Outcome of hybrid visceral debranching endovascular aortic repair

Ahmed Eleshra[a,b], Tilo Kölbel[a], Axel Larena-Avellaneda[a], Giuseppe Panuccio[a], Fiona Rohlffs[a], Nikolaos Tsilimparis[a], Eike S. Debus[a], Khaled Elalfy[b], Ehab Saad[b], Hisham Sharafeldin[b]

[a]German Aortic Center, Department of Vascular Medicine, University Heart and Vascular Center Hamburg, Hamburg, Germany, [b]Department of Vascular and Endovascular Surgery, Faculty of Medicine, Mansoura University, Mansoura, Egypt

Correspondence to Ahmed Eleshra, MD, German Aortic Center Hamburg, Department of Vascular Medicine, University Heart and Vascular Center Hamburg, Martinistraße 52, 20246 Hamburg, Germany. Tel: +49 157 3514 4221; fax: 020502339503; e-mail: eleshraahmed@gmail.com

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Objective
The aim was to study the outcomes of hybrid debranching endovascular aortic repair (H-EVAR) for thoracoabdominal aortic aneurysm.
Patients and methods
Patients who had H-EVAR for treatment of thoracoabdominal aortic aneurysm between January 2010 and December 2018 were included in this study. Early outcome (30 days) in terms of mortality, morbidity, and target vessel patency were analyzed. Follow-up outcomes in terms of late death, endoleak, and re-intervention rates were evaluated.
Results
A total of 33 patients (48% males) with a mean age of 68±13 years were included. Eighteen (55%) patients were asymptomatic, whereas eight (24%) patients were symptomatic and seven (21%) patients had a contained rupture. Six (18%) patients died after the visceral debranching operation (stage 1), and 27 (82%) patients completed both stages of H-EVAR. The 30-day mortality in completed H-EVAR was 5 (19%) of 27 patients. Five (15%) patients developed spinal cord ischemia. Four (12%) patients had post-operative dialysis. Two (6%) patients had a stroke. Four (12%) patients experienced respiratory failure. Four (12%) patients had mesenteric ischemia and two (6%) had ischemic colitis. The 30-day overall primary target vessel patency rate was 92±3%. Early endoleak I rate was 3 (11%) of 27 patients, and endoleak III rate was 2 (7%) of 27 patients (completed H-EVAR). The mean follow-up period was 23±11 months for 22 patients who survived the completed H-EVAR. Late death occurred in 4 (18%) of 22 patients.
Conclusion
Hybrid EVAR had several advantages that included avoiding thoracotomy, aortic cross-clamping, single-lung ventilation, and the need for extensive dissection in multiple aortic segments. However, the controversial outcomes led to criticism, and there is a need to examine the three techniques (open, hybrid, and total endovascular) simultaneously, which would give a unique definition of the selection criteria to achieve the optimum results in each patient.

Keywords:
aorta, debranching, hybrid repair, stent graft, thoracoabdominal aneurysm

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Introduction

The treatment of thoracoabdominal aortic aneurysm (TAAA) is one of the most formidable challenges in cardiovascular surgery [1].

Open repair of TAAA has a high morbidity and mortality rate. These risks have persisted despite advances in operative technique (including left heart bypass, spinal cord protection, hypothermic cardiopulmonary arrest, and selective visceral perfusion) and higher standards of perioperative care [2].

Quinones-Baldrich *et al.* [3] have described hybrid visceral debranching endovascular aortic repair (H-EVAR) firstly through combining both open surgical and endovascular techniques, and since its introduction, the technique has been widely used instead of the open surgery as the treatment option in TAAA [4]. This study was designed to assess the early and follow-up outcomes of H-EVAR.

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Patients and methods

Study patients

All consecutive patients who were treated by H-EVAR for TAAA between January 2010 and December 2018 at our institution were included in this study. Demographics; past medical history; cardiovascular risk profile; and preoperative, intraoperative, and postoperative details were recorded. The American Society of Anesthesiologists classification of physical status was used to define the risk for conventional aortic repair. All patients consented for clinical research, and the institutional review boards approved the study. The IRB of Mansoura University approved the study.

Preoperative image and planning

The method used to plan the H-EVAR was computed tomography angiography (CTA). A length of at least 2 cm of parallel aortic wall without thrombus or excessive calcification was required in the thoracic aorta for stent graft deployment. Visceral branches requiring incorporation were investigated for the presence of occlusive disease, unusual anatomy, and thrombus or excessive calcification. The quality of the inflow site was checked for the presence of occlusive disease. It was of great importance to ensure optimal inflow to the visceral grafts and to ensure enough length within the common iliac artery for attachment of the stent grafts.

Surgical approach and techniques

The technique of H-EVAR consisted of two treatment parts: the visceral debranching (stage 1) and the endovascular treatment (stage 2).

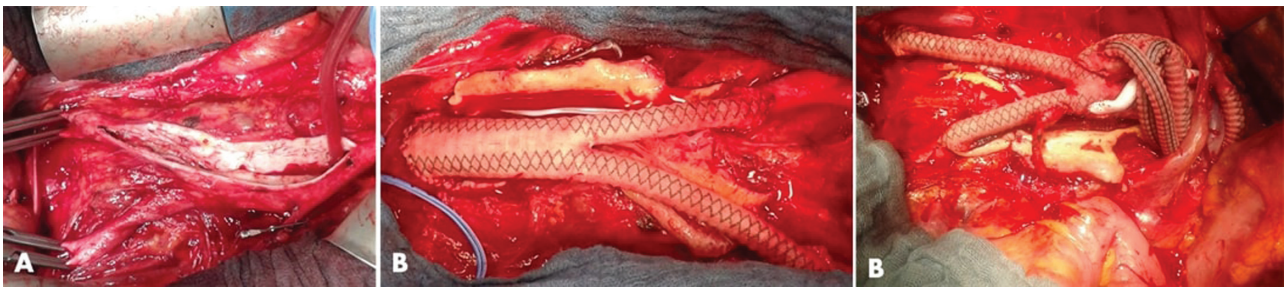
The stage 1 consisted of a surgical retrograde visceral and/or renal re-vascularization based on extra-anatomical bypasses to the renal arteries, the coeliac artery (CA), and the superior mesenteric artery (SMA) (Fig. 1). All the patients were operated under general anesthesia in a dedicated hybrid room. The abdominal aorta and the origins of the renal arteries, the CA, and SMA were exposed through transperitoneal approach in virgin abdomen and retroperitoneal approach in hostile abdomen. The choice of inflow site for the retrograde visceral arterial bypass was determined for each patient according to the previous aortic surgery and the extent of aneurysm. Either two inverted bifurcated Dacron grafts or a single bifurcated graft with extra side branches for the renal arteries was used. The limb to the coeliac axis was tunneled in front of the renal vein through the loose areolar tissue behind the pancreas, and the anastomosis was performed to the inferior aspect of the confluence between the hepatic and left gastric arteries. The graft to the SMA was placed in a 'lazy C' configuration. The grafts were then excluded in the retroperitoneum by primary closure or, if that was not possible, by use of an omental flap to prevent bowel adhesion and consequent problems. In all reconstructions, the grafted vessels were ligated proximally to prevent retrograde perfusion of the sac after endovascular exclusion of the aneurysm. Later in the study, a hybrid vascular graft (W.L. Gore and Associates, Flagstaff, Arizona, USA) was used based on surgeon discretion.

Stage 2 consisted of endovascular exclusion of the TAAA using commercial off-the-shelf stent-grafts (Fig. 2). Adjunctive left common carotid artery to left subclavian artery bypass to expand the proximal landing zone was done when a short proximal landing zone less than 2 cm was present.

Patients with genetic aortic syndrome typically were treated with infrarenal aortic replacement with a Dacron graft during the debranching procedure to land the stent grafts in a prosthetic material (Fig. 1b).

The follow-up protocol called for CTA and clinical assessment within 30 days after the completed procedure, 6 months, 12 months, and annually thereafter.

Figure 1



Visceral debranching (stage 1). (a) Transperitoneal approach show the aneurysm sac after opening it with proximal and distal control; (b) infrarenal aortic replacement with a Y Dacron graft; and (c) the bypass grafts to the coeliac artery, superior mesenteric artery, and renal arteries.

Figure 2

Exclusion of the aneurysm with stent graft (stage 2).

End points

The primary end point was early outcome (30 days) in terms of mortality, morbidity, and target vessel (TV) patency. The secondary end point was the follow-up outcomes in terms of late death, endoleak, and reintervention rates.

Results

Patient characteristics

Thirty-three patients (mean age 68±13, 48% males) were included. Eighteen (55%) patients were asymptomatic, whereas eight (24%) patients were symptomatic and seven (21%) patients had a contained rupture. The mean aneurysm diameter was 67±13 mm. The baseline demographics and comorbidities of the patients are listed in Table 1.

Procedural details

The visceral hybrid procedure (visceral bypass grafting +aortic stent-grafting) was successfully completed in 27 (82%).

Six (18%) patients died before the stage 2, including one patient died from aortic rupture, two from multiorgan failure, and three from septic shock. Table 2 illustrates the morbidities and characteristics of six patients who died between stage 1 and 2. Two of those patients presented to emergency room with ruptured aneurysm and three had symptomatic aneurysm. In addition, three patients had previous aortic replacement.

A spinal drain was used in 22 (67%) patients. Visceral graft bypass was done for 121 TVs. The CA was transpositioned to the SMA in four patients. The right renal artery (RRA) and left renal artery were occluded in three and four patients and not bypassed. The distribution of Dacron grafts vs. hybrid vascular grafts (W.L. Gore and Associates) for the different TVs is shown in Fig. 3. The origin of the bypasses was from the iliac vessels in 23 (70%), from an infra-renal aortic graft in three (9%), and iliac graft in seven (21%) patients. The proximal landing zone of the stent grafts was zone one in one patients, zone two in one patient, zone 3 in 14 patients, and zone 4 in 11 patients. In two patients, a left common carotid artery to left subclavian artery bypass was done. Table 3 illustrates the operative details. In one case with type B aortic dissection in a patient with Marfan syndrome, the true lumen was so compressed. The stage 1 was done as usual but the stent graft was deployed in the false lumen down to the iliac arteries with technical success (Fig. 4). The mean intensive care unit stay was 5±5 days. The mean hospital stay was 13±8 days.

Early mortality

The 30-day mortality in completed H-EVAR was 5/27 (19%) patients. The cause of death was aortic rupture in one, sudden cardiac arrest in one, major

Table 1 Demographics, clinical, and anatomical characteristics of 33 patients treated with hybrid visceral debranching endovascular aortic repair for thoracoabdominal aortic aneurysm

Number of patients	Overall *n*=33 (%) or mean±SD
Demographics	
Age (years old)	68±13
Male sex	16 (48)
Cardiovascular risk factors	
Active smoking	7 (21)
Hypertension	28 (84)
Hypercholesterolemia	17 (53)
Coronary artery disease	8 (24)
Myocardial infarction	7 (21)
CABG	5 (15)
COPD	7 (21)
Peripheral arterial disease	5 (15)
Genetic aortic syndrome	7 (21)
CKD stage III–IV	8 (24)
Diabetes mellitus	6 (18)
Congestive heart failure	12 (36)
Stroke/TIA	1 (3)
Prior aortic repair	
Open ascending or aortic arch or DTA	12 (36)
Open-AAA	4 (12)
EVAR	2 (6)
TEVAR	2 (6)
Previous abdominal surgery	10 (30)
Hostile abdomen	6 (18)
ASA score III–IV	23 (69)
Anatomical characteristics	
Max aortic diameter (mm)	67±13
Status of aneurysm	
Asymptomatic	18 (55)
Symptomatic	8 (24)
Controlled ruptured	7 (21)

AAA, abdominal aortic aneurysm; ASA, American society of anesthesia; CABG, coronary artery bypass graft; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; DTA, descending thoracic aorta; EVAR, endovascular aortic repair; TEVAR, thoracic endovascular aortic repair; TIA, transient ischemic attack.

stroke in one, and multiorgan failure in two patients. Table 4 illustrates the morbidities and characteristics of five patients who died in the first 30 days. Two of those patients presented to emergency room with ruptured aneurysm and three had symptomatic aneurysm.

Early morbidity

Five (15%) of 33 patients developed spinal cord ischemia (SCI). Four (12%) patients had transient para-paresis that improved before discharge and one (3%) had permanent paraplegia. Two (6%) of 33 patients had a stroke.

Four (12%) of 33 patients experienced respiratory failure; two of them required tracheostomy and two of them were weaned from the ventilation. Three (9%) patients developed pneumonia.

Four (12%) of 33 patients required dialysis postoperatively. Two of them were addressed to have preoperative chronic kidney disease stage III and IV. Four (12%) patients had mesenteric ischemia and two (6%) had partial ischemic colitis.

Early CTA for 33 patients showed 30-day overall primary TV patency of 92±3%. There were three celiac, three superior mesenteric, and two renal grafts occlusion. In all patients, early thrombectomy was done and patency regained.

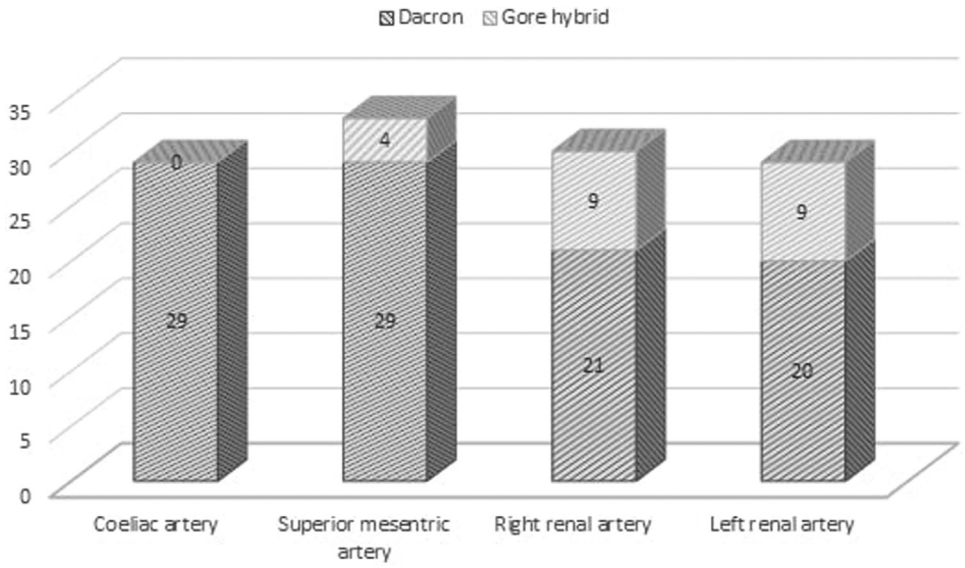
Early endoleak I rate was 3/27 (11%) and endoleak III rate was 2/27 (7%) patients (completed H-EVAR). Reinterventions for type III endoleaks were done through relining of the stent graft. Reintervention for type I endoleaks was done through stent-graft proximal extension in two patients and surgical

Table 2 Illustrations of the morbidities and characteristics of six patients died between stages 1 and 2

Patient no.	Age	Comorbidities	Previous surgery	ASA	Aneurysm diameter	Status of aneurysm	Cause of death
1	69	CHF, VF, MI, CABG, HTN, Smoking, COPD	None	4	70 mm	Symptomatic	MOF
2	79	CHF, CAD, HTN, GAS	Aortic root, aortic arch, DTA, AAA replacement	4	80 mm	Symptomatic	Aortic rupture
3	80	CHF, HTN, Smoking, COPD, CKD	None	4	60 mm	Ruptured	Septic shock
4	70	CHF, HTN, CAD	Aortic root, aortic arch, DTA, AAA replacement	4	65 mm	Asymptomatic	Septic shock
5	76	CAD, HTN, COPD	Hostile abdomen	4	57 mm	Symptomatic	Septic shock
6	34	HTN, COPD, GAS, CHF	Aortic root, aortic arch, DTA, AAA replacement	4	67 mm	Ruptured	MOF

AAA, abdominal aortic aneurysm; CABG, coronary artery bypass graft; CAD, coronary artery disease; CHF, congestive heart failure; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; DTA, descending thoracic aorta; GAS, genetic aortic syndrome; HTN, hypertension; MI, myocardial infarction; MOF, multiorgan failure; VF, ventricular fibrillation.

Figure 3



Distribution of graft type for the target visceral vessels.

Table 3 Illustrations of the morbidities and characteristics of five patients died in early 30-day after completed hybrid visceral debranching endovascular aortic repair

Patient no.	Age	Comorbidities	Previous surgery	ASA	Aneurysm diameter	Status of aneurysm	Cause of death
1	67	HTN, Smoking, COPD	Hostile abdomen	4	70 mm	Symptomatic	Major stroke
2	76	CHF, HTN, Smoking, COPD, CKD	DTA replacement	4	60 mm	Symptomatic	Cardiac arrest
3	71	HTN, MI, VF, COPD	Ascending aorta, aortic arch replacement	3	55 mm	Symptomatic	Aortic rupture
4	72	COPD, Smoking	AAA replacement	5	62 mm	Ruptured	MOF
5	53	HTN, CKD, PAD, CHF	aortic arch replacement	5	70 mm	Ruptured	MOF

AAA, abdominal aortic aneurysm; CHF, congestive heart failure; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; DTA, descending thoracic aorta; HTN, hypertension; MI, myocardial infarction; MOF, multi-organ failure; PAD, peripheral arterial disease; VF, ventricular fibrillation.

interposition iliac artery Dacron graft in one. Table 5 illustrates the early outcome.

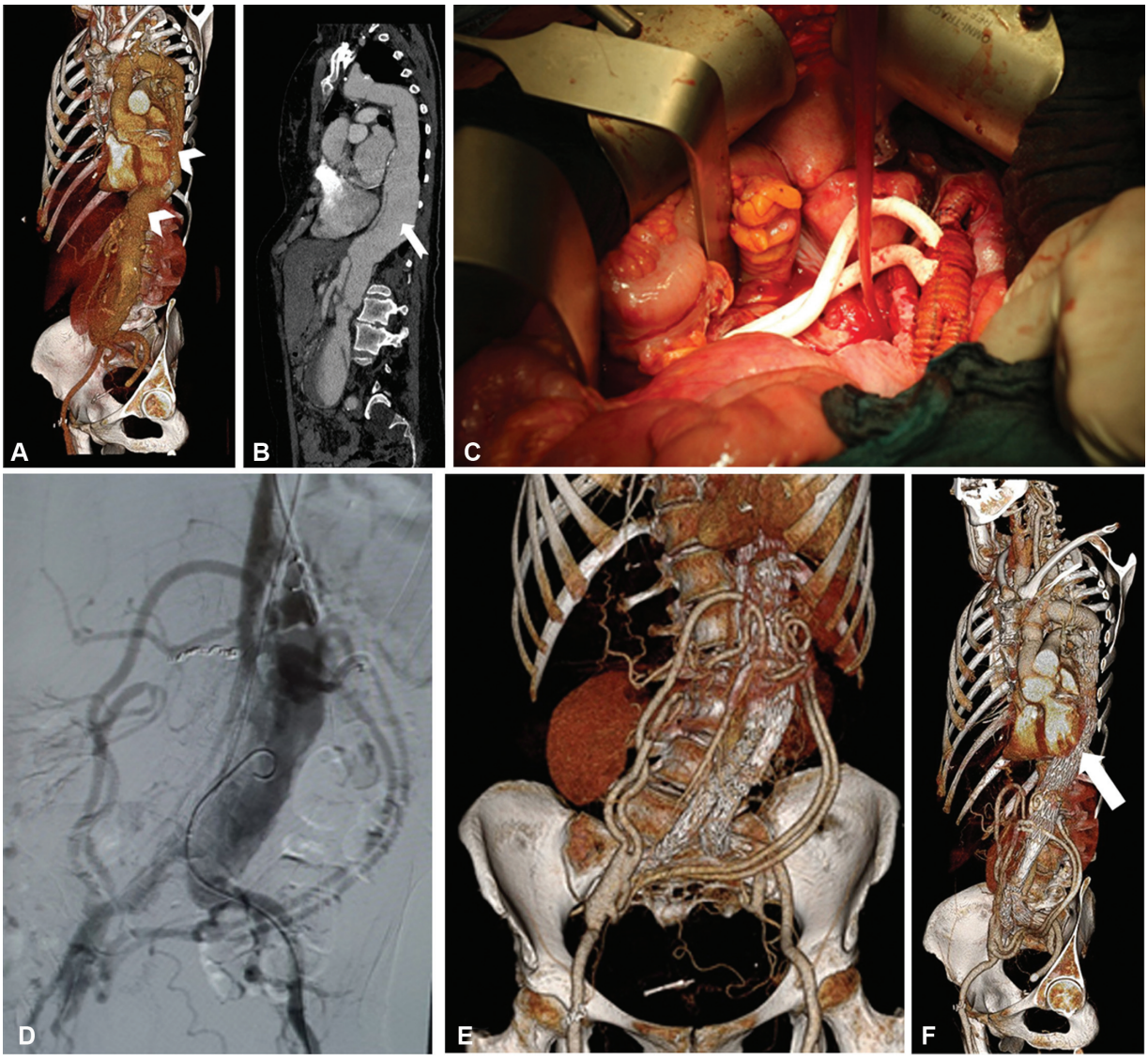
Follow-up outcome

The mean follow-up was 23±11 months for 22 patients who survived the completed H-EVAR. Figure 5 illustrates the effect of H-EVAR on decreasing the diameter of the aneurysm sac during follow-up. Late death occurred with 4/22 (18%) patients owing to stroke in one patient, aortic rupture in another patient, and multiorgan failure in two patients. Five (23%) patients developed late endoleak (type I in two patients and type II in three). Late occlusion of TV bypasses occurred nine times (three SMA, two CA, two RRA, and two left renal artery). All were treated by thrombectomy except for one limb to the RRA that was already attributed intraoperatively to have an unfavorable prognosis. Reintervention for type I endoleak occurred in two patients by proximal extension of the stent grafts, and for type II endoleak through embolization of the aneurysm sac in one patient.

Discussion

Outcomes of complete open surgery for TAAA are impressive in specialized centers with less than 10% mortality for open TAAA repair [5]. However, larger more representative databases show that the operative mortality in the USA averages 20–25% and is even higher in subsets such as older patients [6]. Coselli *et al.* [7] reported 3309 patients treated by open TAAA repair, with an operative mortality of 7.5% and spinal cord injury in 2.9%. Other reports from large-volume aortic centers have shown mortality rates in the range of 4.6–14.6% [8]. However, 'real-world' data using national and regional data sets have demonstrated more ominous results. In the study by Rigberg *et al.* [9] on 797 Medicare

Figure 4



(a) Preoperative computed tomography angiography (CTA) three-dimension reconstruction shows thoracoabdominal aortic aneurysm in chronic type B aortic dissection with compressed true lumen and expanded false lumen (white arrow heads) in Marfan syndrome patient; (b) CTA shows compressed true lumen and expanded false lumen (white arrow); (c) intraoperative image shows bypass graft for both renal arteries; (d) angiography image shows the patency of the inflow sites and the four visceral grafts at the initials of the second stage; (e, f) postoperative CTA three-dimension reconstruction shows exclusion of the aneurysm through deployment of the stent-graft in the false lumen with patency of the four target vessels and their grafts.

beneficiaries who underwent elective open TAAA repair in California, the mortality was 19% at 30 days and 31% in 1 year.

The introduction of total endovascular repair for TAAA reduces the perioperative mortality and morbidity. However, many limitations render this type of treatment such as the learning curve, and experience is still limited to a few dedicated centers worldwide [10,11]. Moreover, it is not always feasible because of restrictive anatomic factors, such as multiple renal arteries of small diameter, severe angulation of the aorta at the level of the renovisceral vessels, or the presence of a genetic aortic syndrome [11].

H-EVAR represents an alternative that allows repair of the aorta without requiring complex endovascular skills while avoiding cross-clamping of the aorta and thoracotomy. Although few centers initially presented satisfactory results with this technique [12], multiple multicenter and single-center series demonstrated high rates of mortality and morbidity with the hybrid procedure, which might be owing to restricted number of patients in each center [1,13].

In the current study, the early mortality rate in completed H-EVAR was 19%. SCI rate was 15% and post-operative dialysis rate was 12%. Early endoleak I rate was 11% and endoleak III rate was 7%. The early TVs patency rate was 92±3%.

The overall early mortality rate is high (33%) including the cases that died before the stage 2. However, it was related to the urgency and high morbidities of the patients, as described in Tables 2 and 3. The range of early mortality in single-center studies was different between studies: 38% in Resch *et al.* [14], 31% in Van de Mortel *et al.* [15], 44% in Da Rocha *et al.* [16], and 24% in Lin *et al.* [17].

The SCI ranged in H-EVAR between 2 and 25% [14–19]. Four of five SCI cases in this cohort were para-paresis and improved with treatment. Old age and renal dysfunction were identified as independent risk factors for SCI postoperatively. In this series, the mean age was 68±13 years old, and 24% of patients had chronic kidney disease stage III–IV. Despite the risk profile of this cohort, the rate of SCI is still acceptable and that rigorous neurologic assessment by third party neurologists may explain the relatively high rate.

The rates of type I endoleak have been reported in the range of 3–15% and type II endoleak in the range of 5–25% [14–19]. The relatively high early bypass graft failure in this study may be hypothesized to the presence of atherosclerosis and calcified vessels. In addition, some of the cases were patients with genetic aortic syndrome, who are known to be at high risk for vessel dissection during the procedures. These occluded bypass graft had its effect on the worse outcome of H-EVAR.

Two recent meta-analysis evaluated the outcome of H-EVAR. Bakoyiannis *et al.* [20] published the outcomes of 108 patients from 15 reports between the period of 1999 and 2008. The early mortality was 10%. SCI occurred in three (3%) patients and renal insufficiency in 12 (11%). A total of 19 (17%) patients had early endoleaks. Another review by Moulakakis *et al.* [4] involved 507 patients and 19 reports that have been published since 1999. The early mortality was 13%. Pooled rates of SCI were 7.5%.

Table 4 Procedural details in 33 patients treated with hybrid visceral debranching endovascular aortic repair for thoracoabdominal aortic aneurysm

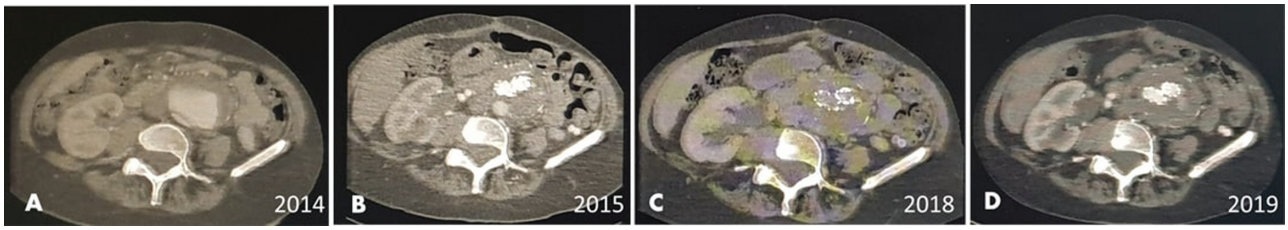
Variables	*N*=33 [*n* (%)]
Spinal drain	22 (67)
TVs	132
Visceral bypasses	121 (92)
Transposition of CA over SMA	4 (3)
Occluded RRA/LRA	3 (2)/4(3)
Proximal anastomosis	
Iliac artery	23 (70)
Iliac graft	7 (21)
Infrarenal aortic graft	3 (9)
Proximal landing zone	
Zone 1	1 (3)
Zone 2	1 (3)
Zone 3	14 (42)
Zone 4	11 (33)
Left CCA-LSA bypass	2 (6)

CA, coeliac artery; CCA, common carotid artery; LRA, left renal artery; LSA, left subclavian artery; RRA, right renal artery; SMA, superior mesenteric artery; TVs, targeted vessels.

Table 5 30 days outcome

Variables	*N*=33 [*n* (%)]
Death	11 (33)
Before second stage	6 (18)
After completed procedure	5 (15)
Morbidities	
Stroke	2 (6)
Spinal cord ischemia	5 (15)
1–2 (para-paresis)	4 (12)
3a–c (paraplegia)	1 (3)
Any pulmonary complication	
Pneumonia	3 (9)
Respiratory failure	4 (12)
Tracheostomy	2 (9)
Postoperative dialysis	4 (12)
Ischemic colitis	2 (6)
Mesenteric ischemia	4 (12)
ICU stay (days)	5±5
Postoperative hospital stay (days)	13±8

Figure 5



(a) Preoperative computed tomography angiography (CTA); (b, c and d) postoperative CTA shows the remodeling and decrease in the aneurysm sac over years.

Bakoyiannis *et al*. [20] in their review reported 3% TVs occlusion and 24% deaths after 10 months of follow-up. After a mean follow-up of 35 months, Moulakakis and colleagues reported 22% endoleak and 4% TVs occlusion rates [4].

The preliminary results of North American Complex Abdominal Aortic Debranching registry that included 208 patients reported an endoleak in 23 (13%) patients and late visceral graft occlusion in 8% after a median follow-up of 21 months [21]. In the current study, the mean follow-up was 23±11 months for 22 patients who survived the completed H-EVAR. We had 23% endoleak, 18% death, and 7% TVs occlusion rates.

Conflicting outcomes of H-EVAR for TAAA treatment led to criticism and ambiguity of this approach, despite initial enthusiasm, and because of small sample and the high risk profile of the patients, it is difficult to judge the hybrid strategy with advantage over the open surgical repair, and it is the same condition for most authors who have explored differences between open and either fenestrated/branched-EVAR or hybrid EVAR, but none have examined all three techniques simultaneously, which defines a unique distinction and contribution of this work [22,23].

The main limitations of this study were the small number of patients and non-comparative group inclusion. However, our findings are consistent with the reported international experience of centers selectively performing H-EVAR.

In our opinion, the open, hybrid, and total endovascular strategies should be viewed as complementary techniques, and all three will likely continue to have a role in selected patients in the future.

Conclusion

Hybrid EVAR had several advantages that included avoiding thoracotomy, aortic cross-clamping, and single-lung ventilation, as well as avoiding the need for extensive dissection in multiple aortic segments. However, the controversial outcomes led to critism, and there is a need to examine the three techniques (open, hybrid, and total endovascular) simultaneously, which gives a unique definition of the selection criteria to achieve the optimum results in each patient.

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Nil.

Conflicts of interest
There are no conflicts of interest.

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