Chimney Stent Grafts in the Era of Custom-made Devices: A Comparative Review of Complex Abdominal Aortic Aneurysm Stenting

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Abstract

Introduction: Surgical treatment of abdominal aortic aneurysms (AAA) has evolved over the past 15 years. Fenestrated endovascular of AAAs (FEVAR) and Chimney endovascular of AAA (Chimney EVAR) are techniques that have been introduced and utilized over the past few years as alternatives to open surgical repair with its high associated morbidity and mortality. The purpose of this study is to compare the results of FEVARs and Chimney endografts in a single institution from an Asian perspective. Materials and Methods: We retrospectively reviewed all patients who underwent FEVAR and Chimney EVAR from January 2011 to August 2014 in a tertiary vascular institution. Results: During this study period, a total of 19 patients underwent Chimney EVAR, and 12 patients underwent FEVAR. All FEVAR patients were operated electively while five patients who underwent Chimney EVAR were operated in an emergency setting. Operative time was longer for FEVAR and more vessels were reconstructed. There was no difference in intraoperative technical events, postoperative general and specific complications between the two groups. One patient passed away within 30 days of repair with Chimney EVAR. Conclusion: In this limited retrospective series, short-term results of FEVAR and Chimney EVAR had no statistical difference. Chimney EVAR is an attractive and useful alternative for patients who are unable to undergo FEVAR.

Keywords: Chevar, chimney stent grafts, fenestrated endovascular of abdominal aortic aneurysms, fenestrated stent grafts, juxtarenal aneurysms

Introduction

Surgical treatment of abdominal aortic aneurysms (AAA) has evolved over the past 15 years with the development of endovascular aortic aneurysm repair (EVAR), resulting in decreased morbidity as it is less invasive. However, up to 30%-40% of AAA patients are not suitable for conventional EVAR with the primary limitation being the length of the proximal landing zone. As the proximal landing zone has been described as the single most important factor for success or failure of therapy for complex juxtarenal AAA, many different surgical techniques have since been described, such as open repair, fenestrated and chimney endografts. Open repair requires a suprarenal cross-clamp, and associated perioperative complications such as renal impairment resulting in need for permanent hemodialysis, acute myocardial infarction, and pneumonia have been well documented. In addition, the 1 year mortality rate of patients over 70 years of age with chronic obstructive pulmonary disease can be as high as 30%.

Fenestrated EVAR (FEVAR) was first described in 1999 as an alternative endovascular solution for juxtarenal AAAs. Their purpose was to extend the proximal sealing zone from the infrarenal segment all the way proximal to the suprarenal aorta by tailoring fenestrations or scallops in the stent graft. This technique has been well documented to be limited by strict anatomic requirements such as neck angulation, high costs, and length of manufacturing time.

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making it only suitable to be performed in an elective setting. Despite this, it has been shown to be superior to open repair. Chimney EVAR was first described in 2003 as a bailout technique for misplaced endografts, where parallel renal stents were placed with the main body stent graft to achieve a more proximal seal. It has since been adopted by many for stenting of juxtarenal AAAs in both elective and emergency settings as off-the-shelf endografts can be used. However, frequency of Type 1A endoleaks through the “gutters” (area between the stent, main body stent graft and the aorta) and the long-term patency of stented vessels are still relatively unknown. When compared to open repair, this technique was found to have similar mortality but lower morbidity rates.

There are a few papers that have compared FEVARs and chimney endografts but none from Asia. The purpose of this study is to compare the results of FEVARs and Chimney endografts in a single institution from an Asian perspective.

**Materials and Methods**

**Patients and inclusion criteria**

We included all consecutive patients who underwent either FEVAR or Chimney EVAR from January 2011 to August 2014 in a tertiary vascular department. Exclusion criteria included EVARs that employed the Chimney technique as a bailout procedure.

For all patients planned for either procedure, preoperatively, their cases and computed tomography (CT) scans are presented during a weekly meeting of vascular surgeons and interventional radiologists. A consensus on which procedure is most suitable for each individual patient is then reached according to the following criteria: patients undergoing FEVAR need to satisfy the manufacturer’s inclusion and exclusion criteria. Exclusion criteria for FEVAR include small or tortuous iliac arteries, iliac occlusive disease, Type 1A endoleak from previous EVAR, or an angulated aorta. In addition, patients required an adequate sealing zone of at least 15 mm in length. Patients undergoing Chimney EVAR are patients who require emergency surgery and are unable to wait for the fenestrated stent to be constructed or patients who do not fulfill the inclusion criteria for FEVAR. These patients also required to have a proximal landing zone of at least 15 mm below the main device. An example of a chimney EVAR that was performed is shown in Figures 1a-d.

**Device implantation**

There have been multiple reports on the technical aspects of both FEVAR and chimney EVAR. All our patients had access from bilateral femoral arteries and left brachial or axillary arteries. When more than one target vessel was to be stented, bilateral brachial arteries were accessed.

**Data collection**

We used an administrative database with prospectively collected data. Preoperative patient data such as age, existing medical conditions, character and measurements of the aortic aneurysms and indications for operation had been recorded in the database and were reviewed. We also collected intraoperative data such as total operation time, number of, and type of reconstructed vessels. Postoperatively, patients underwent follow-up CT aortogram or ultrasound abdominal aorta with contrast at 1 month, 3 months, and 6 months postprocedure. Other data such as postoperative complications that resulted in morbidity and mortality were also collected and reviewed.

**Statistics**

Categorical variables were analyzed using Chi-square or Fisher’s exact test. Continuous variables were analyzed using t-test. All P values were two-sided and values of <0.05 were taken as statistically significant. Statistical analysis was performed using SPSS version 14.0.0 (SPSS Inc, Chicago IL, USA).

**Results**

**Patient population**

From January 2011 to August 2014, a total of 19 patients underwent Chimney EVAR, and 12 patients underwent FEVAR. The first Chimney procedure was performed in March 2011, and the first FEVAR was performed in September 2011. Patient and anatomical characteristics are listed in Table 1. Patients in the Chimney EVAR group were significantly older. The rest of the patient characteristics between the two groups were largely similar.

Renal insufficiency is defined as patients who had baseline serum creatinine levels above normal. In our institution, all patients who had preoperative serum creatinine levels above 101 Umol/L were classified as having renal insufficiency. All patients were hydrated with intravenous fluids perioperatively. Postoperatively, they had their renal function closely monitored through regular blood tests.

Indications for operations are listed in Table 2. Most of the patients (10 out of 12 for FEVAR and 11 out of 19 for
Chimney EVAR) had the operations performed due to the size of the aneurysm at diagnosis. All FEVARs were operated on in an elective setting while five out of 19 of the Chimney EVARs were operated in an emergency setting, out of which four had aneurysmal leak, and one had a dissection into the aneurysm sac.

**Stent grafts and reconstructed vessels**

**Stent grafts – type and configurations**

The number of reconstructed vessels was significantly higher in the FEVAR group as compared to the Chimney EVAR group as stated in Table 3. As a result, time to complete the operation for FEVARs was significantly longer than Chimney EVARs. The renal arteries were most commonly stented in Chimney EVAR while for patients with FEVAR, the superior mesenteric artery was stented in almost all patients as listed in Table 4. The mean diameter of the vessels stented was also measured, and the diameter of stents used for each vessel was upsized by about 20%.

The aortic main body stents used for these patients were varied, ranging from the Zenith Flex® Endovascular Stent Graft from Cook to Endurant® II Stent Graft System from Medtronic. All Chimney stents were the Atrium ADVANTA® V12 Balloon Expandable Covered Stent. The renal arteries were most commonly stented in Chimney EVAR while for patients with FEVAR, the superior mesenteric artery was stented in almost all patients as listed in Table 4. The mean diameter of the vessels stented was also measured, and the diameter of stents used for each vessel was upsized by about 20%.

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**Strategy for proximal graft sizing to accommodate chimneys**

is as per the formula:

\[ X + \left(\frac{a + b}{3}\right) = Z \]

“X” is the diameter of the native aorta. “a” is the diameter of the first chimney stent. “b” is the diameter of the second chimney stent (if required). Having obtained the diameter “Z,” it is then oversized by 10%–20%. That diameter will then be the final diameter used for the proximal end of the stent graft. The seal zone achieved for the proximal neck component is a minimum of 2 cm.

**Intraoperative technical events**

We were unable to cannulate 2 vessels in the FEVAR group as compared to 1 vessel in the Chimney EVAR group. For the FEVAR group, 1 patient’s right renal artery had to be sacrificed as a result while for the other, patient’s coeliac artery could not be cannulated due to stenosis of the native vessel. 1 patient’s left renal artery autodeployed before being placed in the correct position. The free-floating stent had to be retrieved through a cutdown of the common femoral access artery. The left renal artery was successfully stented thereafter. For the patient in the Chimney EVAR group, the left renal artery could not be cannulated. The rest of the intraoperative technical events are listed in Table 5 and there were no significant differences between the 2 groups of patients.

**Postoperative morbidity and mortality**

In the patients who underwent Chimney EVAR, one patient passed away in hospital as a result of an aortoenteric fistula. This occurred 3 months after the primary operation was performed. No other deaths were noted in both groups of patients. Only 1 out of 12 patients from the FEVAR group as compared to 2 out of 19 patients in the Chimney group developed respiratory postoperative complications. In the Chimney group, 2 patients developed urinary tract infections and 4 patients developed cardiac postoperative complications. However, all recovered well enough to be discharged.

Eight out of 12 patients (67%) in the FEVAR group and 9 out of 19 patients (47%) in the Chimney group had access vessel

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**Table 1: Patient and anatomical characteristics**

| Variable                        | Fenestrated EVAR (n=12) | Chimney EVAR (n=19) | P       |
|---------------------------------|-------------------------|---------------------|---------|
| Male                            | 12 (100)                | 18 (94.7)           | 1.00    |
| Mean age (years)                | 65                      | 71                  | 0.014   |
| Coronary artery disease         | 7                       | 11                  | 0.98    |
| Congestive heart failure        | 1                       | 1                   | 0.73    |
| Arrhythmia                      | 0                       | 2                   | 0.24    |
| COPD                            | 1                       | 2                   | 0.84    |
| Hypertension                    | 10                      | 16                  | 0.95    |
| Hyperlipidemia                  | 6                       | 13                  | 0.31    |
| Diabetes mellitus               | 4                       | 2                   | 0.12    |
| Cerebrovascular disease         | 1                       | 5                   | 0.22    |
| Peripheral artery disease       | 0                       | 1                   | 0.42    |
| Renal insufficiency             | 4                       | 6                   | 0.92    |
| Prior aortic surgery            | 1                       | 6                   | 0.13    |
| Smoking                         | 5                       | 9                   | 0.76    |
| ASA classification              | 2                       | 5                   | 0.40    |
|                                 | 3                       | 7                   | 0.8     |
| Mean aneurysm diameter (cm)     | 5.8                     | 6.9                 | 0.11    |
| Infrarenal neck length (mm)     | 3.8                     | 3.8                 | 0.97    |

EVAR: Endovascular aortic aneurysm repair, COPD: Chronic obstructive pulmonary disease, ASA: American Society of Anesthesiologists

**Table 2: Indications for operation**

| Indications for operation       | Fenestrated EVAR (n=12), n (%) | Chimney EVAR (n=19), n (%) | P       |
|---------------------------------|---------------------------------|---------------------------|---------|
| Size of aneurysm                | 10 (83)                         | 11 (58)                   | 0.23    |
| Persistently symptomatic        | 2 (17)                          | 0                         | 0.61    |
| Aneurysmal leak                 | 0                               | 4 (21)                    | 0.09    |
| Endoleak from previous stenting | 0                               | 3 (16)                    | 0.15    |
| Dissection into aneurysm sac    | 0                               | 1 (5)                     | 0.41    |

EVAR: Endovascular aortic aneurysm repair

**Table 3: Number of reconstructed vessels**

| Number of reconstructed vessels | Fenestrated EVAR (n) | Chimney EVAR (n) | P       |
|---------------------------------|----------------------|-----------------|---------|
| 1                               | 0                    | 8               |         |
| 2                               | 1                    | 6               |         |
| 3                               | 6                    | 4               |         |
| 4                               | 5                    | 1               |         |
| Average per patient             | 3.3                  | 1.9             | <0.01   |
| Intraoperative time (min)       | 309.6±16.5           | 234.7±17.7      | 0.007   |

EVAR: Endovascular aortic aneurysm repair
Injuries that required vessel cutdowns and open repair. Two patients from each group had access vessel pseudoaneurysms that required subsequent repair postoperatively. However, both complications were not statistically significant when compared. The rest of the complications are listed in Table 6.

### Postoperative results

Median follow-up duration was 7.4 months for FEVAR (range 0–24 months) as compared to 17.8 months for Chimney EVARs (range 0–36 months). This was found to be statistically significant with \( P = 0.015 \). 1 patient in the Chimney EVAR group was lost to follow-up at the 1-year postoperative time point.

There was renal impairment for 3 out of 12 patients (25%) in the FEVAR group versus 5 out of 19 patients (26%) in the Chimney EVAR group (\( P = 0.94 \)). The patient who had his right renal artery sacrificed in the FEVAR group developed renal impairment but did not require hemodialysis. The patient in the Chimney EVAR group whose left renal artery could not be cannulated did not develop renal impairment.

At the time the project was concluded, 1 out of 12 patients in the FEVAR group had a Type 1B endoleak while 2 out of 19 patients in the Chimney EVAR group had a Type 1A endoleak. Only the patient with the Type 1B endoleak required reintervention with embolization of the Type 1B sac 1 month postprimary procedure. Embolization coils were placed at the Type 1B endoleak sac with good result. No further endoleak was noted on follow-up scans. With regard to the two patients with Type 1A endoleaks, one patient was the patient above who passed away from an aortoenteric fistula. The patient presented to the emergency department with the aortoenteric fistula 3 months after the operation. CT Aortogram then showed the fistula and a Type 1A endoleak. Surgery was offered but the patient declined and subsequently passed on. The other patient with Type 1A endoleak was offered repeat intervention, but he declined and he was subsequently lost to follow-up. Most endoleaks were picked up 1 month postoperation on follow-up imaging.

A total of 17 patients (8 in the FEVAR group and 9 in the chimney EVAR group) had access vessel injury requiring poststenting cutdown and exploration. All were for thrombosis of access vessels and were identified after the sheaths were removed. In addition, 2 patients from each group had pseudoaneurysms of access vessels requiring re-exploration and repair after the main operation was completed.

### Discussion

Endovascular treatment of juxta- or para-renal abdominal aortic aneurysms has evolved over the years with multiple techniques being used. Stenting using chimney and fenestrated grafts have gained popularity over other techniques with multiple reports of good early to midterm results.\(^{11,12}\) Our study results mirror those of previously published papers in western populations. Of importance, there was no difference in sac behavior and mortality between the two groups of patients.

The availability of stents off the shelf to be used in the chimney technique is attractive especially in emergent cases of which we had five. Patients deemed too high risk for open surgical repair in view of age, and multiple comorbidities were able to have their aneurysms repaired through this method.

Stenting using fenestrated grafts for our patients took notably longer. Despite this, they had fewer general postoperative complications in addition to similar endoleak rates compared to the patients stented through the chimney technique. As previously explained, the graft takes up to 5 weeks to manufacture and this can only be performed in an elective setting. As a result, we believe that the patients in this group were better optimized preoperatively as the complications suffered by the patients in the chimney group were mainly cardiac and respiratory in nature.

Even though the technique of stenting with fenestrated grafts was described earlier, our center only performed them more recently, resulting in shorter follow-up time. In addition to the aforementioned long manufacturing time, the grafts cost more than 3 times that of the grafts used for the chimney technique. This could have been prohibitive to many patients. However, with the multiple reports of good early and long-term results of fenestrated grafts,\(^{13–15}\) we have...
used this technique in recent years and have found it to have similarly good early results.

It should be mentioned that there was no significant difference in renal impairment between the two different stenting techniques. Two patients in the chimney group had kidney infarction but only 1 required hemodialysis after. The two patients in the fenestrated group had end-stage renal failure and already required hemodialysis preoperatively. This is similar to other studies.

The concept of the chimney technique is attractive especially for emergency cases, but its main criticism is that placing cylindrical tubes parallel to each other would cause “gutters” that can leak and thrombose. With thrombosis, the aneurysmal sac will be subjected to increased pressure in the long-term.\[16,17\] Indeed, there have been studies that have stated that the long-term outcomes of chimney are poorer than that initially reported and caution has been advised in performing this technique in an elective setting. Scali et al. reported an endoleak rate of 32% with a primary chimney stent patency rate of 85%–88% with a median follow-up of 18.2 months.\[16\] However, fenestrated grafts are not without its critics as there is only a single covered stent placed through a hole in the main body graft, giving a theoretical risk of leak.\[11\] Hence, the importance of planning before surgery for this stenting technique. Indeed, more studies comparing long-term outcomes between these two techniques are required.

Becequemin et al. published their own data of intraoperative adverse events during branched and fenestrated aortic stent grafting in 2014.\[18\] Out of 113 consecutive patients, they had a total of 33 intraoperative adverse events (IOAEs). They divided their IOAEs into 3 types. Type 1 was problems with target vessel cannulation; of which they had 18. Type 2 was malpositioning of one of the following graft components: bridging stents, bifurcated component, or iliac extensions, of which they had 5. Type 3 was difficulty with intraoperative access, of which they had 10. Their IOAEs are similar to the intraoperative technical events that we experienced, as detailed in Table 5.

Other smaller studies also described their intraoperative technical events. Most were related to cannulation failure of renovisceral arteries.\[19\]

In total, there were 5 emergency Chimney EVARs performed in this study. All patients had urgent CT aortograms on presentation. Based on the CT findings, all went for Chimney EVAR using off-the-shelf stent grafts and chimney stents. Three out of the 5 patients developed postoperative renal impairment with 1 patient eventually requiring dialysis. One patient developed a Type 1A endoleak and an aortoenteric

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**Table 6: Postoperative morbidity and mortality**

| Variable                                           | Fenestrated EVAR (n=12), n (%) | Chimney EVAR (n=19), n (%) | P   |
|----------------------------------------------------|--------------------------------|----------------------------|-----|
| Death                                              | 0                              | 1 (5)                      | 0.41|
| 30 day                                             | 0                              | 0                          | NA  |
| Inhospital                                         | 0                              | 1 (5)                      | 0.41|
| Total number of patients with complications       | 6 (50)                         | 13 (68)                    | 0.31|
| Cardiac complications                              | 0                              | 4 (21)                     | 0.089|
| Respiratory complications                          | 1 (8)                          | 2 (10)                     | 0.84|
| Urinary tract infection                            | 0                              | 2 (10)                     | 0.24|
| Operative specific complications                   | 5 (42)                         | 10 (53)                    | 0.55|
| Endoleak                                           |                                 |                            |     |
| 1A                                                 | 0                              | 2 (10)                     | 0.84|
| 1B                                                 | 1 (8)                          | 0                          |     |
| 2                                                   | 1 (8)                          | 3 (16)                     |     |
| 3                                                   | 0                              | 0                          |     |
| Gastrointestinal complications                     | 0                              | 0                          | NA  |
| Renal impairment (>50% basal creatinine)          | 3 (25)                         | 5 (26)                     | 0.94|
| Hemodialysis                                        | 2 (17)                         | 1 (5)                      | 0.30|
| Kidney infarction                                  | 1 (8)                          | 2 (10)                     | 0.84|
| Neurological complications                         | 0                              | 1 (5)                      | 0.42|
| Vascular                                           |                                 |                            |     |
| Target vessel                                      | 2 (17)                         | 2 (10)                     | 0.62|
| Access vessel                                      | 8 (67)                         | 9 (47)                     | 0.29|
| Access site pseudoaneurysm                         | 2 (17)                         | 2 (10)                     | 0.62|
| Other                                              |                                 |                            |     |
| Access site hematoma                               | 1 (8)                          | 2 (10)                     | 0.84|
| Graft infection                                    | 0                              | 0                          | NA  |
| Reperfusion syndrome                               | 0                              | 0                          | NA  |
| Trash foot                                         | 0                              | 3 (16)                     | 0.15|

EVAR: Endovascular aortic aneurysm repair, NA: Not available
fistula 3 months postoperatively and passed on. Many studies have advocated Chimney EVAR as a good endovascular option for treatment of complex aortic aneurysms.[20] Bin Jabr et al. also reported only a 6% chimney-related mortality with 93% long-term patency of Chimney EVARs performed in the emergent setting.[21] However, there are studies that preach caution when performing Chimney EVARs as there could potentially be a higher rate of endoleak and chimney patency than previously reported.[16] In our study, we have too small a number of patients who underwent emergent Chimney EVAR to provide any compelling evidence that Chimney EVAR will have good long-term outcome when used in the emergency setting. More studies dedicated to this topic are required.

Our rate of access vessel injury requiring cutdown and exploration of access vessel is noted to be relatively high as compared to other studies. All were due to postoperative thrombosis and identified after the sheaths were removed. We postulate that this could be due to the fact that Asians have smaller arterial diameters and the arteries tend to be more tortuous. Masuda et al. identified this issue[22] in Asians for the iliac arteries. In relation to this, the stented arteries in our Asian population are also likely to be smaller than those of the western population but we do not see a stent patency rate that is worse, with all stent arteries patent at conclusion of the study. This highlights the importance of proper planning and appropriate choice of diameters of stents. Assessing the vessel diameter preoperatively could also aid in patient selection and future decrease in this complication postoperation.

Our study is limited by the small sample size of patients which could lead to Type II error and relatively short follow-up time. We also acknowledge that with the shorter follow-up time for the FEVAR group as compared to the chimney group, there could potentially be other long-term postoperative complications such as endoleaks that have yet to be picked up and this is a limitation of our study. In addition, this is a retrospective study.

CONCLUSION
From our center’s experience, stenting of juxta- and para-renal abdominal aortic aneurysms using either chimney or fenestrated graft techniques has similar results. More studies are required to assess long-term results of these two techniques. Patients of Asian ethnicity have smaller diameter vessels; hence, there is a higher probability of access vessel injury.

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Conflicts of interest
There are no conflicts of interest.

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