. However, the success of the procedure is directly linked to accurate anatomical assessment of the aneurysm, choice of the graft device, and technical skill of the operating surgeon. There are unique sets of complications in relation to endograft repair of aneurysms, in addition to overall complications related to anesthesia, blood loss, and the patient's co-morbidity.
Complications

A. Immediate and primarily technical during the placement of endografts

1. Tear or rupture of access artery (femoral, iliac) usually is because of poor preoperative assessment of access artery, unyielding attitude to an alternative approach or choice of the graft.

2. Rupture or penetration of the aneurysm sac is usually because of careless and unprotected manipulation of guide wire, sheath or graft device.

3. Occlusion of renal artery is due to the deployment of the graft across the renal artery origin. The graft can easily be misplaced because of poor visualization of the renal artery or the angle of the aortic neck is not taken into consideration during deployment. The aortic neck angle should be corrected by acquiring the image at the corrected angle prior to graft deployment. It is also of utmost importance to adequately visualize and map the origins of the renal artery prior to graft deployment. As long as the occlusion of the renal artery is recognized immediately, the deployed graft can be manipulated down to release the renal artery occlusion.

4. Embolic occlusion of renal, mesenteric, iliac and lower extremity arteries. A soft atheromatous plaque at the aortic neck, sac or at the iliac artery is usually visible on contrast preoperative CT scans. An atheromatous plaque can potentially be dislodged or squeezed out during advancement and inflation of the graft at the proximal or distal anchoring ends. These complications can be avoided with diligent advancement of the guide wire, sheath, deployment and inflation of the graft.

5. Acute occlusion or bleeding at the access site is self-explanatory.

B. Delayed and are related to graft device

1. Endoleaks are classified into four types:
   i. Type 1 endoleak is reported in 8-10% of the procedures. This happens during the deployment of the graft or delayed. Endoleaks during deployment of the graft is usually because of misplacement or under sizing of the graft. It also can be result of angulation, calcification or plaque of aortic neck. Delayed endoleaks are because of migration of the graft, enlargement of the aortic neck, and displacement of the graft secondary to remodeling of the aneurysm over a period of time. Most of the Type 1 endoleaks are amenable to placement of either a proximal or distal extender graft or stent larger than the graft size, depending on localization of the endoleak.
   ii. It is considered a Type 2 endoleak when the residual aneurysm sac fills through the inferior mesenteric or lumbar collaterals. The incidence of a Type 2 endoleak varies from 10-15%. Type 2 endoleaks are usually followed with serial CT scans, unless there is a rapid fill of the residual aneurysm sac or noted significant expansion of the residual aneurysm sac. Type 2 endoleaks can be difficult to localize.
and manage. When the endoleak is localized, the contributing feeding artery and its collaterals can be occluded by coiling, embolization or a combination of both. Other procedures such as injection of onyx or thrombin into the aneurysm sac and retroperitoneal laparoscopic clipping of inferior mesenteric or lumbum artery been described with varying degree of success.

iii. Type 3 endoleaks are due to failure of graft integrity or separation of the graft module, either because of primary failure of graft or secondary to aneurysm sac remodeling. The incidence of type 3 endoleaks depends on the graft device, and the true incidence of Type 3 has not been published. Management of a Type 3 endoleak would certainly depend on the extent of the leak and degree of graft failure. Patient may require surgical explantation of the graft and resection of the aneurysmal sac if leak can not be controlled with endovascular procedures.

iv. Type 4 endoleaks are secondary to graft porosity. Type 4 endleak was noted in early stage of graft development. With the advancement of graft technology this complication is extremely rare.

2. Migration of the graft has been reported in 12-14% of the procedures in various series depending on the graft device. Aortic neck dilatation and aneurysm sac remodeling may contribute to the cause in migration of the graft and cause type 1 or type 3 endoleaks.

3. Thrombosis of the graft or limb has been reported in 14% of the cases and results from kink in the graft or outflow stenosis/occlusion. If detected early, occlusion of the graft can be managed by graft lysis with tissue plasminogen activator infusion. Post lysis of the graft, the patient may need placement of a stent graft or stent depending on the findings on follow-up angiogram. If the graft or limb occlusion is chronic, the patient would need the appropriate reconstructive procedure or extra-anatomic bypass graft.

4. Expansion of the aneurysm sac is believed to be either because of known or occult endoleak, thus resulting in increased tension in the residual sac. In general, expansion of aneurysm sac can be managed by endovascular placement of stented graft or stent when type 1 or type 3 endoleak is detected and localized, otherwise patient would require open surgical resection of the aneurysm depending on the size and rate of expansion. There also have been many reported cases of sac expansion because of seroma around the graft. The majority of these cases are followed carefully with serial CT scans in the absence of definite endoleaks.

Discussion
The annual rate of secondary procedures for open surgical resection of an aneurysm has remained stable over the last several decades at 3%. The annual rate of secondary procedures for endovascular repair of an aneurysm is 9.6% in a cumulative experience. The first year rate of procedures is 6%, increases every year, and is reported at 14% on fourth year. The rupture-free rate is very similar to an open procedure at 99.5% at one year and 97.2% at four years.

Endovascular repair of abdominal aneurysms has certain distinct advantages. The procedure has significantly reduced blood loss, decreased complications even with multiple co-morbidities, and potentially can reduce the operating time depending on surgeon skill. The procedure has markedly shortened hospital stays and postoperative recovery time. The disadvantages of the procedure are that the device is expensive, long-term diagnostic follow up is required, and there is a significantly higher incidence of secondary procedures.

Endovascular repair of ruptured aneurysms is also feasible. Several series with small numbers of ruptured aneurysm patients treated with endograft have been reported. 50-60% of the patients in the series with ruptured abdominal aneurysms were suitable for endograft repair and 80-90% of those were technically successful. The complication rate with endograft repair of ruptured AAA is significantly lower at 24% compared to a complication rate of 40-50% in open surgical resection. A major percentage of morbidity
and mortality in relation to endograft repair of ruptured AAA is contributed to blood loss, related coagulopathy and the unique complication of acute abdominal compartment syndrome.

The long-term follow up and outcome have not yet been established, especially since the development of endograft is still evolving. However, endovascular repair of abdominal aneurysm is a technically and clinically acceptable procedure and is significantly beneficial for patients with multiple co-morbidities.

Conclusion
Endovascular repair of abdominal aortic aneurysm is technically as well as clinically successful procedure. The procedure has advantage of reducing mortality and morbidity over conventional open repair of abdominal aneurysm, especially patient with significant cardiac, pulmonary and renal co-morbidity. Long term outcome yet to be determined since graft devices are still evolving, however there is no significant deference in rupture free and mortality rate in five years follow up between open and endovascular repair of abdominal aortic aneurysm.

References