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Original Article

Open extent IV thoracoabdominal aneurysm repair: 22-year experience of the Scottish National Service

Rachael O. Forsythe, Calvin Eng, Chloe Roy, John Cafferkey, Darja Clinch, Nicholas Ventham, Andrew L. Tambyraja, Phillipa J. Burns, Orwa Falah* and Roderick T. A. Chalmers

Scottish National Service for Thoracoabdominal Aneurysms, Royal Infirmary of Edinburgh, Edinburgh, UK

*Correspondence to: Orwa Falah, Scottish National Service for Thoracoabdominal Aneurysms, Royal Infirmary of Edinburgh, Edinburgh EH16 4SA, UK (e-mail: orwa.falah@nhslothian.scot.nhs.uk)

Abstract

Background: Since 1999, the Scottish National Service for Thoracoabdominal Aneurysms has offered repair of thoracoabdominal aneurysms (TAAAs) to a population of 5.5 million people. The open operation most commonly performed by the service is the extent IV TAAA repair.

Methods: All extent IV open TAAA repairs performed at the Scottish National Service for TAAAs from June 1999 until April 2021 were evaluated for clinical features, technical details, and clinical outcomes. The primary outcome measure was 30-day mortality; secondary outcomes included short-term (90 days, 6 months, 1 and 2 years) and long-term (5 and 10 years) survival, perioperative complications, and reintervention. Survival was assessed using Kaplan–Meier analysis.

Results: Some 248 patients underwent extent IV TAAA repair, with elective surgery in 204 (82.3 per cent). A totally abdominal transperitoneal approach was used for all patients, with a median visceral ischaemia time of 40 (i.q.r. 35–48) min. Overall, 18 patients (7.3 per cent) died within 30 days. The proportion of patients surviving at 90 days, 6 months, 1, 2, 5, and 10 years was 0.91, 0.90, 0.89, 0.85, 0.72, and 0.41, respectively. Ten patients (4.0 per cent) required a reintervention while in hospital, four (1.6 per cent) experienced permanent spinal cord ischaemia, 19 (7.9 per cent) required temporary renal replacement therapy (RRT), and four (1.6 per cent) required permanent RRT.

Conclusion: Open extent IV TAAA repair performed in a high-volume national centre is associated with favourable short- and long-term survival, and acceptable complication rates.

Introduction

There has been an increase in the use of endovascular techniques in the approach to Crawford extent IV thoracoabdominal aneurysm (TAAA) repair over the past decade. This minimally invasive therapy is associated with higher rates of reintervention, cost, and concerns about durability compared with open surgical repair. Furthermore, some patients are anatomically unsuitable for endovascular intervention.

In 1999, the Scottish National Service for TAAAs was established at the Royal Infirmary of Edinburgh, and currently offers open, endovascular, and hybrid repair for all types of TAAA, serving Scotland's population of almost 5.5 million people. The open operation most commonly performed by the service is the extent IV TAAA repair, carried out via a totally abdominal transperitoneal approach. The aim of this study was to describe the clinical outcomes of open type IV TAAA repair in this national tertiary referral centre over the past 22 years.

Methods

Population and data collection

The database of the Scottish National Service for TAAAs was reviewed retrospectively. Consecutive patients undergoing open Crawford extent IV TAAA repair were studied. Patients with a type IV TAAA (defined according to the Crawford classification as involving the aorta at the level of the diaphragm extending distally to include the coeliac, superior mesenteric and renal arteries, and the infrarenal aorta), or those requiring a type IV approach for a suprarenal aneurysm, with an anteroposterior diameter over 5.5 cm, rapid aneurysm expansion (more than 0.5 cm in 6 months), or a symptomatic aneurysm (abdominal or back pain with no other obvious cause with or without radiological evidence of aneurysm rupture) were included.

Follow-up data were collected retrospectively from hospital records. Information about death and cause of death was obtained from hospital records and the Scottish Statutory Register of Deaths.

Primary and secondary outcomes

The primary outcome was 30-day mortality. Secondary outcomes included short-term survival (at 90 days, 6 months, 1 year, 2 years), long-term survival (at 5 years, 10 years), perioperative complications, and reintervention. Perioperative complications were subdivided into cardiac (including myocardial infarction, arrhythmia requiring treatment, pulmonary oedema or cardiac arrest), respiratory (lower respiratory tract infection requiring

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antibiotics, reintubation, prolonged postoperative ventilation for more than 48 h), neurological (temporary or permanent signs of spinal cord ischaemia), renal (temporary or permanent renal replacement therapy), and other. Reintervention was defined as any operative procedure required as a direct consequence of the aneurysm repair and performed during the follow-up.

Preoperative assessment

All patients undergoing elective intervention underwent a comprehensive preoperative evaluation of cardiorespiratory fitness and subsequent multidisciplinary team (MDT) discussion. Preoperative evaluation evolved over the years. From 1999 to 2011, it included CT angiography (CTA), exercise electrocardiography or stress echocardiography, and pulmonary function tests. If deemed high risk, patients underwent further testing with coronary CTA or catheter angiography. More recently (from 2011 to the present day), the preoperative assessment protocol has included cardiopulmonary exercise testing for all patients unless contraindicated (*Fig. 1*). In the event of symptomatic aneurysms, it was not possible to perform a full preoperative cardiopulmonary assessment, but patients underwent pulmonary function tests and echocardiography, where possible.

Operative approach

A standard technique was used for all patients. Using a totally abdominal transperitoneal approach under general and epidural anaesthesia, all patients underwent laparotomy via a rooftop incision, with left-sided medial visceral rotation to allow exposure from the supracoeliac aorta to the aortic bifurcation, requiring partial division of the left crus of the diaphragm. A supracoeliac clamp was used in all patients. Moderate passive hypothermia was achieved (32–34°C) during the period of visceral ischaemia and a clamp-and-sew technique was used, incorporating the visceral ostia into a Dacron® (Du Pont, Wilmington, Delaware, USA) graft, using a bevelled anastomosis. If required, jump grafts were used for any anatomically outlying arteries (most commonly a low-lying left renal artery). The decision on whether to use a jump graft was usually made during the operation, based on anatomical findings. Renal or visceral protection adjuncts were not used routinely; no local cooling of the organs or perfusion of drugs or fluids directly into the arteries was used.

Rewarming was initiated on completion of the proximal anastomosis and reperfusion of the visceral arteries. Invasive monitoring was used throughout the procedure (pulmonary artery catheterization and gastric tonometry until 2013; now replaced by transoesophageal echocardiography), with use of cell salvage and rapid warmed blood transfusion for all patients. Near-patient testing of arterial blood gases, levels of lactate, glucose, haemoglobin, and electrolytes, and coagulation (using ROTEM® thromboelastometry, Pentapharm, Munich, Germany) were used to allow frequent intraoperative evaluation and correction of these parameters. Neither spinal drainage nor left heart bypass was used routinely in this group of patients.

Most patients were extubated in the operating theatre and further care was provided in the high-dependency unit; patients were managed initially in the ICU if immediate extubation was not possible. Owing to the potential breach of the pleura as a result of partial division of the left crus of the diaphragm, all patients underwent insertion of a left-sided intercostal chest drain before extubation.

All patients received intraoperative systemic heparin (except in the event of rupture, when heparin was given at the discretion of the operating surgeon), mannitol before aortic clamping, and postoperative prophylaxis against venous thromboembolism using low molecular weight or unfractionated heparin.

Statistical analysis

Summary demographic data are presented as median (i.q.r.), depending on the spread of data. Estimated survival rates are shown using Kaplan–Meier survival curves; data were censored at death

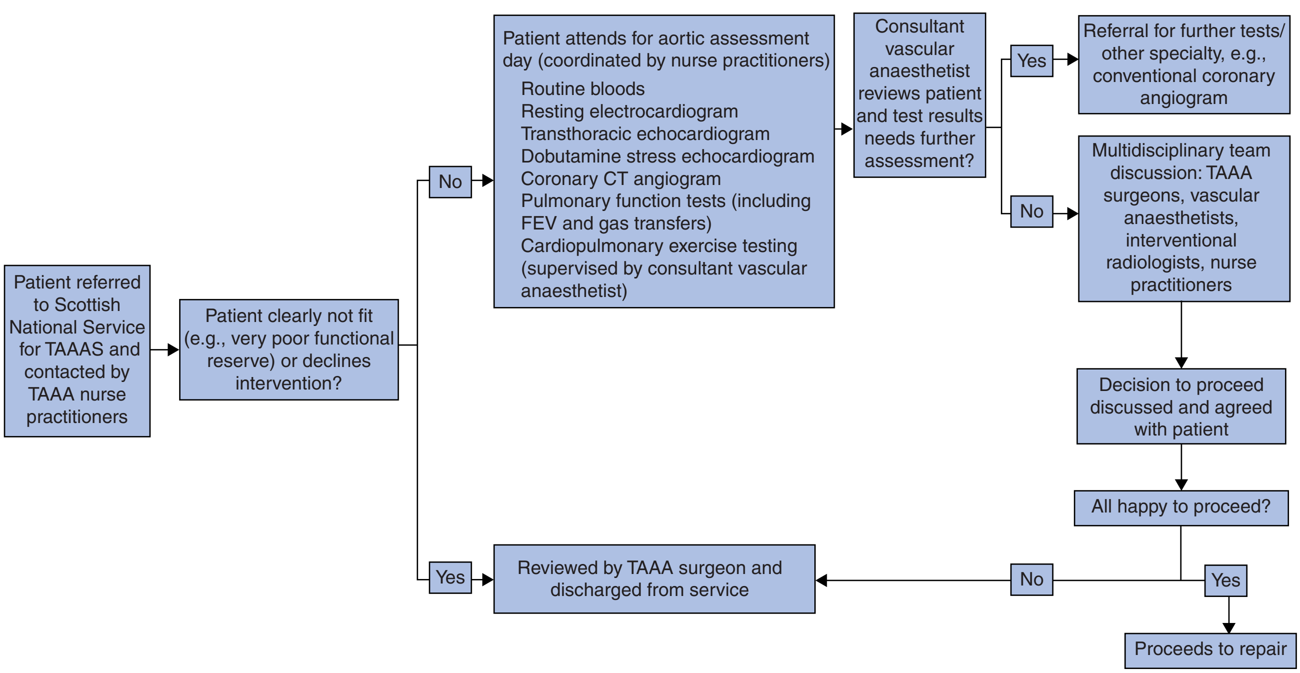

Fig. 1 Current preoperative assessment schematic for patients with type IV thoracoabdominal aortic aneurysm referred to the Scottish National Service for Thoracoabdominal Aneurysms

TAAA, thoracoabdominal aortic aneurysm; FEV, forced expiratory volume.

or end of follow up for the primary outcome (6 June 2021). Other outcomes are summarized as percentages. Data were analysed in using SPSS® version 25 (IBM, Armonk, NY, USA).

Results

Data were available for 248 open extent IV TAAA repairs performed at this centre between June 1999 and April 2021 (*Table 1*). The majority of operations (204, 82.3 per cent) were performed electively for asymptomatic TAAA; 17.7 per cent were undertaken urgently for symptomatic TAAA or contained rupture (including only those stable enough to undergo urgent repair within 24 h). Eleven patients (4.4 per cent) had a history of previous abdominal aortic aneurysm (AAA) repair; seven underwent open repair (2.8 per cent) and four (1.6 per cent) endovascular aneurysm repair (EVAR).

The median aneurysm diameter was 6.3 (i.q.r. 5.9–7.4) cm; 23 aneurysms (9.3 per cent) were considered inflammatory in nature on the basis of clinical and radiological findings. The median visceral ischaemia time was 40 (35–48) min and 22 patients (8.9 per cent) required concurrent splenectomy.

The median duration of stay in the critical care unit was 4 (3–7) days, and the median length of stay in hospital was 11 (8–16) days.

Primary outcome: 30-day mortality

Overall, 18 patients (7.3 per cent) died in hospital within 30 days of surgery, most commonly from multiple organ failure (9 patients). Other reasons for death within 30 days included disseminated intravascular coagulation, septic shock, anoxic brain injury, cardiac arrest due to fatal arrhythmia, and acute myocardial infarction.

Secondary outcomes: survival

Median survival was 102 (i.q.r. 51–173) months. With regard to short-term survival, the estimated cumulative proportion surviving at 90 days, 6 months, 1 year, and 2 years was 0.91, 0.90, 0.89, and 0.85 respectively. The estimated cumulative proportion

Table 1 Demographic details

	No. of patients* ($n = 248$)
Age (years)†	70.0 (65–74)
Men	194 (78.2)
BMI (kg/m²)†	26.5 (24.0–30.0)
Ischaemic heart disease	91 (36.7)
Previous myocardial infarction	59 (23.8)
Coronary artery bypass graft	34 (13.7)
Previous percutaneous intervention	25 (10.1)
Hypertension	180 (72.6)
Chronic obstructive pulmonary disease	60 (24.2)
Diabetes mellitus	34 (13.7)
Symptomatic peripheral artery disease	44 (17.7)
Cerebrovascular disease	45 (18.1)
Current or previous smoker	211 (85.1)
Preoperative assessment	
Left ventricular systolic function‡	
Good	171 (69.0)
Mild impairment	38 (15.3)
Moderate impairment	11 (4.8)
Not done/unknown	28 (11.1)
Positive dobutamine stress echo	33 (13.3)
FEV1 (% predicted)†	90.5 (77.0–103.0)
FVC (% predicted)†	105.0 (93.0–116.0)
FEV1/FVC†	68.9 (61.3–74.3)
Preoperative medications	
Antiplatelet	190 (76.6)
Warfarin	11 (4.4)
Statin	193 (77.8)
Beta-blocker	118 (47.6)
ACE inhibitor	111 (44.8)
Other antihypertensive	124 (50.0)
Aneurysm features	
Diameter (cm)†	6.3 (5.9–7.4)
Degenerative	220 (88.7)
Inflammatory	23 (9.3)
Mycotic	4 (1.6)
Connective tissue disorder	1 (0.4)

*With percentages in parentheses unless indicated otherwise; †values are median (i.q.r.). ‡Good: ejection fraction above 55 per cent; mild impairment: ejection fraction 40–55 per cent; moderate impairment: ejection fraction 30–39 per cent; severe impairment: ejection fraction below 30 per cent. FEV1, forced expiratory volume in 1 s; FVC, forced vital capacity.

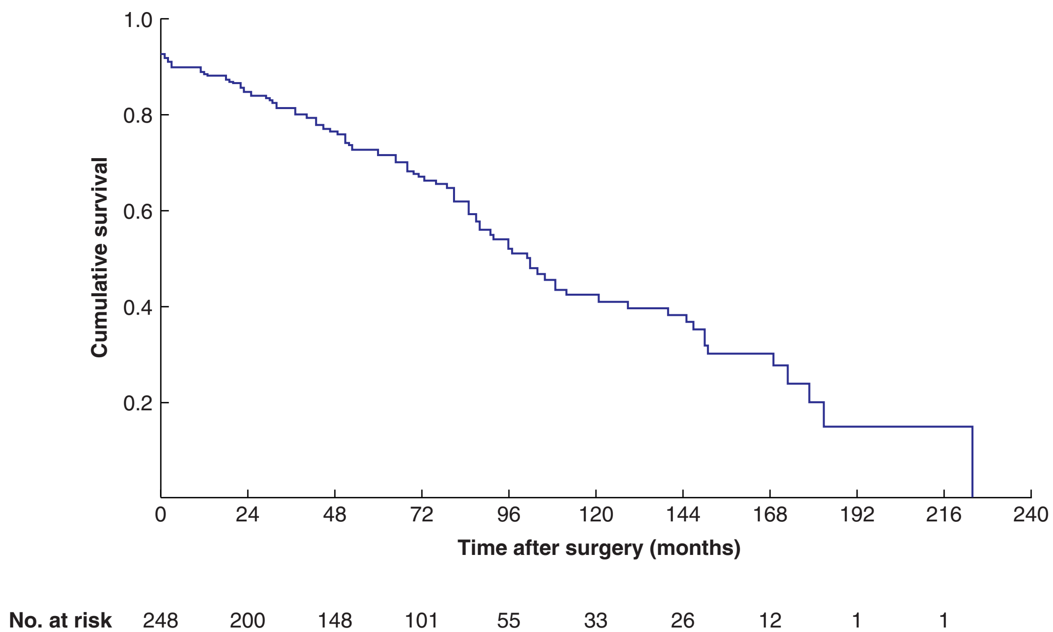

Fig. 2 Kaplan–Meier survival curve illustrating cumulative survival after open type IV thoracoabdominal aortic aneurysm repair

Patients were censored at death or end of follow-up (6 June 2021).

surviving was 0.72 at 5 years; by 10 years, it had reduced to 0.41 (Fig. 2).

Following discharge from hospital, there were seven aneurysm-related deaths (2.8 per cent): two patients (0.8 per cent) died from graft infection, and five (2.0 per cent) from rupture of the aorta proximal to the previous repair at a median of 37 (range 3–179) months after the initial operation. Twenty-one patients (8.5 per cent) died from other cardiovascular causes, 14 (5.6 per cent) from lung cancer, and 11 (4.4 per cent) as a result of other malignancy.

Table 2 Operative details and in-hospital complications

	No. of patients* ($n = 248$)
Technical/perioperative details	
Tube graft	135 (54.4)
Renal jump graft	31 (12.5)
Splenectomy	22 (8.9)
Visceral ischaemia time (min)†	40 (35–48)
In-hospital complications	
Neurological	
Paralysis/paraplegia—temporary	5 (2.0)
Paralysis/paraplegia—permanent	4 (1.6)
Cardiac	31 (12.5)
Myocardial infarction	17 (6.9)
Cardiac arrest	10 (4.0)
Pulmonary oedema	12 (4.8)
New arrhythmia	21 (8.5)
Respiratory	92 (37.1)
Lower respiratory tract infection	89 (35.9)
Ventilated for > 48 h after surgery	19 (7.7)
Reintubation	18 (7.3)
Cerebrovascular	
Transient ischaemic attack/stroke	5 (2.0)
Renal	23 (9.3)
Preoperative creatinine (μmol/l)†	91.0 (75.0–111.0)
Peak creatinine rise (% increase from baseline)†	43.3 (15.9–150.0)
Creatinine rise on discharge (% increase from baseline)†	1.1 (−16.4 to 23.9)
Renal replacement therapy—temporary	19 (7.9)
Renal replacement therapy—permanent	4 (1.6)
Other	18 (7.3)
Bowel ischaemia	6 (2.4)
Acute limb ischaemia	3 (1.2)
Upper gastrointestinal bleed	5 (2.0)
Reintervention (in hospital)	10 (4.0)
Laparotomy for suspected bowel/visceral ischaemia	6 (2.4)
Embolectomy for acute limb ischaemia	2 (0.8)
Endoscopy for gastrointestinal bleeding	1 (0.4)
Insertion of feeding tube	1 (0.4)
Death within 30 days	18 (7.3)

*With percentages in parentheses unless indicated otherwise; †values are median (i.q.r.).

Secondary outcomes: complications and reinterventions

Six patients (2.4 per cent) underwent laparotomy for suspected bowel or visceral ischaemia in the early postoperative phase, of whom four required bowel resection (Table 2). Of the 31 patients (12.5 per cent) who experienced a cardiac complication in the postoperative phase, three died as a direct result: one patient died from cardiogenic shock on postoperative day 4, one had a large fatal myocardial infarction on postoperative day 5, and one had a cardiac arrest on postoperative day 9. Lower respiratory tract infection was a common postoperative complication, occurring in 89 patients (35.9 per cent); however, no patient died from respiratory complications within 30 days. Five patients (2.0 per cent) exhibited temporary signs of spinal cord ischaemia, which resolved after instigation of a combination of the following treatments: maintaining adequate oxygenation, maintaining an adequate haemoglobin level, increasing the mean arterial pressure, and/or inserting a spinal drain. Four patients (1.6 per cent) experienced permanent paralysis or paraplegia.

The median postoperative peak creatinine rise was 43.3 (i.q.r. 15.9–150.0) per cent higher than baseline, but this resolved in the majority of patients, and the median creatinine level on discharge was only 1.1 (−16.4 to 23.9) per cent higher than at baseline. Although 19 patients (7.9 per cent) required temporary renal replacement therapy while in hospital, only four (1.6 per cent) required permanent renal replacement therapy after discharge.

Following discharge from hospital, four patients (1.6 per cent) required reintervention to treat wound complications: drainage of seroma in one patient, washout of a groin wound in one patient, and percutaneous drainage of infected haematoma in two patients. Two patients required repair of an incisional hernia and one underwent renal artery angioplasty.

Table 3 Scottish National Service for Thoracoabdominal Aneurysms multidisciplinary team outcomes from 2014 to 2020 to illustrate contemporaneous turn-down rates

Year	No. of patients discussed	Outcome of MDT discussion				
		Ongoing surveillance	Surgery	Unfit	Patient declined	Other
2014	35	7	20	5	1	Below threshold 1 Died before assessment complete 1
2015	40	5	23	9	0	Died on day before surgery 1 Below threshold 1 Died before assessment complete 1
2016	35	3	24	7	0	Referred to other specialty 1
2017	25	3	16	6	0	0
2018	32	4	21	3	0	Required treatment for other pathology 2 Died after assessment but before planned surgery 1 Died before assessment complete 1
2019	24	2	11	7	1	Required treatment for further pathology 3
2020	28	6	9	10	1	Below threshold 1 Treatment delayed for other reason 1

MDT, multidisciplinary team.

Table 4 Case series presenting outcomes of open extent IV thoracoabdominal aneurysm

Reference	Year	Country	No. of patients	Operative mortality (%)	Survival % (± Standard Error)	Spinal cord deficit (%)	Renal replacement therapy (%)
Coselli et al.[1]	2016	USA	669	Within 30 days: 3.4 In hospital: 5.1	n.p.	Temporary: 1.8 Permanent: 2.4	Temporary: 1.8 Permanent: 5.8
Patel et al.[2]	2011	USA	179	In hospital: 2.8	1 year: 89 (± 2) 5 years: 62 (± 4) 10 years: 36 (± 5)	2.2	Haemodialysis-dependent: 2.8
Kieffer et al.[3]	2008	France	171	Within 30 days: 11.7 In hospital: 13.4	n.p.	4.7	n.p.
Bicknell et al.[4]	2003	UK	130	Within 30 days: 16.9 In hospital: 20	n.p.	Temporary: 3.8	Temporary: 15.4
Cinà et al.[5]	2002	Canada	52	In hospital: 3.8	n.p.	1.9	Temporary: 7.7 Permanent: 3.8
Schepens et al.[6]	2004	Netherlands	42	In hospital: 7.1	n.p.	4.8	6.1
Greenberg et al.[7]	2008	USA	64	Within 30 days: 6	1 year: 22	2	n.p.

n.p., Not presented.

Turn-down data

Data on the number of patients assessed with extent IV aneurysms by the service was incomplete for the whole study interval. In the last 7 years, some 219 patients were referred to the service and discussed by the MDT, of whom 124 (56.6 per cent) proceeded to intervention (*Table 3*).

Discussion

This study reports a 22-year series of open Crawford extent IV TAAA repairs by the Scottish National Service for TAAAs, from the introduction of the TAAA service in 1999 to the present day. The service now offers all types of repair for TAAA, including complex endovascular repair. Although the historical preference has been for open repair, some 13 complex endovascular repairs for extent IV TAAAs have bene undertaken since 2017.

Data on open extent IV TAAA repair are relatively sparse in the literature and outcomes are often reported in combination with more extensive types of TAAA, leaving a paucity of comparable case series (*Table 4*). Published early mortality rates vary between 2.8 and 20 per cent[1–7]; data from the present study fall well within these parameters. In the UK National Vascular Registry 2020 Annual Report[8], the in-hospital mortality rate for complex open AAA repair (including juxtarenal and suprarenal AAAs) was 14 per cent.

Although there are proponents of an endovascular-first strategy for TAAA, there are no randomized trials of open *versus* endovascular repair for patients with type IV TAAA to support this practice. Direct comparison of observational data with outcomes of complex endovascular repair can be hampered by the heterogeneity of aneurysm morphology often included in endovascular case series and a failure to adjust for case mix. One non-randomized comparative study[9] compared 30-day outcomes and costs for patients undergoing fenestrated or branched (f/b) EVAR (using prospective data from the WINDOW registry) matched with patients undergoing open surgery (using data extracted from the French national hospital discharge database). In a subgroup analysis of patients with infradiaphragmatic TAAA, 42 patients who underwent f/b EVAR were compared with 225 who underwent open repair, and increases in 30-day mortality rate (11.9 *versus* 4.0 per cent; $P = 0.010$) and cost (€37 927 *versus* 17 530; $P = 0.18$) were noted in patients who underwent f/b EVAR. In another propensity-matched study[10] of f/b EVAR and open repair for pararenal and paravisceral aneurysms (including patients requiring a supracoeliac clamp), the authors found no difference in 30-day mortality, organ-specific complications or dialysis, with the exception of a higher rate of postoperative acute kidney injury in the open surgery group, although this almost always resolved before discharge from hospital.

In a cohort of patients with type IV TAAA treated at the Cleveland Clinic between 2001 and 2006, Greenberg and colleagues[7] reported no difference in open (64 patients) *versus* endovascular (69) repair in terms of spinal cord ischaemia or mortality at 30 days (spinal cord ischaemia 2 *versus* 3 per cent; estimated 30-day mortality 6 *versus* 4 per cent). However, the estimated 1-year mortality rate for open repair was surprisingly high at 22 per cent.

Finally, in a large registry study[11] from the USA comparing open repair (1091 patients) *versus* f/b EVAR (264) for complex AAA (including those involving the visceral aorta), the authors reported improved 30-day mortality and morbidity with f/b EVAR compared with open repair. However, the study was limited by a high risk of bias, with no data presented on the anatomical complexity of the aneurysms in either group, and controlled for only a limited number of co-morbidities.

When considering endovascular aortic repair as an alternative to open surgery, the greatest concern is that of poor durability, with reintervention rates highest following complex endovascular repair. A retrospective database review[12] of endovascular management of extent IV TAAA in high-risk patients demonstrated a 30-day mortality rate of 2.6 per cent, with 27 per cent requiring a secondary intervention within 24 months and an overall estimated 24-month survival rate of 83 per cent. Other contemporary data suggest an estimated 5-year rate of freedom from reintervention of 50–60 per cent for fenestrated EVAR for juxtarenal aneurysms[13,14]. In comparison, the data here and those of others[1,2] have shown open type IV TAAA to be a durable solution, associated with acceptable reintervention rates and long-term survival.

This is the largest reported series of open extent IV TAAA repair in the UK to date. A study[4] of 130 patients undergoing open extent IV TAAA repair in St Mary's Hospital, London, UK, was published in 2003, and reported comparable rates of spinal cord ischaemia and renal dysfunction. The previous report[15] from the authors' centre is superseded by the present data; however, outcomes remain consistent, if not improved.

Open type IV TAAA repair is undertaken in few hospitals in the UK. There are ample data to support the management of AAA in high-volume centres, even more so those affecting the thoracic and thoracoabdominal aorta[16]. It is clear that such operations should take place only in centres with high hospital and surgeon volumes, given that lower-volume hospitals and surgeons are associated with significantly higher mortality rates[17,18]. Having demonstrated outcomes comparable to those of larger case series in the USA, the authors believe that the ongoing centralization of open type IV TAAA repair in a high-volume centre such as theirs (which can offer the full range of endovascular and open solutions) is justified.

The limitations of this study are acknowledged. The retrospective nature of data collection inevitably leads to incomplete records, but the use of national death registry data captured the most accurate mortality data available in order to satisfy the primary outcome measure. Unfortunately, the cause of some of the most recent deaths is listed as unknown, as the national records have not released full death certificates at this time owing to a backlog of data upload during the COVID-19 pandemic. In addition, the use of autopsy in the UK is low and the certified cause of death may not be correct for all patients. Although the centre accepts referrals from all over Scotland for consideration of open or endovascular repair of TAAA, these data may not reflect the total burden of patients with extent IV TAAA.

A robust RCT would go some way towards informing practitioners as to the most appropriate intervention for patients with extent IV TAAA. However, one important limitation is that few centres currently provide both endovascular and open options for these patients and the question of clinical equipoise is debatable. The UK Complex Aneurysm Study (UK-COMPASS) is currently recruiting patients with juxtarenal aortic aneurysms to a study comparing open surgery, endovascular techniques, and medical management in a risk-adjusted and anatomically stratified cohort. The results of this important study are awaited (NIHR 15/153/02).

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