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Editor's Choice — Hospital Incidence, Treatment, and In Hospital Mortality Following Open and Endovascular Surgery for Thoraco-abdominal Aortic Aneurysms in Germany from 2005 to 2014: Secondary Data Analysis of the Nationwide German DRG Microdata

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WHAT THIS PAPER ADDS

Hospital incidence, treatment modality and mortality after surgery for thoraco-abdominal aortic aneurysms (TAAAs) by endovascular or open means on a nationwide level are reported. This analysis reveals that 76% of TAAAs were treated endovascularly in 2014 with increasing frequency over a decade. The in hospital mortality is lower when endovascular repair is performed. High annual caseload is significantly associated with decreased in hospital mortality. Rupture, age, and severe comorbidities are associated with worse outcomes.

Objective: Hospital incidence, treatment modality, and in hospital mortality after surgery are reported for thoraco-abdominal aortic aneurysms (TAAAs) treated by endovascular or open means in Germany from 2005 to 2014.

Methods: Data were extracted from diagnosis related group statistics from the German Federal Statistical Office. All inpatient cases with a diagnosis of ruptured and non-ruptured TAAA (ICD-10 I71.5 and I71.6) and procedure codes for fenestrated or branched endovascular aortic repair (f/bEVAR 5-38a.7x and 5-38a.8x), open aortic repair (OAR 5—384.4), or hybrid procedure (5-384.b/c, 5-38a.a/b/8/80) were included. To adjust for sex, age, medical risk (Elixhauser comorbidity score), type of procedure, and type of admission, a multilevel multivariable regression model with robust error variance was applied. The primary outcome was in hospital mortality; secondary outcomes were organ complications. The relationship between annual hospital volume and outcome was analysed.

Results: A total of 2607 cases (406 rTAAA, 2201 nrTAAA) were included. f/bEVAR was performed in 856 cases (32.8%), OAR in 1422 cases (54.5%), and hybrid repair in 354 cases (13.6%). Endovascular repair became more frequent over time (6% in 2005 vs. 76% in 2014 for nrTAAA). Hypertension (75.2%), peripheral artery disease (including abdominal aortic aneurysm, 49.5%), other heart diseases (44.6%), coronary heart disease (30.6%), and renal failure (28.7%) were the most frequently coded comorbidities. The number of hospitals treating TAAAs almost tripled within 9 years. The in hospital mortality was 46.1% for rTAAA and 15.9% for nrTAAA. f/bEVAR (RR 0.35, 0.24—0.51) and high hospital volume ($p < .001$) were significantly associated with decreased in hospital mortality. Aortic rupture, increasing age, and comorbidity were significantly associated with higher mortality (RR 3.17, 2.45—4.09; 1.52, 1.32—1.76, and 1.05, 1.04—1.06).

Conclusions: Seventy-six percent of all TAAAs were treated endovascularly in 2014 with increasing frequency over a decade. In hospital mortality is lower with endovascular repair and in high volume centres. Aortic rupture, age, and severe comorbidities are associated with worse outcomes.

Keywords: Thoracoabdominal aortic aneurysm, In hospital mortality, Hospital incidence, fEVAR, bEVAR, Secondary data analysis
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INTRODUCTION

Aneurysmal dilatation of the thoraco-abdominal aorta (TAAA) is rare with an incidence of 5.9 per 100,000 inhabitants.[1] Until recently, open aortic thoraco-abdominal repair (OAR) of complex and extensive aortic pathologies was considered to be the gold standard for patients with a life expectancy > 10 years and those suffering from connective tissue disease.[2] However, OAR with the need for left

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heart bypass is a highly invasive procedure that is associated with considerable morbidity and mortality, especially when the aneurysm spans the thoraco-abdominal aorta.[3]

The development and implementation of fenestrated and branched endografts (f/bEVAR) has been revolutionary. Aneurysms involving the visceral and renal segments can be treated endovascularly in one step or as a staged procedure. Major complications of OAR can be reduced and off the shelf devices allow immediate treatment of symptomatic and ruptured aneurysms.

Large series comparing outcomes after open or endovascular repair are rare. Often the study population is small, and aneurysms of the descending thoracic aorta or aortic dissections are also included. Furthermore the existing single centre reports represent data from highly specialised surgical groups for either open repair or the use of fenestrated/branched endografts. Mortality rates varying between 4.3 and 14%,[4−6] are lower for endovascular repair and type I and IV aneurysms and higher for ruptured aneurysms.[7−9]

Reports of German DRG data (full survey from 2005 − 2014) of patients with abdominal aortic aneurysms (AAAs) and thoracic aortic aneurysms (TAAs) added evidence on incidence, treatment, and mortality under routine conditions, and risk factors for this cohort. A volume outcome analysis revealed that high hospital volume is associated with decreased mortality after AAA repair.[10−13] Nationwide data for unselected patient cohorts of TAAA in Germany have not been published yet. Therefore, the diagnosis related group (DRG) microdata from 2005 − 2014 were analysed, and hospital incidence, treatment modality, and in hospital mortality after treatment of TAAA by endovascular, hybrid, or open means are reported.

METHODS

Data processing and patient flow

Methods have been previously described in detail.[12,14−16] In short, the data were extracted from diagnosis related group statistics from the research data centre of the German Federal Statistical Office (GFSO), covering all inpatient cases (except psychiatry and special services) from 2005 to 2014. Study ethics were approved by the local Ethics Committee of the Medical Faculty, Technical University of Munich (Reference 21/16 S). The analysis was conducted according to Good Practice of Secondary Data Analysis guidelines[17] and reporting follows the STROSA2 guideline (modification of the RECORD guideline that addresses specific characteristics of the German healthcare system).[18,19] Data have been saved and are available on the GFSO servers. They were accessed using controlled remote data processing, which means individual patient data or institutional identifiers for hospitals were not available to the authors. A protocol for the study was submitted to the GFSO during the application process, but has not been published separately.[10] This research did not receive any specific grant or outside funding.

Inclusion and exclusion criteria

All cases with a diagnosis of ruptured and non-ruptured TAAA (ICD-10 I71.5, I71.6) and procedure codes (OPS 2005−2014) for f/bEVAR (5-38a.7x and 5-38a.8x), OAR (5−384.4), or hybrid procedure (5-384.b/c, 5-38a.a/b/8/80) treated between 2005 and 2014 were included. Patients that received supra-aortic debranching were excluded, on this assumption that some of these patients suffer from ascending aortic or arch pathologies or an aneurysm of the descending thoracic aorta. Between 2005 and 2014, 12,102 cases with TAAA as the principal diagnosis were recorded, of which 2242 were ruptured (ICD I71.5) and 9860 were non-ruptured TAAA (ICD I71.6). Patients with unknown or foreign domicile were excluded from the analysis. Ruptured and non-ruptured thoracic aortic aneurysms (ICD-10 I71.1. and I71.2, $n = 4969$) were excluded (Fig. 1).

Age, sex, type of admission (referred by a physician, without referral/emergency, or transferred from another hospital), and type of surgery (f/bEVAR vs. OAR vs. hybrid) were compiled. To scan for comorbidities in the administrative database, definitions were used as established in the Elixhauser comorbidity score for hypertension, chronic pulmonary disease and coagulopathy and as in the Charlson comorbidity score for peripheral vascular disease (PVD), diabetes, renal disease, and malignant disease.[20] As an overall measure of comorbidity, the internationally validated modified Elixhauser score was calculated.[21]

Outcome definition

The primary outcome of this study was death up to discharge. Reporting in hospital death in Germany is mandatory and monitored by a governmental institution. Mortality rates were given as raw values and standardised for sex, age, and medical risk (using the Elixhauser score) applying an indirect standardisation approach.[12,22] Secondary outcomes were prolonged ventilation requirement, blood transfusion (none, 1 − 5 units, > 5 units), transfusion of thrombocytes, acute myocardial infarction, peripheral arterial thrombosis and embolism, mesenteric thrombosis and embolism, renal artery thrombosis and embolism, as well as the necessity of bowel resection or major amputation of lower limbs, and length of hospital stay. Outcomes were analysed according to rupture status (ruptured or non-ruptured) and type of treatment (f/bEVAR, OAR, hybrid). Time trends with reference to treatment modality were analysed.

Five age groups were arbitrarily set in order to analyse outcomes with regard to age (age $<$ 65 years, 65 − 69 years, 70 − 74 years, 75 − 79 years, and $\geq$80 years).

Volume outcome analysis

For analysing a volume outcome effect, each year hospitals have been grouped by *k*-means clustering[23] into low, medium, and high volume facilities subject to their annual TAAA procedure numbers. This was done in order to avoid arbitrary categorisation, and to arrange homogeneous clusters based on empirical data. Allowing for a diminishing marginal utility effect on the experience growth by an

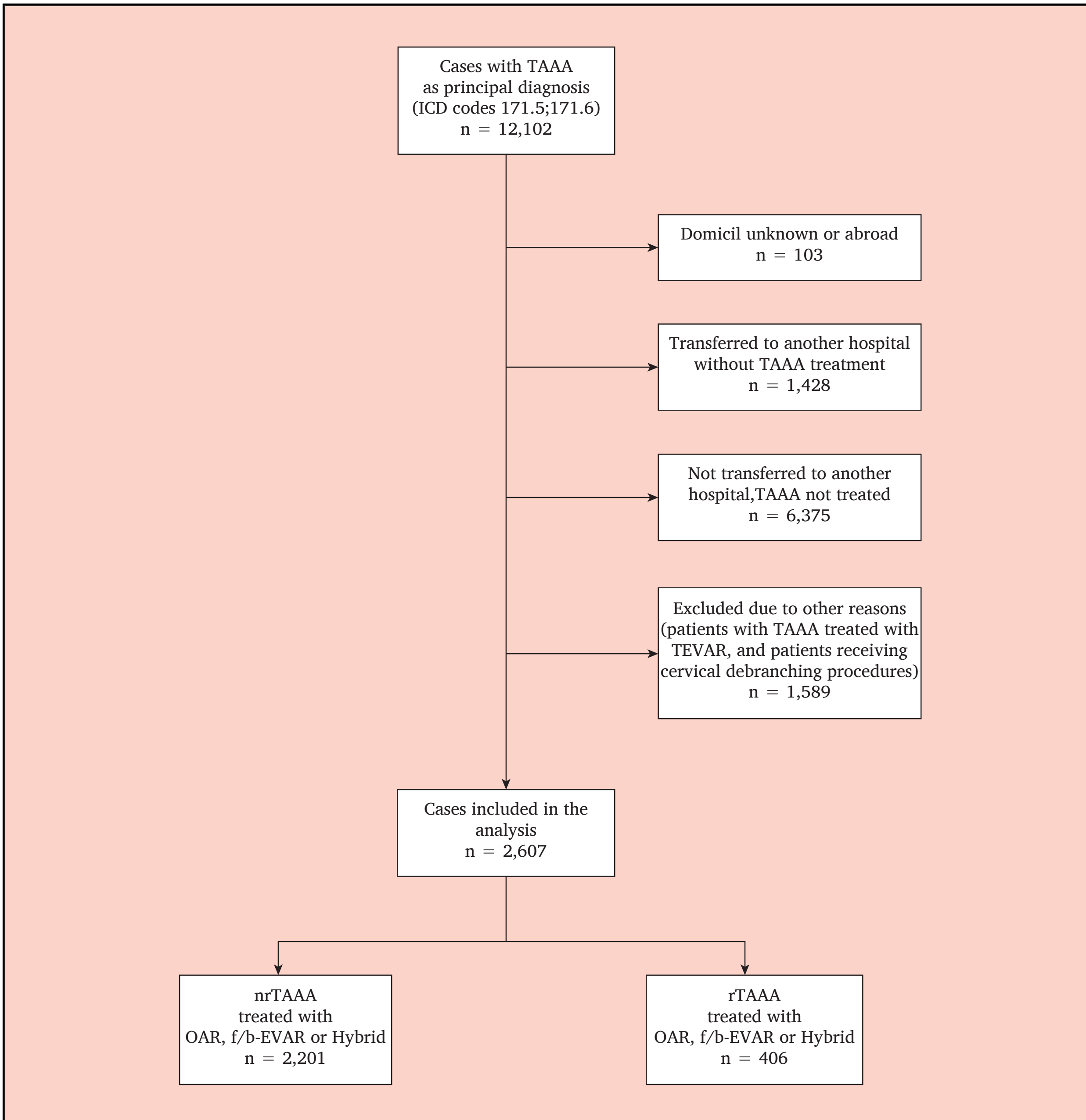

Figure 1. Flowchart. f/bEVAR = fenestrated or branched endovascular aortic repair; OAR = open aortic repair; TAAA = thoracoabdominal aortic aneurysm; TEVAR = thoracic endovascular aortic repair; nrTEVAR = non-ruptured thoracic endovascular aortic repair; rTEVAR = ruptured thoracic endovascular aortic repair; rTAAA = ruptured thoracoabdominal aortic aneurysm; ICD = international classification of diseases.

additional procedure, the clustering algorithm used the logarithmised annual volume as separating variable.

Additionally, a multivariable regression model has been used to analyse the continuous volume outcome effect while adjusting for sex, age, comorbidities, and type of treatment.

Statistical analysis

Categorical variables are presented as absolute numbers and percentages. Continuous, non-normal variables are presented as the median with the first (Q_1) and third (Q_3) quartiles. To adjust for confounding, a multilevel multivariable regression model (generalised linear mixed model, GLMM) was applied. Age, sex, treatment modality, and Elixhauser score were entered into the model as fixed effects. Additionally, unique centre ID and geo-coordinates of hospitals were entered as random effects in order to take clustering of patients within centres and spatial autocorrelation of outcomes into account. For remote data processing and statistical analysis, SAS software (version 9.2 for Microsoft Windows, © 2015 SAS Institute Inc., Cary, NC, USA) was used. Processing of secondary diagnoses and procedure codes was performed using the “NewVar-Macro” provided by the Federal Statistical Office (Statistisches Bundeamt, StBA, version 1.2, April 2017).

RESULTS

Patient characteristics and comorbidities

An endovascular or open surgical treatment was performed in 2607 cases (21.5%; Fig. 1). The average age of the entire population was 67 years (standard deviation 10 years) with a tendency for increasing age each year; 66% were male (Table 1).

In all, 75.2% of patients had hypertension. Other frequent comorbidities were peripheral artery disease including abdominal aortic aneurysm (49.5%), other heart diseases (44.6%), coagulopathy (51.6%), coronary heart disease (30.6%), and renal insufficiency (28.7%).

Overall comorbidity (measured by the Elixhauser co-morbidity score) was more frequently coded in patients with a ruptured aneurysm than those with a non-ruptured aneurysm (10.5 vs. 8). Patient characteristics are summarised in Table 1.

TAAA treatment modality: time trends

Overall, 54.5% of patients with TAAA were treated by open surgery (1422 patients), 32.8% (856 patients), and 13.6% (354 patients) with f/bEVAR or hybrid repair, respectively (Table 2). The choice of treatment modality shifted towards endovascular treatment (endovascular repair, ER) during the time period from 2005 to 2014: 6% of elective TAAA cases were treated with f/bEVAR in 2005 and 76% percent in 2014 (Fig. 2).

In 2014, 131 hospitals treated patients with TAAA, which is 2.5 times more than in 2004 (53 hospitals). The median number of cases per hospital was 2 (Q_1: 1, Q_3: 5), although the overall case load increased over time (Fig. 3A).

For nrTAAA the standardised hospital incidence was 0.31 per 100,000 inhabitants in 2005 and increased to 0.88 per 100,000 inhabitants in 2014. For rTAAA it was 0.06 (2005) and doubled in 2015 (0.12 per 100,000; Fig. 3B).

Primary outcomes and multivariable analyses

The overall raw mortality was 20.5%: 46.1% for ruptured TAAA and 15.9% for non-ruptured TAAA (Table 3). For endovascular, open, or hybrid repair the overall in hospital mortality was 10.6% (89/839), 23.9% (340/1422), and 30.9% (107/346), respectively. Raw overall mortality in women was 3.9 percentage points higher than in men. Relative risk of in hospital mortality increased with every five years of age by 15% (RR 1.15, 0.93—1.43, for men vs. women).

For elective repair, mortality improved from 21% in 2005 to 12% in 2014. Mortality rates for emergency repair (ruptured TAAA) ranged between 34% (2005) and 45% (2014; Fig. 4).

The in hospital mortality was significantly reduced when endovascular treatment was performed (RR 0.35; 0.24—0.51). A ruptured aneurysm, increased age, and higher co-morbidity strongly correlated with increased in hospital mortality (RR 3.17, 2.45—4.09, for ruptured vs. non-ruptured; RR 1.52, 1.32—1.76, for age per 10 years increase; and RR 1.05, 1.04—1.06, for Elixhauser score per 1 point increase) (Fig. 5).

Secondary outcomes

Complications were more frequent following hybrid repair than OAR and ER for dialysis (33.5, 31.6, and 10.5%), acute mesenteric infarction (11.3, 4.3, and 3%), and bowel resection (9.5, 3.9, and 2.5%), acute peripheral limb ischaemia (9.8, 5.2, and 5%), and acute renal artery infarction (5.5, 2.8, and 3.5%). Myocardial infarction and acute paraplegia/spinal infarct were more frequent after f/bEVAR (Table 4).

Table 1. Thoraco-abdominal aortic aneurysms. Patient characteristics

	Total (n = 2607)	Ruptured (n = 406)	Non-ruptured (n = 2201)
Mean age ± SD, years	67 ± 10	70 ± 9	67 + 10
Male sex	1721 (66)	266/140 (65.5)	1454/747 (66.1)
Coronary heart disease	799 (30.6)	121 (29.8)	678 (30.8)
Other heart diseases	1162 (44.6)	197 (48.5)	965 (43.8)
Cerebrovascular disease	297 (11.4)	44 (10.8%)	253 (11.5)
PAD including AAA	1290 (49.5)	177 (43.6)	1113 (50.6)
Hypertension	1960 (75.2)	253 (62.3)	1707 (77.6)
COPD	533 (20.4)	73 (18)	460 (20.9)
Diabetes	339 (13%)	72 (17.7)	267 (12.1)
Renal failure	748 (28.7)	129 (31.8)	619 (28.1)
Malignant diseases	59 (2.3)	9 (2.2)	50 (2.3)
Coagulopathy	1347 (51.6)	256 (63.1%)	1091 (49.6)
Obesity	288 (11)	36 (8.9%)	252 (11.4)
Elixhauser score, median ($Q_1 - Q_3$)	n/a	10.5 (5 − 17)	8 (4 − 15)

Values are presented as *n* (%), unless stated otherwise. PAD = peripheral artery disease; AAA = abdominal aortic aneurysm; COPD = chronic obstructive pulmonary disease; n/a = not available; SD = standard deviation.

Table 2. Procedures and management of thoraco-abdominal aortic aneurysm ($n = 2607$)

	Total (n = 2607)	Ruptured (n = 406)	Non-ruptured (n = 2201)
f/bEVAR	839 (32.2)	48 (11.8)	791 (36)
OAR	1422 (54.1)	281 (69.2)	1141 (51.8)
Hybrid	346 (13.2)	77 (19)	269 (12.2)
Visceral debranching	504 (19.3)	121 (29.8)	383 (17.4)
Management			
ICU stay (yes/no)	924 (35.2)	171 (42.1)	753 (34.3)
Monitoring of motor evoked potentials	184 (7)	8 (2)	176 (8)
Cerebrospinal fluid drainage	362 (13.9)	29 (7.1)	333 (15.1)
Ventilation (yes)	1510 (57.9)	296 (73)	1214 (55.2)
DOV, h, median (Q1 − Q3)	n/a	140 (40.5 − 414)	88 (29 − 348)
Packed red blood cell transfusion (1–5 units)	667 (25.6)	58 (14.3)	609 (27.7)
Packed red blood cell transfusion (>5 units)	1468 (56.3)	321 (79.1)	1147 (52.1)
Platelet concentrate (1–5 units)	941 (36)	183 (45.1)	758 (34.3)
Platelet concentrate (>5 units)	326 (12.4)	64 (15.8)	262 (11.9)
Cell saver autotransfusion	708 (27.2)	119 (29.3)	589 (26.8)
Heart–lung machine use	212 (4.6)	66 (16.3)	146 (6.6)
LOS, days; median (Q1 − Q3)	n/a	18 (11 − 30)	16.5 (5 − 31)
CT with contrast performed	1378 (52.9)	239 (58.9)	1139 (51.7)
Complications			
Acute/recurrent myocardial infarction	51 (1.9)	9 (2.2)	42 (1.9)
Acute paraplegia/spinal infarction	135 (5.2)	23 (5.6)	112 (5.1)
Acute peripheral limb ischaemia	150 (5.8)	40 (9.9)	110 (5)
Major amputation lower limb	3 (0.1)	xxx	3 (0.1)
Acute mesenteric infarction	125 (4.8)	38 (9.4)	87 (4)
Bowel resection	109 (4.2)	31 (7.6)	78 (3.5)
Acute renal artery infarction	86 (3.3)	16 (3.9)	70 (3.2)
Dialysis/haemofiltration	654 (25.1)	178 (43.8)	476 (21.6)
Type of discharge			
Regular discharge	1152 (44.2)	65 (16)	1087 (49.4)
Rehabilitation	406 (15.6)	56 (13.8)	350 (15.9)
Other hospital	489 (18.8)	95 (23.4)	394 (17.9)

Values are presented as n (%), unless stated otherwise. f/bEVAR = fenestrated/branched endovascular aortic repair; OAR = open aortic repair; ICU = intensive care unit; DOV = duration of ventilation; LOS = length of stay; CT = computed tomography, xxx = $n < 3$, cases not included in analysis for privacy protection reasons; n/a = not assessed.

Ventilation time and length of hospital stay were longer after hybrid repair, followed by OAR and ER. The need for transfusion of red blood cells and platelets was lowest after f/bEVAR. Around 60% of patients received a computed tomography (CT) scan after f/bEVAR and hybrid repair vs. 45% after OAR. Discharge to a rehabilitation hospital seems to be more common after hybrid and open repair. Details on management and complications with regard to treatment modality are summarised in Table 4.

Volume outcome analysis

An annual caseload per hospital of one or two was defined as low volume, three to 12 cases/year, and ≥13 (99% CI 1 − 27) cases/year as medium and high volume, respectively. The majority of cases were treated in medium (43.8%) and high volume centres (38.1%), with 18% in a low volume hospital. f/bEVAR was more frequently performed in high volume hospitals, whereas the share of hybrid procedures was highest in low volume centres. The in hospital mortality was twice as high in low volume hospitals as in high volume centres (13.9% vs. 32.1%, $p < .01$). Multivariable analysis revealed that an increase in annual case load (as a continuous variable) was significantly associated with decreased in hospital mortality (RR 0.87, 95% CI 0.82–0.92) for an increase of five cases/year ($p < .0001$), Fig. S1. Details on outcome by hospital volume are summarised in Table 5.

DISCUSSION

This study is the first to report and analyse the outcome of surgical treatment of TAAA at national level in Germany. The data confirm that the in hospital incidence of TAAA is low. The choice of treatment modality shifted over the study period in favour of ER with a much lower in hospital mortality than open or hybrid repair.

Hospital incidence

TAAA is a rare disease with an incidence of 5.9 per 100,000 inhabitants.[1] However, it remains unclear where these data derive from and exact data regarding epidemiology are not available. In this analysis, the standardised in hospital incidence is below 1 per 100,000 inhabitants and tripled within a decade for non-ruptured cases. Interestingly, a sudden and steady increase in the incidence after 2010 was

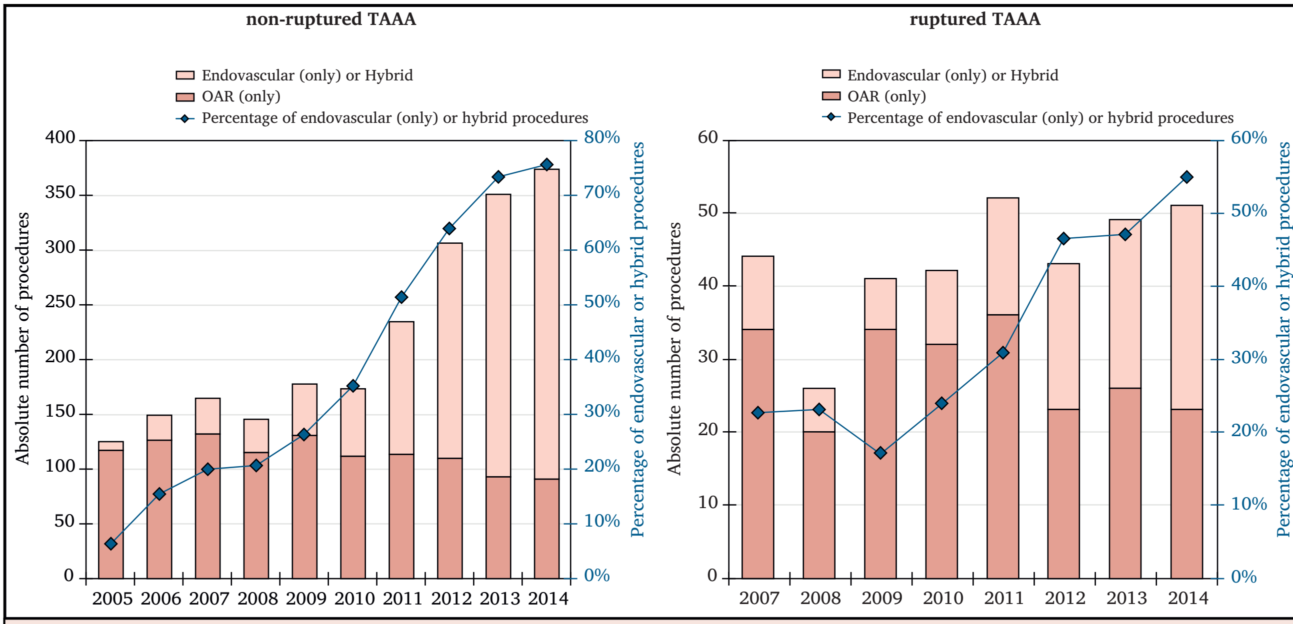

Figure 2. Proportions of patients treated by endovascular only including hybrid procedures or open surgery between 2005 and 2014 and percentage of endovascular only including hybrid procedures (blue line, right axis). Data for ruptured thoraco-abdominal aortic aneurysms were not available for 2005 and 2006 because of the small numbers that were treated by fenestrated or branched endovascular aortic repair at that time. OAR = open aortic repair; TAAA = thoraco-abdominal aortic aneurysm.

observed. The reasons remain unclear but this might be associated with demographic changes: an elderly patient population and a broad implementation of imaging techniques such as CT or magnetic resonance imaging.

Treatment modality

So far, open repair of the thoraco-abdominal aorta was believed to be the gold standard for patients with a life expectancy >10 years and patients with connective tissue disease.[2] For emergency procedures and old or frail patients, endovascular treatment offers a less invasive alternative. The data reveal that under real world conditions the treatment regimen has changed for the majority of patients in Germany. The share of endovascularly treated patients with TAAA has increased markedly, while the number of open repairs has declined.

In hospital mortality

Open procedures are believed to be associated with a much higher peri-operative risk, morbidity, and mortality because of operative trauma, and the need for aortic cross clamping or left heart bypass. In two large series, Eagleton et al.[8] (354 patients) and Coselli et al.[7] (3309 patients) reported experience with f/bEVAR and OAR, respectively. Greenberg et al.[9] analysed the outcome of 724 patients who received endovascular or open repair of their TAA(A). Mortality rates in these series are similar, although slightly lower for ER (Coselli, 7.5% OAR; Eagleton, 4.8% ER; Greenberg, 8.3% vs. 5.7%). The extent of the aneurysm is considered to be a major risk factor for mortality and morbidity. For ER, the authors describe a learning curve associated with improvement of results over time. Coselli et al.[7] could not observe different outcomes when analysing a large patient cohort by time periods. Given the fact that results improve with experience and high volume is associated with decreased mortality, these reports emphasise that extensive endovascular and open TAAA repair should be performed at experienced centres only, a finding that was already published by the group for the treatment of abdominal aortic aneurysms in Germany.[10]

In addition, an independent analysis of the Nationwide Inpatient Sample (NIS database) including 1542 patients with intact TAAA who underwent surgical treatment reports in hospital mortality rates of 15% (high volume hospital) and 27.4% (low volume hospital).[24] These data correspond with the findings that in hospital mortality is as high as 24% for open thoraco-abdominal aortic repair and 30.9% for hybrid procedures, whereby the in hospital mortality is 10.6% for ER. A volume outcome analysis revealed that in Germany, in hospital mortality is also twice as high in low volume hospitals as in high volume centres. Despite the fact that mortality decreases with annual caseload, paraplegia rates are higher in high volume centres. One reason might be that more extensive aneurysms are more frequently treated in experienced centres. However, as the extent of the aneurysm is not relevant for remuneration, it is not documented in this DRG dataset and no subgroup analysis is feasible.

Aortic rupture, advanced age, and higher comorbidity are clearly associated with worse outcome. For each patient, the individual[3] needs to be carefully considered when a highly invasive, high risk and costly operation is recommended, bearing in mind the operative risk. Quality of life, life

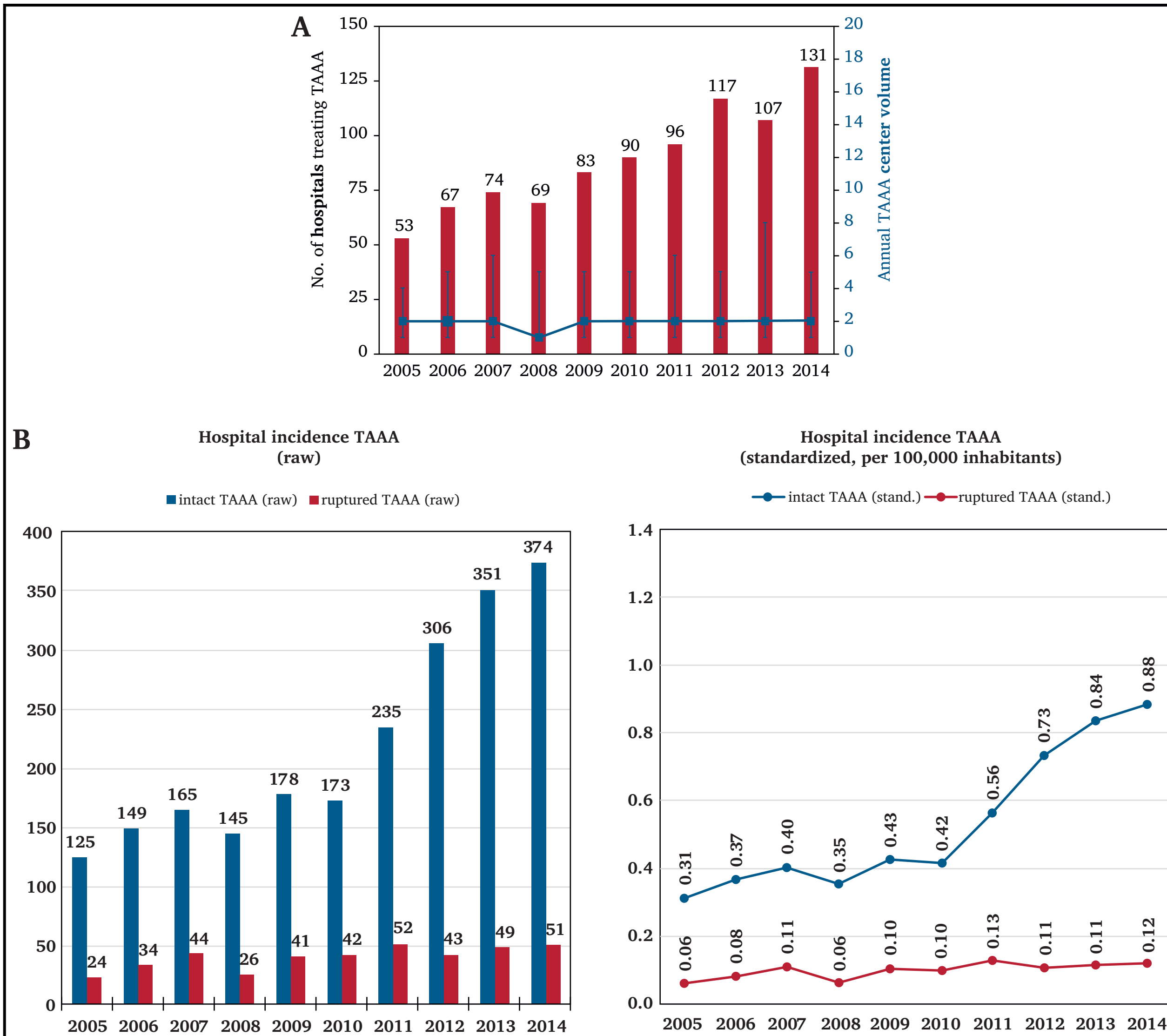

Figure 3. (A) Number of hospitals treating TAAA (left axis) from 2005 – 2014 and median annual centre caseload (right axis). (B) In hospital incidence (raw and standardised). TAAA = thoraco-abdominal aortic aneurysm.

Table 3. Thoraco-abdominal aortic aneurysm primary outcome: in hospital mortality

	Totals (n = 2607)	Ruptured (n = 406)	Non-ruptured (n = 2201)
Overall	536/2607 (20.5)	187/406 (46.1)	349/2201 (15.9)
By sex			
Men	331/1720 (19.2)	120/266 (45.1)	211/1454 (14.5)
Women	205/887 (23.1)	67/140 (47.9)	138/747 (18.5)
By age group			
<65 years	113/832 (13.6)	28/93 (39.1)	85/739 (11.5)
65–69 years	103/519 (19.8)	36/69 (52.2)	67/450 (14.9)
70–74 years	146/652 (22.4)	41/103 (39.8)	105/549 (19.1)
75–79 years	106/422 (25.1)	48/90 (53.3)	58/332 (17.5)
≥80 years	68/182 (37.4)	34/51 (66.7)	34/131 (26)
By treatment			
Open aortic repair only	340/1422 (23.9)	128/281 (45.6)	212/1141 (18.6)
Endovascular only	89/839 (10.6)	16/48 (33.3)	73/791 (9.2)
Hybrid	107/346 (30.9)	43/77 (55.8)	64/269 (23.8)

Data are presented as n (%), unless stated otherwise.

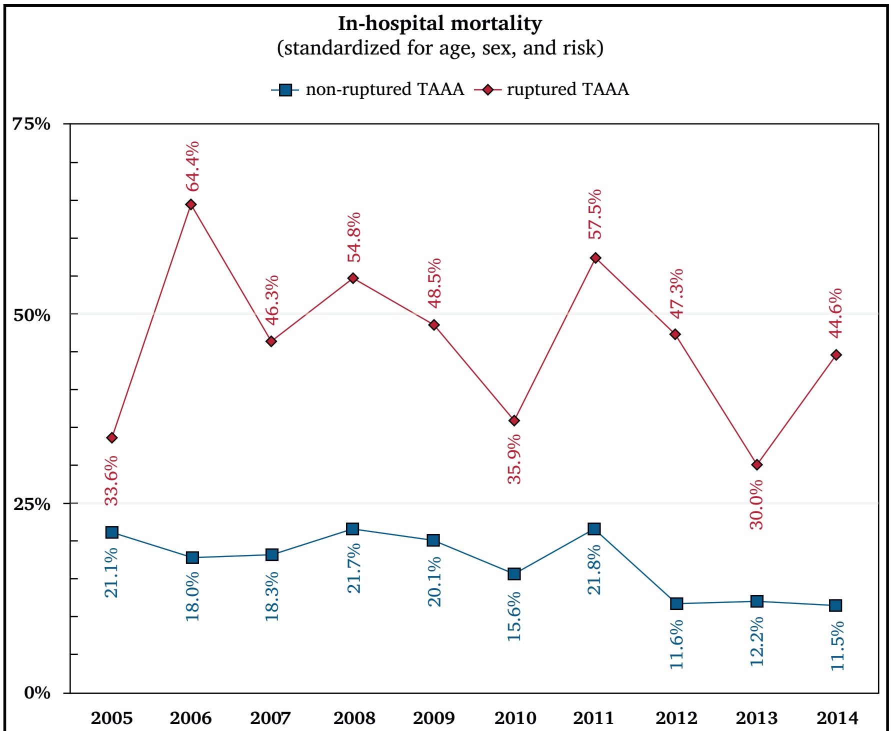

Figure 4. In hospital mortality for ruptured and non-ruptured TAAA by year. TAAA = thoraco-abdominal aortic aneurysm.

expectancy, and individual factors predisposing to complications should be evaluated when deciding the optimal treatment time and modality. Almost all reports of outcome after OAR or ER are based on heterogeneous patient subgroups and do not provide accurate comparison of patient populations and treatment strategies. Patient selection bias is also possible, younger patients and those with fewer comorbidities tend to receive open surgery, whereas those treated endovascularly include a patient cohort considered unfit for open surgery. The vast majority of patients with degenerative aortic aneurysms have a high risk profile. Those patients would have been rejected for surgery earlier and can be offered endovascular treatment today. In both cohorts, patients who received ER tend to be older but, interestingly, the Elixhauser comorbidity score was higher in patients with open or hybrid repair. In their report of 166 consecutive patients who received either ER or OAR, Verhoeven et al.[4] emphasised that 65% of individuals who were refused for OAR were successfully treated by ER. The data in the current study clearly show that mortality decreased over time for elective cases. This might be associated with growing experience with endovascular techniques among other factors, and thus being able to offer a more individual and less invasive therapy to frail patients.

Strengths and limitations

General limitations of this study and the methodology applied have been previously described.[12]

Missing data

The analysis of DRG microdata does not allow for information to be gathered about the extent of the aneurysm (Crawford type I — IV), which significantly affects outcome[9] and might be one reason for inconsistent reports of mortality rates in the literature. Thus, subgrouping would be interesting but exact data are missing. Intergroup differences regarding expansion of the aneurysm, patient comorbidities, age, and surgeon experience with the applied technique significantly influence outcome. Thus, only patients with diagnosis and procedure codes for thoraco-abdominal aortic aneurysms were included (TAA only were excluded). However, this is a report of a large unselected patient cohort undergoing endovascular or open surgical treatment that represents treatment reality in Germany. The authors did not intend to compare outcome of ruptured and non-ruptured TAAA or f/bEVAR and OAR, but rather describe incidence and mortality, and time trends over a period of 9 years.

From DRG data, it is not possible to distinguish between pre-existing conditions and post-operative complications. As there are no "present on admission" flags, the distinction between "comorbidity" and "complication" was based on theoretical assumptions only. For example, it was assumed that diabetes or coronary heart disease (chronic) were most likely pre-existing whereas an acute mesenteric infarction is considered more likely to be a complication of treatment. In order to address this, subheadings were inserted in order to

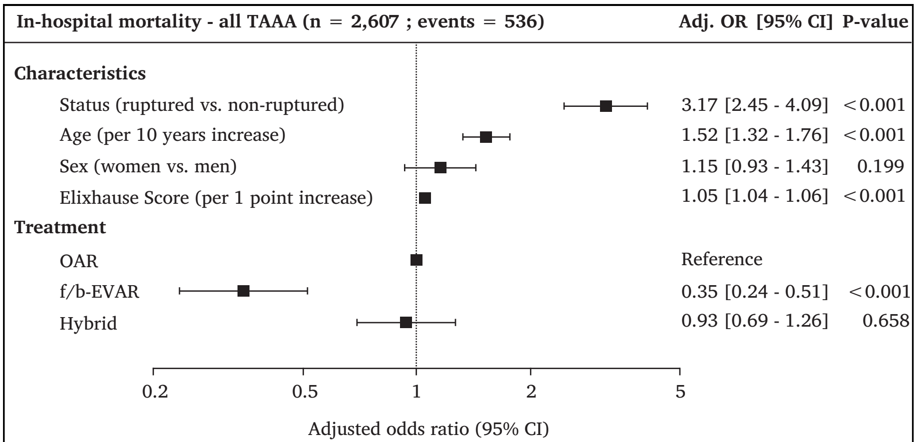

Figure 5. Multilevel multivariable regression analysis of factors associated with mortality. f/bEVAR = fenestrated or branched endovascular aortic repair; TAAA = thoraco-abdominal aortic aneurysm; OAR = open aortic aneurysm; Adj. OR = confounder-adjusted odds ratio; CI = confidence interval.

Table 4. **Outcome by treatment modality (n = 2607 interventions)**

	f/bEVAR n = 839 (32.2%)	OAR n = 1422 (54.5%)	Hybrid n = 346 (13.3%)
Non-ruptured TAAA, $n = 2201$	791 (35.9)	1141 (51.8)	269 (12.1)
Ruptured TAAA, $n = 406$	48 (11.8)	281 (69.2)	77 (19)
Management			
ICU stay (yes)	309 (36.8)	481 (33.8)	134 (38.7)
Monitoring of motor evoked potentials	24 (2.9)	155 (10.9)	5 (1.4)
Cerebrospinal fluid drainage	180 (21.5)	135 (9.5)	47 (13.2)
Ventilation	214 (25.5)	1073 (75.5)	223 (64.5)
DOV, hours, median (Q1 − Q3)	53 (19 − 203)	103 (34 − 368)	127 (30 − 485)
Packed red blood cell transfusion (1−5 units)	315 (37.5)	262 (18.4)	90 (26)
Packed red blood cell transfusion (>5 units)	201 (24)	1064 (74.8)	203 (57)
Platelet concentrate (1−5 units)	92 (11)	749 (52.7)	100 (28.1)
Platelet concentrate (>5 units)	13 (1.5)	284 (20)	29 (8.4)
Cell saver autotransfusion	78 (9.3)	554 (39)	76 (22)
Heart−lung machine use	xxx	740 (52)	6 (1.7)
LOS (days, median Q1 − Q3)	14 (9 − 22)	21 (13 − 33)	24 (12 − 37)
CT with contrast performed	514 (61.3)	647 (45.5)	217 (62.7)
Complications			
Acute/recurrent myocardial infarction	26 (3.6)	18 (1.3)	7 (2)
Acute paraplegia/spinal infarct	48 (5.7)	70 (4.9)	17 (4.9)
Stroke	xxx	4 (0.3)	xxx
Acute peripheral limb ischaemia	42 (5)	74 (5.2)	34 (9.8)
Major amputation lower limb	xxx	3 (0.2)	xxx
Acute mesenteric infarction	25 (3)	61 (4.3)	39 (11.3)
Bowel resection	21 (2.5)	55 (3.9)	33 (9.5)
Acute renal artery infarction	29 (3.5)	40 (2.8)	19 (5.5)
Renal Failure	301 (35.9)	337 (23.7)	110 (31.8)
Dialysis/haemofiltration	88 (10.5)	450 (31.6)	116 (33.5)
Type of discharge			
Regular discharge	566 (67.5)	459 (32.3)	xxx
Rehabilitation	88 (10.5)	261 (18.4)	57 (16.5)
Other hospital	86 (10.3)	351 (24.7)	52 (14.6)

Values are presented as n (%), unless stated otherwise. TAAA = thoracoabdominal aortic anuerysm; f/bEVAR = fenestrated/branched endovascular aortic repair; OAR = open aortic repair; ICU = intensive care unit; DOV = duration of ventilation; LOS = length of stay; CT = computed tomography; xxx = $n < 3$, cases not included in analysis for privacy protection reasons.

clarify that categorisation (pre-existing comorbidity and complication) were not definite but assumptions.

Additionally, the intention was to separate the analysis into ruptured and non-ruptured for open/hybrid repair and f/bEVAR but small numbers would have led to censorship of data because of German data protection law.

Internal and external validation

Reporting of a standardised dataset on hospital episodes is mandatory by law for all hospitals in Germany. However, German soldiers treated in German military hospitals ($n = 5$) are not included. Additionally, DRG coding is necessary for hospital remuneration (incentive for coding) but regularly monitored by the Health Insurance Medical Service (incentive to avoid additional expenditure due to upcoding or over reporting). Thus, these administrative data are considered valid.

Miscoding

In Germany, OPS codes are entered by surgeons. Reimbursement is highest for TAAA, and it is a rare disease, so most cases are reviewed by the Health Insurance Medical Service. Therefore, OPS Codes and ICD-10 principal diagnosis are most likely valid.

TAAAs treated by TEVAR were excluded in the flowchart. Indeed, TAAA cases treated by staged repair with TEVAR as one step are excluded for this procedure. But cases treated by hybrid repair would be captured when receiving the open part of hybrid repair (coded as 5-384.b/c, 5-38a.a/b/8/80) and not be double counted.

These cases were excluded as the majority were assumed to be wrongly coded TAAs treated by TEVAR. Unfortunately, there is no information whether the open/hybrid procedures were performed in stages or not. An open procedure might be coded as open repair AND hybrid repair, and therefore some double counting might be possible.

The important increase in incidence of disease and ER might be due to a misclassification of aneurysms based on aortic coverage with a stent graft in the endovascular era vs. the true anatomical extent of the aneurysm in the open repair era. Aortic coverage in f/bEVAR is often more extensive than open aortic repair. It would be of great interest to classify outcome with regard to the extent of the TAAA (especially paraplegia and renal insufficiency). Unfortunately, information about the type of aneurysm is not

Table 5. Characteristics and outcome by hospital volume for TAAA treatment in Germany 2004–2015: volume outcome analysis

	Low volume hospitals (n = 371)	Medium volume hospitals (n = 203)	High volume hospitals (n = 48)
Cases with TAAA	471 (18)	1142 (43.8)	994 (38.1)
No. of cases per hospital/year	1–2[a]	3–12	≥13
Non-ruptured cases	365 (77.5)	945 (82.8)	891 (89.6)
Type of treatment			
f/bEVAR	98 (20.8)	267 (23.4)	474 (47.7)
OAR	267 (56.7)	676 (59.2)	479 (48.2)
Hybrid	106 (22.5)	199 (17.4)	41 (4.1)
Sex (male)	307 (65.2)	727 (63.7)	686 (69)
Age (mean ± standard deviation)	69 ± 10	68 ± 10	66 ± 10
Mortality	151 (32.1)	247 (21.6)	138 (13.9)
Type of admission			
Scheduled admission	316 (67.1)	747 (65.4)	712 (71.6)
Emergency	105 (22.3)	228 (20)	178 (17.9)
Transferred	50 (10.6)	167 (14.6)	104 (10.5)
Elixhauser score, median ($Q_1 - Q_3$)	10 (5 − 16)	9 (5 − 15)	8 (4 − 14)
Length of hospital stay, d; median ($Q_1 - Q_3$)	19 (9 − 32)	18.5 (11 − 31)	17 (11 − 28)
Type of discharge			
Regular discharge	173 (36.7)	452 (39.6)	527 (53)
Rehabilitation	90 (19.1)	188 (16.5)	128 (12.9)
Other hospital	53 (11.3)	241 (21.1)	195 (19.6)
Complications			
Acute/recurrent myocardial infarction	14 (3)	20 (1.8)	17 (1.7)
Stroke	xxx	xxx	xxx
Acute paraplegia/spinal infarction	15 (3.2)	64 (5.6)	56 (5.6)
Acute peripheral limb ischaemia	30 (6.4)	75 (6.6)	45 (4.5)
Major amputation lower limb	xxx	xxx	xxx
Acute mesenteric infarction	31 (6.6)	70 (6.1)	24 (2.4)
Bowel resection	27 (5.7)	58 (5.1)	24 (2.4)
Acute renal artery infarction	16 (3.4)	42 (3.7)	30 (3)
Renal failure	151 (32.1)	314 (27.5)	283 (28.5)
Dialysis/haemofiltration	140 (29.7)	331 (29)	183 (18.4)

Data are presented as n (%), unless stated otherwise. f/bEVAR = fenestrated/branched endovascular aortic repair; OAR = open aortic repair; TAAA = thoracoabdominal aortic anuerysm; xxx = $n < 3$, cases not included in analysis for privacy protection reasons.
[a] 99% confidence interval 1–27.

coded in the DRG system. This is one reason why the current data were not compared with existing reports regarding complications.

SUMMARY

This analysis includes the largest series of patients with TAAA in Europe. The report of the outcome of 2607 patients who received surgical treatment reveals that a relevant change of the treatment regimen especially for extensive thoraco-abdominal aortic pathologies has taken place. The implementation of fenestrated or branched endografts has a high impact on in hospital mortality and is already the treatment of choice for the vast majority of patients. The number of hospitals treating TAAA has tripled over a decade. In hospital mortality is lower with ER, and rupture, age, and comorbidity are associated with higher comorbidity. Deliberate patient selection, evolution in device development, and the surgeon learning curve might even improve outcomes further since high annual hospital volume is significantly associated with decreased in hospital mortality in patients with TAAA.

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CONFLICTS OF INTEREST

None.

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APPENDIX A. SUPPLEMENTARY DATA

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