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Editor's Choice — Outcomes After One Stage Versus Two Stage Open Repair of Type II Thoraco-abdominal Aortic Aneurysms

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WHAT THIS PAPER ADDS

This study confirms that staged open and hybrid surgery of type II thoraco-abdominal aortic aneurysm (TAAA) may be related to favourable results in terms of decreased mortality rates versus one stage type II TAAA open repair.

Objective: This study compared the outcomes of open one stage with open two stage repair of type II thoraco-abdominal aortic aneurysms (TAAA).

Methods: This retrospective study included 94 patients (68 men) with a mean $\pm$ SD age of 54.5 $\pm$ 14 years who underwent open type II TAAA repair from March 2006 to January 2016. The mean aneurysm diameter was 65 $\pm$ 14.4 mm. The median follow up was 42 months (range 12—96). Seventy-six patients received one stage open repair and 18 patients were treated in two steps: 12 received two open procedures (thoracic and abdominal) and six received hybrid repair (one open and one endovascular procedure). This study focused on the comparison of open one stage and open two stage TAAA repair. The median time between the two steps was 31.5 days (range 1—169).

Results: In hospital mortality after open one stage repair versus open two stage type II repair was 22.4% versus 0% (odds ratio 7.352, 95% confidence interval [CI] 0.884—959.1]; $p = .19$). The one year survival rate after one stage repair versus open two stage repair was 74.7% (95% CI 62.7—83.3) versus 90.9% (95% CI 50.8—98.7 [$p = .225$]). The five year survival rate after one stage repair versus open two stage repair was 53.0% (95% CI 37.2—66.5) versus 90.9% (95% CI 50.8—98.7 [$p = .141$]). The hazard ratio for survival after one stage repair and after open two stage repair was 4.563 (95% CI 96.9—81.4 [$p = .137$]). Paraplegia was observed after open one stage repair versus open two stage in 10.5% vs. 8% ($p = 1$). Acute kidney injury requiring permanent dialysis and myocardial infarction were assessed for after open one stage repair and open two stage and were seen in 3.9% vs. 0% ($p = 1$) and in 5.3% vs. 0% ($p = 1$), respectively.

Conclusion: Open two stage repair may be recommended as a treatment option for type II TAAAs if anatomically feasible, as it has a lower mortality and similar complication rates to one stage repair.

Keywords: Open repair, Staged repair, TAAA, Type II thoraco-abdominal aortic aneurysm
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INTRODUCTION

Thoraco-abdominal aortic aneurysm (TAAA) is a rare and potentially lethal condition. Even in high volume centres, both open and endovascular repair of type II TAAAs is associated with severe complications and an in hospital mortality rate of 15—26%.[1] Several surgical techniques and protective adjuncts have improved outcomes in recent decades; in particular, the use of moderate hypothermia, distal bypass perfusion, sequential cross clamping, and cerebrospinal fluid drainage (CSFD) have decreased the mortality and morbidity rates of TAAA surgery.[2—5] Maintaining spinal cord perfusion remains crucial, and selective re-implantation of intercostal arteries and the use of neuromonitoring during TAAA surgery has reduced the incidence of spinal cord ischaemia (SCI).[6,7] Nonetheless, the incidence of SCI is reported to be 3—16%.[2,8] As the rate of SCI after TAAA repair is strongly related to the

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extent of the disease, repair of type II TAAA is associated with an even higher rate of SCI.[8,9]

In this context, a two stage procedure has been described as a good treatment option for type II TAAA in terms of increasing the spinal cord collateral flow and thereby reducing the SCI rate.[10–12] The aim of this study was to compare the operative and long-term results of one stage and two stage open repair of type II TAAA.

PATIENTS AND METHODS

Definitions

There is no consistent definition of staged TAAA repair in the literature. Authors use different descriptions for a staged procedure, regardless of whether it is performed by open or endovascular means.[10,12,13] In this study an operation was classified as a two stage repair if the maximum period between the steps was < 6 months. The procedure had to be planned from the start as a repair involving two operations, performed using open or endovascular means. The period between the surgical procedures was intended to allow the patient to recover. A two stage open repair can only be performed when the anatomy of the aortic aneurysm allows aortic cross clamping in the distal descending aorta. A maximum diameter of no more than 40 mm is needed to perform an appropriate aortic anastomosis, so that the thoracic part of the aorta can be treated in one step and the abdominal part in a following step or vice versa (Figs. 1 and 2). The segment with the largest diameter (thoracic or abdominal) is operated on first. Hybrid repair was conducted by open repair and thoracic endovascular aortic repair (TEVAR) to avoid re-thoracotomy and single lung ventilation; no fenestrated or branched prosthesis were used in this study.

Urgent TAAA repair was performed for symptomatic patients with back pain. Ruptured aneurysms were excluded from this study. SCI was defined as an objective worsening in motor function in the peri-operative period; in addition, any pathological finding that did not resolve during the motor evoked potential (MEP) assessment was recorded. Patients were assessed clinically by a physician for neurological dysfunction every 4 hours during their intensive care stay or more frequently if necessary. Overall procedure time was defined as the combined operation time of both interventions for open two stage and hybrid repair (minutes). Length of hospital stay was defined as all hospital stays related to the type II TAAA repair (days). Total ventilation time was defined as the complete ventilation time during the operation in minutes. Proximal aortic neck was defined as the length of the proximal aortic clamping zone. It was measured by computed tomography (CT) pre-operatively.[14]

Any stroke, cerebral bleeding, SCI, or critical illness polyneuropathy that occurred after TAAA surgery was considered a severe neurological complication in the statistical analysis. Critical illness polyneuropathy was defined as a syndrome of severe limb weakness and prolonged weaning in critically ill patients. It is a complication primarily affecting the motor and sensory axons.[15] Paraplegia was defined as complete loss of motor function of the lower extremity, while paraparesis was defined as an incomplete loss of the motor function of the lower extremity.[16] Major revision was defined as any surgical re-intervention during the hospital stay or during follow up, with the exception of minor wound revisions.

Surgical protocol

The indication for treatment was a type II TAAA with a diameter > 6 cm or an aneurysm expansion of > 5 mm in six months. The operative protocol for open TAAA repair has been published in detail previously.[17] Briefly, the protocol includes intubation with a double lumen endotracheal tube, CSFD, peri-operative monitoring of motor evoked potentials (MEP), sequential aortic clamping if possible, and extracorporeal circulation (ECC) with distal aortic perfusion, selective visceral perfusion, and mild hypothermia of 32–33 °C. Since 2014, 4 °C Custodiol (Dr. Franz Köhler Chemie, Bensheim, Austria) has been used for renal perfusion instead of blood. Thoraco-laparotomy through the fifth to eighth intercostal space, depending on the extent of the aneurysm, was used for surgical access, as well as a groin cut down to the femoral vessels to place the ECC cannulas (Fig. 3). TEVAR as a second stage procedure was performed under general anaesthesia with CSFD.

Post-operatively, the mean arterial pressure was adjusted based on MEPs, the spinal cord pressure was maintained at

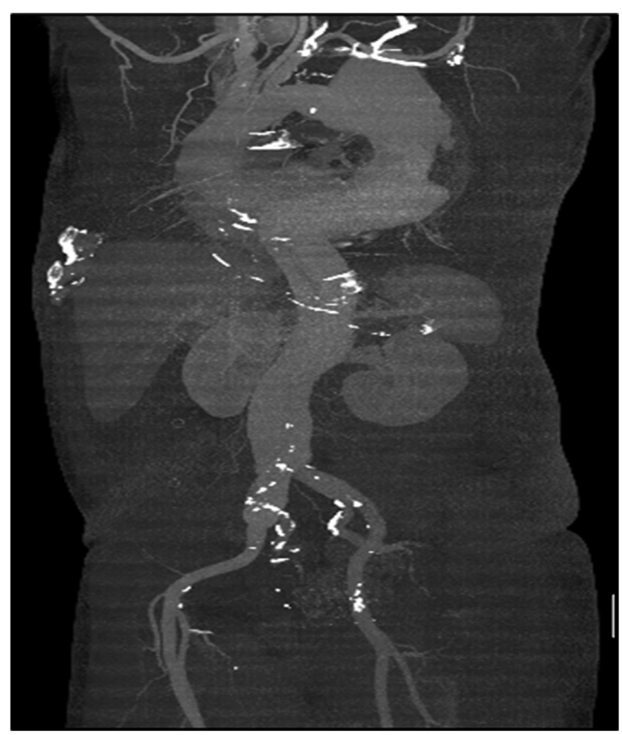

Figure 1. Computed tomography of a patient who underwent type II thoraco-abdominal aortic aneurysm repair showing an appropriate clamping zone in the mid-segment of the descending thoracic aorta.

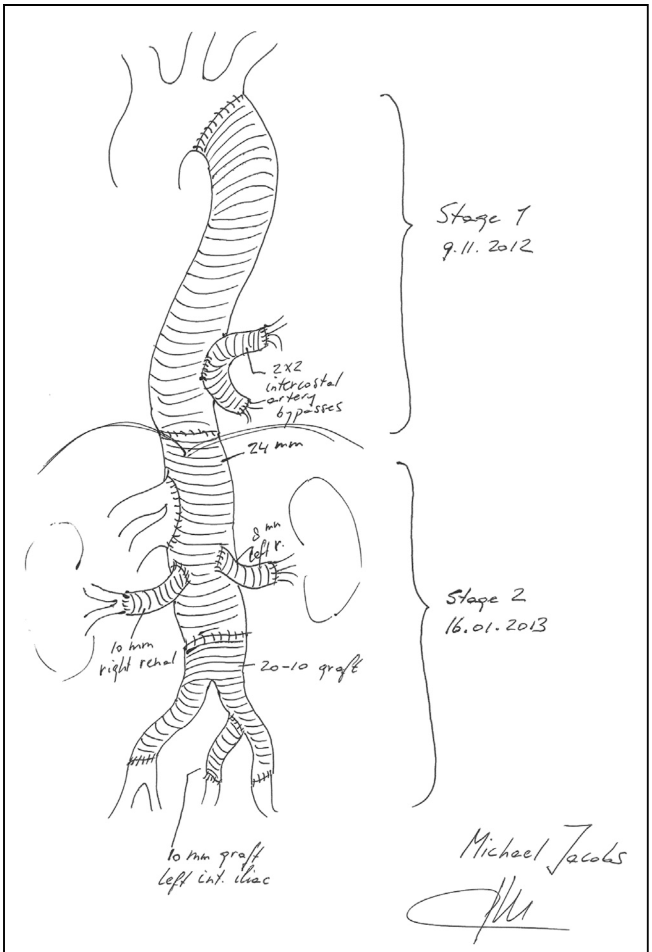

Figure 2. Schematic drawing of the post-operative site of an open two stage type II thoraco-abdominal aortic aneurysm repair.

≤ 10 mmHg during the first 72 hours for all patients, and extubation was performed as soon as possible.

Follow up

Follow up data were obtained during routine clinical examinations, which included physical examination. If these data were not available, for example for international patients, the patients and/or the referring physicians were contacted after obtaining patient consent. The follow up of patients receiving endovascular repair was augmented by CT scans after six and 12 months. Median length of follow up was 42 months (range 2—156). To assess completeness of individual follow up, the follow up index was calculated.[18]

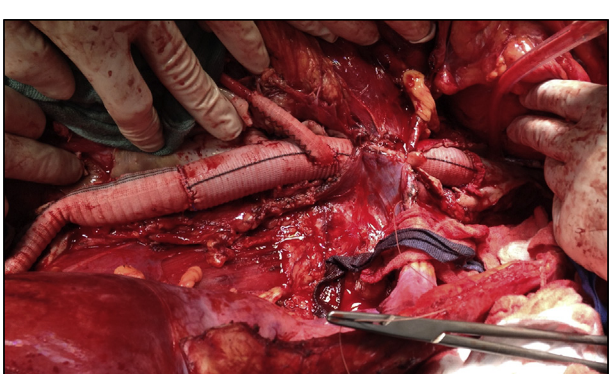

Figure 3. Intra-operative site of an open two stage type II thoraco-abdominal aortic aneurysm repair.

Statistical analysis

Statistical analyses were performed with MedCalc Version 15.8 (MedCalc Software, Ostend, Belgium), SPSS (version 22; IBM, Armonk, NY, USA), and SAS software version 9.4 (SAS Institute, Cary, NC, USA). All continuous variables are expressed as mean ± SD or as median (range) in case of skewed data. Categorical variables are expressed as absolute frequencies and percentages. Two tailed unpaired *t*-tests were performed to compare continuous baseline characteristics or procedural details between the open one and two stage TAAA repair (or between open two stage and hybrid repair). If data were skewed, a two tailed Mann Whitney *U*-test was used instead. Comparisons between frequencies were done with Fisher's exact tests.

The incidence rates of hospital mortality and the development of SCI were compared between the one stage and the open two stage repair groups using Firth's logistic regression. Odds ratios (OR) and corresponding 95% confidence intervals (CI) are reported. The influence of selected covariables, such as clinical, operative, and imaging data, was also investigated. Kaplan—Meier estimates were computed to assess the survival rates within the three different groups. A Cox regression model was used to compare the survival times between the one stage repair and the open two stage repair groups, and to evaluate the influence of selected covariables on the survival of patients. The corresponding hazard ratios (HRs) and 95% CIs are given. The level of significance was set at 5%. No adjustments were made for multiple comparisons.

RESULTS

Patient characteristics

This retrospective single centre study included 94 patients with type II TAAA treated between March 2006 and January 2016. The study was approved by the local ethics committee.

A total of 76 patients received one stage type II TAAA repair, and 18 patients were treated by two stage repair. Of the latter, 12 received open two stage repair and six received hybrid repairs that included open and endovascular treatment. The open two stage and the hybrid two stage repair groups have been assessed separately throughout the study. Seventy-one patients were male (75.5%); mean age was 55.52 ± 14 in the open one stage group, 50.0 ± 12.7 years in the open two stage group ($p = .23$), and 50.2 ± 19.6 in the hybrid repair group. The mean aortic aneurysm diameter was 63 mm (range 55—70) in the open one stage group and 60.5 mm (range 59—75) in the open two stage group (p = .684), and 66 mm (range 60—71) in the hybrid repair group. There were eight urgent/symptomatic cases (14.6%) in the open one stage group and one (9.1%) in the open two stage group (p = 1), and one in the hybrid repair group (20%).

Degenerative aneurysms occurred in 26 patients (34.2%) in the open one stage group and in five patients (41.6%) in the two stage group (p = .74), and in one in the hybrid repair group (16.6%).

A prior type B dissection was observed in 27 patients (37%) in the open one stage group and in seven patients (58.3%) in the open two stage group (p = 0.2; hybrid repair: two cases [33.3%]). Fifteen patients (19.7%) in the open one stage group had had prior open surgery of the ascending aorta, while three patients (25%) in the open two stage repair group had a history of open thoracic aortic surgery (p = .704; hybrid repair: two cases [33.3%]). There were no other differences between the two groups for any other comorbidity. Table 1 shows the patient characteristics.

The two stage subgroup

Twelve of 18 patients (66.6%) in the two stage group received type II TAAA open repair, while six (33.3%) received hybrid treatment involving TEVAR for the thoracic aortic aneurysm. The first open, as well as hybrid, staged repair were performed in 2006. The mean age was 50 ± 12.7 years in the open repair subgroup and 50.2 ± 19.6 years in the hybrid subgroup (p = .98). The mean interval between the two steps of the repair was 78.2 ± 61.3 days in the open repair subgroup and 14.2 ± 15.3 days in the hybrid subgroup (p = .004). The mean maximum diameter was 60.5 mm (range 59—75) in the open group and 66 mm (range 60—71) in the hybrid group (p = .85). The median length of the proximal aortic neck to the proximal landing zone for endovascular repair was 57.3 ± 22.6 mm in the open group and 37.0 ± 3.5 mm in the hybrid group (p = .001). Table 2 shows further details.

The indications for two open procedures (thoracic and abdominal) were connective tissue disease (CTD) in three cases and suitable anatomy according to the applied definition in nine cases. The indications for hybrid two stage procedures were severe chronic heart failure, and, in three cases, severe chronic kidney disease with a glomerular filtration rate < 30 mL/min/1.73 m^2 in one case and TAAA associated with severe thoracic deformity in two cases. The latter two patients suffered from type II TAAA related to Marfan syndrome and had had prior open aortic arch repair, which enabled an endovascular approach by creating a suitable proximal landing zone for the stent. One of these aneurysms was symptomatic. TEVAR was preferred to avoid re-thoracotomy in these two cases. Owing to the larger diameter, the first step in the open repair subgroup was a type I repair in 11 cases (91.6%) and a type IV repair in one case (8.4%) defined according to the guidelines of European Society of Vascular Surgery.[1] In the hybrid subgroup, open

Table 1. Demographics and comorbidities of patients undergoing one stage and two stage thoraco-abdominal aortic aneurysm type II repair

Parameter	Open repair			Hybrid repair
	One stage repair (n = 76)	Open two stage repair (n = 12)	p[a]	Hybrid two stage repair (n = 6)
Women, n (%)	23 (30.3)	2 (16.7)	.496	1 (16.7)
Age, years	55.2 ± 14.2	50.0 ± 12.7	.236	50.2 ± 19.6
Median ASA category (IQR)	3 (3—3) [63]	3 (3—3) [10]	.893	3 (3—4)
BMI (kg/m^2)	25.4 ± 4.6 [72]	25.7 ± 3.4 [11]	.856	23.9 ± 3.6
Mean aortic aneurysm diameter (mm)	63 ± 14.4 [74]	60.5 ± 15.0	.685	66 ± 7.6
Symptomatic/urgent, n (%)	8 (14.6) [55]	1 (9.1) [11]	1	1 (20.0) [5]
Degenerative aneurysm, n (%)	26 (34.2)	5 (41.6)	.747	1 (16.6)
CTD, n (%)	18 (23.7) [75]	4 (33.3)	.489	2 (33.3)
Type B dissection, n (%)	27 (37.0) [73]	7 (58.3)	.201	2 (33.3)
Prior open ascending aorta or arch repair, n (%)	15 (19.7)	3 (25)	.705	2 (33.3)
HAT, n (%)	58 (79.5) [73]	11 (91.7)	.449	3 (50.0)
Coronary artery disease, n (%)	14 (25.9) [54]	3 (27.3) [11]	1	1 (20.0) [5]
PAD, n (%)	7 (12.7) [55]	1 (8.3)	.658	1 (16.7)
CRI, n (%)	10 (13.5) [74]	1 (8.3)	1	1 (16.6)
Baseline creatinine (mg/dl)	1.1 ± 0.4 [74]	1.0 ± 0.2	.711	0.9 ± 0.2
Baseline haemoglobin (mg/dl)	12.8 ± 1.7 [55]	12.3 ± 2.2	.406	12.5 ± 2.0
COPD, n (%)	10 (13.5) [74]	3 (25.0)	.381	1 (16.7)
Smoking, n (%)	29 (61.7) [47]	4 (57.1) [7]	1	1 (50) [2]

Data are given as absolute numbers and percentages, n (%), if not indicated otherwise. Continuous data is reported as mean ± standard deviation (SD). In the case of missing values, the number of observed values is given in parentheses [*n*]. ASA = American Society of Anesthesiologists; BMI = body mass index; CTD = connective tissue disease; HAT = arterial hypertension; PAD = peripheral artery disease; CRI = chronic renal insufficiency; COPD = chronic obstructive pulmonary disease; SD = standard deviation; IQR = interquartile range..

[a] Comparison between one stage and open two stage repair using an unpaired *t*-test, Mann Whitney *U*-test or Fisher's exact test.

Table 2. Comparison of baseline characteristics between the two stage groups

Parameter	Open two stage repair (n = 12)	Hybrid two stage repair (n = 6)	p[a]
Age, years	50.0 ± 12.7	50.2 ± 19.6	.983
CTD, n (%)	4 (33.3)	2 (33.3)	1
Interval between steps (days)	78.2 ± 61.3	14.2 ± 15.3	.004
Aortic aneurysm diameter (mm)	60.5 (59–75)	66 (60–71)	.850
Length of proximal aortic neck/landing zone (mm)	57.3 ± 22.6	37.0 ± 3.5	.011
Neuromonitoring, n (%)	12 (100)	5 (100) [5]	1

Continuous data are reported as mean ± SD or as median (range) in case of skewed data. In the case of missing values, the number of observed values is given in parentheses [n]. CTD = connective tissue disease; IQR = interquartile range; SD = standard deviation.
[a] Comparison between open two stage and hybrid repair using an unpaired t-test, Mann Whitney U-test or Fisher's exact test.

type IV repair was followed by TEVAR as the second step in all cases. Two patients required left carotid-subclavian bypass, which was performed as a separate intervention before the TAAA repair.

Procedural details

The open two stage group had a longer overall procedure time: open one stage 484.2 ± 132.5 minutes versus open two stage 731.8 ± 130.4 minutes ($p < .001$); hybrid repair: 638.5 ± 267.3 minutes. The in hospital stay was also longer in the two stage group (one stage: 25 days [range 14.5–43.5]; open two stage: 51 days [range 31.5–72.5; $p < .001$]; hybrid repair: 35.5 days [range 30–51]). Total ventilation time was not different between the groups (open two stage: 211.5 minutes [range 30.5–501]; open one stage: 211.5 minutes [range 200–501; $p = .67$]; hybrid repair: 236 minutes [range 200–380]). Further details are given in Table 3.

Post-operative mortality and long-term survival

The in hospital mortality rate was 22.4% ($n = 17$) for open one stage repair, 0% for open two stage ($p = .112$), and 0% for hybrid repair.

The one year survival rate was higher in the open two stage group than in the open one stage group (one stage: 74.7% [$n = 57$; 95% CI 62.7–83.3]; open two stage: 90.9% [$n = 10$; 95% CI 50.8–98.7%]; hybrid repair: 100% [$n = 6$]). Similarly, the five year survival rate was higher in the open two stage group than in the one stage group (one stage: $n = 49$ [53.0%; 95% CI 37.2–66.5]; open two stage: $n = 10$ [90.9%; 95% CI 50.8–98.7]; hybrid repair: $n = 6$ [100%]). The follow up index was 0.8. The Kaplan–Meier curve displays long-term survival rates of patients receiving one and two stage type II TAAA repair (Fig. 4). The Cox regression analysis of the survival times after open one stage repair compared with open two stage repair showed a HR of 4.563 (95% CI 0.969–81.482; $p = .137$) (Table 4). Age was identified as a factor with significant influence on in hospital mortality rate and patient survival in the multivariable analysis (OR 1.059, 95% CI 1.013–1.120 [$p = .019$]; HR 1.056, 95% CI 1.020–1099 [$p = .005$]).

Further details regarding the multivariable analysis of factors influencing the in hospital mortality and the

Table 3. Comparison of procedural details of patients undergoing one stage and two stage thoraco-abdominal aortic aneurysm type II repair (open two stage repair and hybrid two stage repair illustrated separately)

Parameter	Open repair			Hybrid repair
	One stage repair (n = 76)	Open two stage repair (n = 12)	p[a]	Hybrid two stage repair (n = 6)
Procedural details				
Procedure time (min)	484.2 ± 132.5 [72]	731.8 ± 130.4	<.001	638.5 ± 267.3
Ventilation time (min)	211.5 (30.5–501) [56]	211.5 (200–501)	.678	236 (200–380)
Pathological MEPs, n (%)	42 (55.3)	3 (25)	.066	1 (16.7)
Stay on ICU (days)	12 (4–22) [72]	10 (5.5–18)	.858	6.5 (4–7)
In hospital stay (days)	25 (14.5–43.5)	51 (31.5–72.5)	.011	35.5 (30–51)
Re-implanted visceral/renal/infrarenal arteries/bypasses				
Coeliac, n (%)	28 (36.8)	2 (20.0) [10]	.483	2 (40.0) [5]
Superior mesenteric, n (%)	28 (36.8)	2 (16.7)	.208	2 (33.3)
Left renal, n (%)	76 (100)	12 (100)	1	6 (100)
Right renal, n (%)	28 (36.8)	2 (16.7)	.208	2 (33.3)
Combined re-implantation CT, SMA, right renal artery, n (%)	48 (63.2)	10 (83.3)	.208	4 (66.7)
Intercostal/lumbar, n (%)	42 (55.3)	6 (50.0)	.764	3 (50.0)

Continuous data are reported as mean ± standard deviation (SD) or as median (range) in case of skewed data. Categorical data are given as absolute frequencies and rates (%). In the case of missing values, the number of observed values is given in parentheses [n]. MEP = motor evoked potentials; ICU = intensive care unit; CT = coeliac trunk; SMA = superior mesenteric artery.
[a] Comparison between one stage and open two stage repair using an unpaired t-test, Mann Whitney U test or Fisher's exact test.

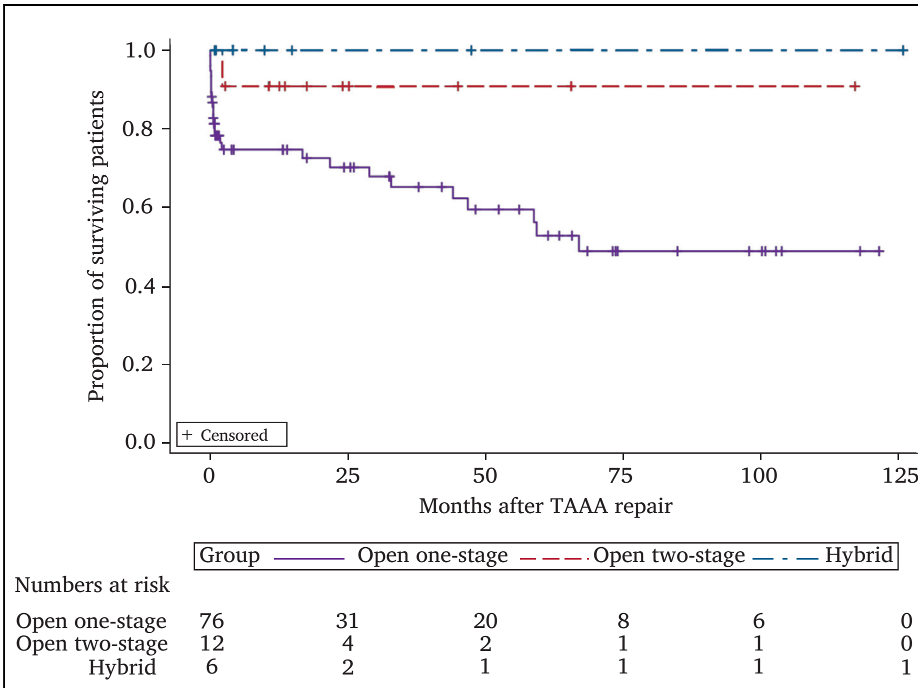

Figure 4. Kaplan Meier estimates of long-term survival of patients who underwent one stage and two stage type II thoraco-abdominal aortic aneurysm repair (TAAA).

survival rate can be found in the Tables S1 and S2 (Supplementary Material).

Post-operative morbidity

Paraplegia occurred in 10.5% ($n = 8$) after open one stage repair and 8.3% ($n = 1$) after open two stage repair ($p = 1$; hybrid repair 0%). Severe neurological complications were observed in 54% ($n = 41$) after open one stage repair and in 25% ($n = 3$) after open two stage repair ($p = .11$; hybrid repair: $n = 2$ [33.3%]). Further details regarding factors affecting the spinal cord ischaemia rate can be found in Table S3 (Supplementary Material).

Post-operative acute kidney injury (AKI) requiring permanent dialysis was observed in 3.9% ($n = 3$) of patients in the open one stage group and 0% in the open two stage group ($p = 1.0$; hybrid repair 0%). Post-operative myocardial infarction occurred in 5.2% ($n = 4$) of patients in the one

Table 4. Mortality of patients undergoing one stage and two stage thoraco-abdominal aortic aneurysm (TAAA) type II repair (open two stage repair and hybrid two stage repair illustrated separately)

Parameter	Open repair			Hybrid repair
	One stage repair ($n = 76$)	Open two stage repair ($n = 12$)	Estimated OR/HR (95% CI); p[a]	Hybrid two stage repair ($n = 6$)
Hospital mortality	17 (22.4)	0	7.352 (0.884–959.488); .191	0
Symptomatic patients, n (%)	8 (10.7)	0	–	0
Haemorrhage, n (%)	4 (5.3)	0	–	0
Neurological, n (%)	2 (2.6)	0	–	0
Cardiac, n (%)	4 (5.3)	0	–	0
Pulmonary, n (%)	5 (6.6)	0	–	0
Intestinal, n (%)	3 (3.9)	0	–	0
Intermediate to long-term survival estimates				
One year survival rate (%)	74.7 (62.7–83.3)	90.9 (50.8–98.7)	3.478 (0.717–62.591); .225	100
Five year survival rate (%)	53.0 (37.2–66.5)	90.9 (50.8–98.7)	4.485 (0.950–80.117); .141	100
Overall survival rate (%)	49.0 (32.6–63.4)	90.9 (50.8–98.7)	4.563 (0.969–81.482); .137	100

Intermediate to long-term survival is based on Kaplan-Meier estimates with 95% confidence interval (CI) if applicable. OR = odds ratio; HR = hazard ratio between one stage and open two stage.
[a] Analysed using Firth's logistic regression (hospital mortality) or Cox's proportional hazards model to compare the survival curves until 1, 5, or 10 years (survival times).

stage group and 0% in the open two stage group ($p = 1$; hybrid repair 0%). Stroke occurred in 9.2% ($n = 7$) of patients in the one stage group and in 8.3% ($n = 1$) of patients in the open two stage group ($p = 1$; hybrid repair 0%). Pulmonary complications, including acute respiratory distress syndrome and pneumonia, occurred more often in the two stage group (one stage: n = 35 [46.1%]; open two stage: $n = 18$ [66.7%]; $p = .22$; hybrid repair: $n = 1$ [16.6%]). Major revisions were more common after one stage repair (open one stage: $n = 43$ [56.5%]; open two stage: $n = 4$ [33.3%]; $p = .021$; hybrid repair: $n = 1$ [16.6%]). Post-operative morbidity data are summarised in Table 5.

DISCUSSION

The findings of this study indicate that open two stage repair for type II TAAA may have a favourable outcome compared with one stage repair in terms of mortality and comparable complication rates. Based on the favourable results, the authors' department uses the open two stage approach if anatomically feasible. Yet, nowadays, endovascular repair is the first line treatment for the majority of patients with TAAAs.[1,19,20] Today, open type II TAAA repair is performed in younger, fit patients, in patients with CTD, and in patients in whom endovascular repair is not feasible for anatomical reasons.

In hybrid two stage procedures, the abdominal part of the aorta was replaced by open means first (owing to the larger aortic diameter) followed by TEVAR within a few weeks.

Although the overall operative time was longer for the two stage group, the duration of each step was shorter than in the one stage group. Notably, the time between the surgical steps of a two stage repair allows patients to recover. As operative time is an independent risk factor for complications, this may explain the better outcome in the two stage group.[21] Furthermore, operative time and the extension of surgery are directly related to the surgical stress response and systemic inflammatory reaction.[22] Overall, the length of hospital stay was > 3 weeks in the open one stage group and > 7 weeks in the two stage group. Open one stage and two stage TAAA repair had a similar outcome with regard to post-operative myocardial infarction and cardiac mortality, yet there was no case in the in the two stage group. This may be owing, in part, to the younger age of the two stage repair group, as age is thought to strongly influence post-operative cardiac events and cardiac mortality.[23] Yet, the rate of coronary artery disease was similar for patients who underwent one stage and two stage repair. A non-significant increased rate of pulmonary complications was observed in the two stage repair group, which may be a result of the re-thoracotomy and could be considered a potential limitation of the two stage approach.

Regarding SCI, the incidences of paraplegia and paraparesis were lower after open two stage repair; in fact,

Table 5. Morbidity of patients undergoing one stage and two stage thoraco-abdominal aortic aneurysm type II repair

Parameter	Open repair			Hybrid repair
	One stage repair ($n = 76$)	Open two stage repair ($n = 12$)	p[a]	Hybrid two stage repair ($n = 6$)
Paraplegia[b]	8 (10.5)	1 (8.3)	1	0
Paraparesis[c]	9 (11.8)	0	.351	0
Stroke	7 (9.2)	1 (8.3)	1	0
Cerebral seizure	5 (6.6)	0	1	0
Critical illness polyneuropathy	5 (6.6)	2 (16.7)	.242	2 (33.3)
Intracerebral bleeding	4 (5.3)	0	1	0
Severe neurological complications	41 (54)	3 (25)	.118	2 (33.3)
Major revisions	43 (56.6)	4 (33.3)	.212	1 (16.7)
Re-laparotomy	17 (22.4)	3 (25)	1	1 (16.7)
Major bleeding requiring massive transfusion	21 (27.6)	2 (18.2) [11]	.720	1 (20) [5]
Endoleaks requiring re- intervention	0	0	1	1 (16.7)
Splenectomy	11 (14.5)	1 (8.3)	1	0
Incomplete abdominal closure	7 (9.2)	1 (8.3)	1	0
Pulmonary complications (pneumonia, ARDS)	35 (46.1)	8 (66.7)	.224	1 (16.7)
Tracheotomy	23 (30.7) [75]	4 (33.3)	1	1 (16.7)
AKI	39 (51.3)	6 (50)	1	3 (50)
AKI requiring temporary dialysis	36 (47.4)	6 (50)	1	3 (50)
AKI requiring permanent dialysis	3 (3.9)	0	1	0
Sepsis	21 (27.6)	6 (50)	.176	1 (16.7)
Peripheral ischaemia	2 (2.6)	1 (8.3)	.359	0
MI	4 (5.3)	0	1	0
Cardiac arrhythmia	12 (15.8)	5 (41.7)	.050	1 (16.7)

Data are given as absolute frequencies and proportions (%). In the case of missing values, the number of observed values is given in parentheses [*n*]. ARDS = acute respiratory distress syndrome; AKI = acute kidney injury; MI = myocardial infarction.

[a] Comparison between one stage and open two stage repair using Fisher's exact test.

[b] Paraplegia: complete loss of the motor function of the lower extremity.

[c] Paraparesis: incomplete loss of the motor function of the lower extremity.

there was only one case of paraplegia in the two stage group. Because of the small sample size, no significant differences were observed. These findings were comparable to those from other studies that reported favourable outcomes for spinal cord function after two stage type II TAAA repair.[10–12,24,25] In general, the rate of SCI in the one stage open repair group is increased particularly if compared to the reported rate after endovascular TAAA repair.[26] Sacrificing the intercostal and lumbar arteries changes the arterial network of the spinal cord and leads to an amplified inflow to the spinal cord.[13] Based on these findings, a two step type II TAAA repair may facilitate this compensation process.

Likewise, the rates of intracerebral bleeding and cerebral seizure were lower after two stage repair.

Two stage repair had no advantage over one stage repair regarding post-operative AKI. The ischaemia—reperfusion damage caused by aortic cross clamping is one of the most relevant factors in terms of inducing AKI after open TAAA repair.[27] Both one stage and two stage repair involve cross clamping, which may explain the comparable rates of kidney injury in the two groups.

The surgical repair of TAAA is associated with a high risk of complications, regardless of whether it is by open or endovascular means; open type II TAAA repair is related to the highest complication and mortality rates.[2,28] Even in specialised centres the mortality rate of these repairs can be as high as 20%, as seen in the Cleveland Clinic series.[9] Coselli et al. reported the largest series with favourable results and observed a mortality rate of 9.5% following type II TAAA repair.[28] Regarding the in hospital mortality rate in the present study, several factors have to be considered. First, the number of the procedures performed under urgent conditions. Furthermore, the number of patients who had prior surgery of the aortic arch or the ascending aorta, which may have influenced the complication and mortality rates, as described by Lombardi et al.[29] Notably, the five year survival rate after two stage TAAA repair in this study was favourable considering the overall survival rate of 63.6% of Coselli et al.[2] With regard to patient age, a significant influence on the hospital mortality rate and five year survival could be observed. Yet, there was no impact on the comparison of one stage and open two stage TAAA repair, as no difference in age was assessed between the group.

The surgical indication for an open two stage repair has to be considered carefully, especially regarding aneurysms of very large diameter. The increased arterial pressure during aortic cross clamping may lead to intra- or post-procedural aneurysm rupture or aortic dissection in the untreated segment of the aorta. If an aneurysm is symptomatic, the open two stage repair may be not feasible because of the necessity for an interval between the two steps of the surgical repair. Thus, a hybrid two stage procedure could be a better treatment option for symptomatic type II TAAA because of the much shorter interval between the required steps compared with a solely open two stage procedure. With regard to the hourglass configuration of the open two staged TAAAs, a lower aortic aneurysm volume could be assumed. This could be considered as a potential confounder, as a lower aortic aneurysm volume may correlate with a decreased mortality rate. A significantly longer proximal aneurysm neck could be observed in the open two stage repair group compared with the proximal landing zone in the hybrid group; this finding is considered to be statistical randomness.

Notably, the findings of this study are limited by its retrospective design and the sample size. Based on the size of the study group no significant results could be assessed regarding patient outcome after two stage repair compared with the one stage open repair. Yet, an improved outcome after two stage open type II TAAA repair remains likely.

Moreover, the hourglass shape of the open two stage treated TAAAs has to be mentioned as a potential confounder with regard to the lower aortic volume and thus lower mortality rate.

Furthermore, the data should be considered as hypothesis generating, as the two stage repair group only included 18 patients, six of whom were treated by a hybrid approach. As non-homogeneity of the intervention group should be avoided as much as possible, hybrid and open two stage repairs were assessed separately.

CONCLUSIONS

Open surgical repair of type II TAAAs is associated with a high risk of complications and mortality. In the present, not entirely comparable cohorts, a two stage type II TAAA repair showed a favourable in hospital mortality and long-term survival rate compared with one stage repair. If anatomically and surgically feasible, a two stage repair for type II TAAAs may therefore be recommended.

CONFLICTS OF INTEREST

None.

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APPENDIX A. SUPPLEMENTARY DATA

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