Original Article

Xenogeneic materials for the surgical treatment of aortic infections

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Background: The surgical treatment of aortic infections (AIs) is challenging. In situ aortic reconstructions represent nowadays the favored therapy for fit patients and xenogeneic materials are used increasingly. The aim of this study was to present our experience with xenogeneic reconstructions for AI using self-made bovine pericardium tubes and/or the biosynthetic Omniflow® II graft.

Methods: This retrospective single-center study included all patients undergoing xenogeneic aortic and aortoiliac reconstructions from December 2015 to June 2020. Patient comorbidities, symptoms, procedural characteristics, types of pathogens and postoperative outcomes were analyzed.

Results: Twenty-eight patients [23 male (82%), median age 68 (range, 28–84) years] were included. Ten patients (36%) had native AIs and 18 (64%) had graft infections, including 3 (11%) aortoesophageal and 2 (7%) aortoduodenal fistulas (ADF). Twenty-four patients (86%) were symptomatic, the most common symptoms being contained aortic rupture (n=8) and sepsis (n=4). The surgical procedures were infra- and juxtarenal aortic repairs (n=11, 39% and n=7, 25%), thoracoabdominal aortic repairs (type IV: n=1, 4%; type V: n=3, 11%), descending thoracic aortic repairs (n=4, 14%) and 2 reconstructions (7%) involving the ascending aorta/aortic arch. Most were urgent (n=10, 43%) or emergent operations (n=11, 35%). Identification of pathogen(s), mostly Gram-positive bacteria, was possible in 25 patients (89%). Twelve patients (43%) had polymicrobial infections and 6 (21%) infections with multi-resistant bacteria. In-hospital mortality was 32% (n=9) due to acute cardiac failure (1/9), endocarditis (1/9), bleeding (3/9) and sepsis (4/9). The most frequent complications were transient need for dialysis (n=12, 43%) and persisting sepsis (n=11, 39%). Two early occlusions of Omniflow® II grafts were observed (7%). Median follow-up (FU), during which 2 patients died of non-aortic causes, was 14 months (95% CI: 9–19 months). Freedom from reoperation was 100%, there was no evidence for reinfection during FU.

Conclusions: Xenogeneic orthotopic reconstructions for AI can be performed at all aortic levels. Combining bovine pericardium and the Omniflow® II graft can be useful for reconstructing the branched aortic segments and both materials show appropriate early to midterm outcomes. Nonetheless, AIs are serious conditions associated with relevant morbidity/mortality rates, even in a specialized center.

Keywords: Aneurysm; infected; prosthesis-related infections; bioprosthesis; vascular grafting; transplants

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Introduction

Aortic infections (AIs), including aortic graft infections (AGI) as well as mycotic aortic aneurysms (MAA), are rare (1,2). However, as laid out in the recent European Society of Vascular Surgery (ESVS) guidelines on AGI management, they represent a special challenge in clinical practice (1,2). One reason is the wide range of possible symptoms from clinically almost unapparent conditions to emergency situations in case of sepsis and/or rupture with consequently very high mortality rates of up to 43–75% (1-3).

Surgical therapy is usually required and orthotopic reconstruction, with graft explantation in case of AGI, is considered the treatment of choice (1). However, the choice of graft material is still a matter of debate (4,5). Xenogeneic materials are increasingly used because of the unlimited availability, good biocompatibility, avoidance of harvesting trauma and low reinfection rates (6). Most publications on xenogeneic reconstructions for AIs report the use of bovine pericardium (5,7-9). Another option is the biosynthetic Omniflow® II graft, for which favorable results have been shown when used for peripheral arterial reconstructions in an infected field (10,11). However, only few studies describe its use in the aortoiliac segment (12-15).

The aim of this study was to present our experience with xenogeneic aortic and aortoiliac reconstructions using bovine pericardium and the biosynthetic Omniflow® II graft either individually or as a composite graft.

We present the following article in accordance with the STROBE reporting checklist (available at http://dx.doi.org/10.21037/jtd-20-3481).

Methods

This was a retrospective single-center study. All patients who, in our center, underwent open aortic or aortoiliac reconstructions using xenogeneic grafts between December 2015 and June 2020 were included. These were all patients treated for aortic or aortoiliac infections during this time period. Indications, patient and procedural characteristics as well as the postoperative course including complications, mortality and follow-up were analyzed retrospectively. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Ethical board approval was obtained (EK 20-031), individual consent waived due to the retrospective study design. Results are reported according to the recommendations for reporting treatment of AGI (16).

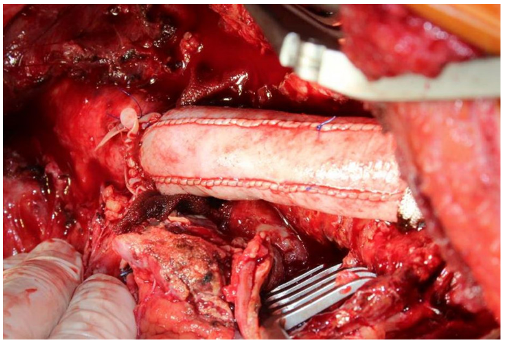

Figure 1 Self-made bovine pericardium tube graft for aortic reconstruction. It is manufactured on-table from a rectangular pericardium patch by suturing it around a metal dilator or a syringe of the respective size. We use a double running suture line with intermittent knots so that the length of the graft can be adjusted as required.

Xenogeneic graft materials

Either a bovine pericardium patch (XenoSure® Biologic Patch, LeMaitre Vascular, Sulzbach/Ts., Germany) or the ovine Omniflow® II Biosynthetic Vascular Prosthesis (LeMaitre Vascular, Sulzbach/Ts., Germany) or a combination of both materials were used to perform an orthotopic reconstruction. The choice of graft material was made individually by the surgeon and the xenogeneic graft was self-made during the procedure. Bovine pericardium was used to manufacture a tube graft (*Figure 1*) and an 8-mm Omniflow® II vascular prosthesis was used for reconstruction of the aortic bifurcation or of visceral arteries (*Figure 2A,B,C*).

Indications for orthotopic xenogeneic reconstruction

In one of the patients the indication for xenogeneic reconstruction was given due to a high risk for graft infection after extirpation of a very extensive malignoma with infiltration of the aortoiliac vessels and indication for subsequent chemotherapy and radiation. In all other patients xenogeneic reconstruction was performed for microbiologically proven or clinically suspected graft or native vessel infection. The diagnostic strategy was according to the criteria proposed by the MAGIC (Management of Aortic Graft Infection) group (17). In brief, after taking the medical history and a blood sample for laboratory analysis as well as blood cultures, all

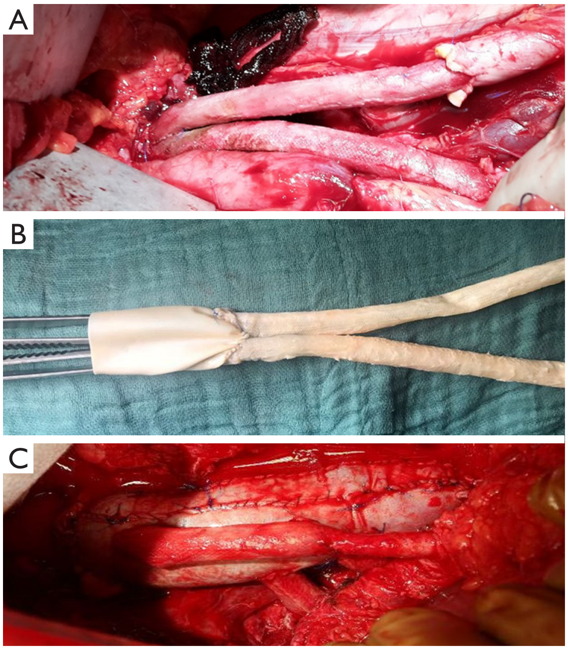

Figure 2 Omniflow® II graft used for xenogeneic reconstruction. (A) Reconstruction of the aortic bifurcation using only the Omniflow® II graft; (B) composite reconstruction of the aortic bifurcation consisting of a bovine pericardium tube and the Omniflow® II graft; (C) composite reconstruction of the visceral aorta using a bovine pericardium tube graft and the Omniflow® II graft for the visceral artery bypasses.

patients underwent a clinical examination and a computed tomography angiography (CTA) scan of the entire aorta. Further diagnostic steps were depending on the urgency of the situation, clinical presentation and the type of the (suspected) problem. For instance, when a periaortic fluid collection was detected that could be reached by CT-guided puncture, this was used for gathering a sample for microbiological analysis. When a fistula was suspected, endoscopy was performed (bronchoscopy and/ or gastroduodenoscopy and /or colonoscopy, depending on the localization). An additional 18-fluoro-D-deoxyglucose positron emission tomography/computed tomography (18-FDG-PET CT) scan is usually performed, especially in patients with low grade infections and thus little symptoms and often unremarkable findings on the CTA scan

Surgical protocol

The surgical access was a thoracolaparotomy through the 5th to 8th intercostal space for thoracic and thoracoabdominal aortic procedures, a sternotomy for treatment of an infected aneurysm of the brachiocephalic trunc and a clamshell access in a patient who needed simultaneous replacement of the ascending aorta, aortic arch and proximal descending aorta. Aortic and aortoiliac procedures were performed using a transperitoneal approach through a median laparotomy.

Thoracic and thoracoabdominal aortic procedures were realized according to our standard protocol for organ protection (18) including the use of cerebrospinal fluid drainage (CSFD), intraoperative monitoring of motor evoked potentials (MEPs), sequential aortic clamping if possible, extracorporeal circulation (ECC) with distal aortic perfusion as well as selective visceral perfusion under mild hypothermia of 32 to 33 ℃ and, since 2015, cold renal perfusion using 4 ℃ Custodiol®. If the ascending aorta and the aortic arch where involved, the operation was performed in moderate hypothermic circulatory arrest (25 ℃) and with antegrade cerebral perfusion as well as with additional transcranial doppler and electroencephalography monitoring. Following thoracic and thoracoabdominal aortic surgery, the mean arterial pressure (MAP) was adjusted based on MEPs and the intracranial pressure (ICP) was kept ≤10 mmHg during the first 48 to 72 hours postoperatively.

In all patients with graft infections the infected graft was removed completely.

Whenever possible intraoperative samples of the graft or aortic/aortoiliac tissue were gathered for microbiological analysis, otherwise swabs were taken from the aorta and periaortic area. Furthermore, a local debridement was performed by resecting periaortic/perigraft tissue and followed by rinsing with a polyhexanide solution and saline.

Adjunctive measures

All patients received an individualized perioperative anti-infective treatment after consulting with an infectiology specialist. If the pathogen was not known this was a calculated broad-spectrum therapy which was adapted as soon as the microbiological test results including resistance testing were available. The intraoperative antibiotic prophylaxis was chosen similarly. In non-emergent cases it was our goal to achieve an optimal infection control preoperatively. The duration of preoperative antibiotic therapy in those cases was usually at least two weeks intravenously. When the blood cultures were positive, the surgery was deferred until negative blood cultures could be asserted. The duration of a prolonged anti-infective treatment after discharge was determined individually according to the recommendation of the infectiology specialist.

Moreover, adjunctive interdisciplinary surgical measures were required in a number of patients. For instance, all patients with aortoesophageal fistula (AEF) underwent a staged treatment as described before (19), including esophagectomy followed by aortic reconstruction and, in a third stage, esophageal reconstruction. In patients with aortoduodenal fistula (ADF) an intestinal Roux-en-Y reconstruction was performed. The patient with the ureteral fistula underwent ureteral splinting prior to surgery followed by intraoperative end-to-end reconstruction of the ureter and placement of a temporary nephrostomy. Finally, in one patient presenting with a ruptured type V thoracoabdominal aortic aneurysm following MRSA-associated TEVAR infection and pleural empyema a simultaneous atypical resection of the destructed lower pulmonary lobe was necessary.

Anticoagulation regime

Intraoperatively all patients were anticoagulated with heparin aiming at an activated clotting time >200 seconds or >400 seconds if extracorporeal circulation was used. Postoperatively, prophylactic heparin and a single anti-platelet therapy (aspirin, 100 mg daily, or clopidogrel, 75 mg daily, in case of an allergy) were administered. Stronger anticoagulation was not given routinely, only when specific indications (e.g., atrial fibrillation) existed.

Follow-up (FU)

Whenever possible, the follow-up information was obtained from clinical routine controls including physical examination and imaging by duplex ultrasound and/or computed-tomography (CT)-angiography. In case of unavailability of those data, the patients were contacted for a telephone interview.

Statistical analysis

The statistical analysis was performed using SPSS Statistics for Windows, version 25 (IBM, Armonk, USA). Aside from the Kaplan-Meier survival analysis and calculation of median FU using the reverse Kaplan-Meier method according to Schemper *et al.* (20), only descriptive statistics are reported because of the small cohort size. The data are described as percentages, rounded to whole numbers in order to enhance readability, or as median and range. A 10% standard error was defined as a cut-off point for the Kaplan-Meier analysis. The patients lost to FU were excluded from the Kaplan-Meier analysis.

Results

Patient characteristics

A total of 28 patients were included. Twenty-three patients (82%) were male. The median age was 68 years (range, 28–84 years). Patient demographics and comorbidities are reported in *Table 1*. According to the MAGIC recommendation (17), the leading diagnostic criteria for AI were laboratory findings (positive cultures, elevated inflammatory markers) in 25 patients (89%) and clinical plus radiological findings, including suspicious fluorodeoxyglucose (FDG)-positron emission tomography (PET) scan, in the other 3 patients (11%). Ten patients (29%) had native AIs and 18 patients (64%) had graft infections, including 3 (11%) AEF and 2 (7%) ADF. A detailed overview over the types of infected aortic grafts, respectively the types of prior aortic procedures, is given in *Table 2*. All graft infections were cavitary infections (15). Furthermore, 16 were late (>4 months) and 2 early graft infections. Additionally, 4 patients (14%) had a history of abdominal non-aortic surgery. Twenty-four patients (86%) were symptomatic with varying clinical presentation. The most common symptoms were contained aortic rupture in 8 patients (29%) followed by sepsis in 4 patients (14%) whereas mild or unspecific symptoms were less frequent. *Table 3* gives an overview over symptoms and laboratory parameters.

Procedural characteristics

As demonstrated in *Table 4* most of the procedures were urgent (n=10, 36%) or emergent operations (n=11, 39%). The majority were infrarenal and juxtarenal aortic repairs (n=11, 39% and n=7, 25%, respectively). One patient (4%) underwent a thoracoabdominal type IV repair, 3 patients (11%) underwent type V thoracoabdominal aortic repairs and 4 patients (14%) underwent thoracic aortic repairs. Moreover, 1 patient (4%) with an AEF and a history of ascending and aortic arch repair as well as TEVAR as a bridging procedure was treated by a redo replacement of the ascending aorta, aortic arch and proximal descending aorta via a clamshell approach and 1 patient (4%) with an

Table 1 Patient characteristics

Patient characteristics	Overall (n=28)	Subgroup death (n=11)
Basic demographics		
Age (years)	68 [28–84]	68 [28–84]
Male, n [%]	23 [82]	9 [82]
Comorbidities, n [%]		
Hypertension	26 [93]	9 [82]
Coronary artery disease	11 [39]	4 [36]
Chronic renal insufficiency	6 [21]	4 [36]
Diabetes	6 [21]	3 [27]
COPD	3 [11]	2 [18]
Malignoma	4 [14]	1 [9]
Under immunosuppression	4 [14]	2 [18]
Rheumatoid arthritis	2 [7]	1 [9]
Crohn's disease	1 [4]	1 [9]
Psoriasis	1 [4]	0 [0]
PAD	10 [36]	3 [37]
Thrombophilia	1 [4]	0 [0]
Congestive heart failure	1 [4]	1 [9]
Obesity (BMI >25)	10 [36]	4 [36]
ASA class ≥4	15 [54]	6 [55]
Graft infection	18 [64]	6 [55]
Native aortic infection	10 [29]	5 [45]
Prior aortic surgery	18 [64]	6 [55]
Urgent/emergent procedure	5 [18]	2 [7]
Prior open abdominal surgery (non-aortic)	4 [14]	2 [18]
Urgent/emergent procedure	2 [7]	1 [9]

Data are presented as n [%] or median [range]. PAD, peripheral arterial disease; COPD, chronic obstructive pulmonary disease; BMI, body mass index; ASA, America Society of Anesthesiologists.

infected aneurysm of the brachiocephalic trunc was treated by aneurysm resection and bypasses from the ascending aorta to the right carotid and right subclavian arteries.

The median operating time was 383 minutes (247–585 minutes).

Pathogens

The responsible microorganism(s) were identified in 25 patients (89%) based on positive blood cultures alone (2/25), positive cultures from intraoperative specimens or periaortic aspirate (15/25) or a combination of both of the aforementioned sources (7/25). Gram-positive bacteria were found in 32 cases, Gram-negative bacteria in 7 cases and fungi in 5 cases. The types of identified pathogens are presented in *Figure 3*. 12 patients (43%) had infections with multiple microorganisms and 6 patients (21%) with multi-resistant bacteria.

Table 2 Types of aortic graft infections/prior aortic procedures

Type of graft infection/prior aortic procedure	Total patient number: n=28
AEF	3 [11]
After TEVAR	2 [7]
After ascending + arch OAR	1 [4]
ADF	2 [7]
After infrarenal OAR	2 [7]
Infrarenal OAR	4 [14]
BEVAR	1 [4]
TEVAR + chimney	2 [7]
TEVAR + chimney left subclavian artery	1 [4]
TEVAR + reverse chimney celiac trunc	1 [4]
EVAR	6 [21]

Data are presented as n [%]. Percentages are calculated referring to the total study population of 28 patients. AEF, aortoesophageal fistula; ADF, aortoduodenal fistula; OAR, open aortic repair; EVAR, endovascular aortic repair; TEVAR, thoracic EVAR; BEVAR, branched EVAR.

Early outcomes

In-hospital mortality was 32% (n=9). One patient died intraoperatively during an urgent TAA repair due to acute cardiac insufficiency. He suffered from congestive heart failure (ejection fraction <40%) and had requested the operation despite the high operative risk. One patient developed endocarditis of the aortic valve and died due to subsequent refractory ventricular fibrillation. Four patients died due to sepsis despite maximal therapy. In one of those patients, the postoperative course was complicated by acute mesenteric ischemia due to an early aortomesenteric bypass occlusion requiring, after mesenteric revascularization, hemicolectomy and small bowel resection. Finally, 3 patients had recurrent diffuse bleeding from the operating site requiring re-operations. One of those patients had undergone extirpation of an extensive retroperitoneal tumor and showed a very rapid tumor progression postoperatively so that a palliative care approach was ultimately adopted. In the two other patients, the combination of septic and hemorrhagic shock was fatal. There were no anastomotic breakdown and no signs of residual infection in the operative situs in those patients.

The median duration of stay in the intensive care unit was 6 days (3–147 days) and the median duration of hospital stay was 30 days (4–177 days). The early morbidity is summarized in *Table 5*. The most common complication was acute renal insufficiency requiring transient dialysis in 12 patients (43%). Seven of those patients died while on dialysis but none of the survivors required permanent dialysis. The second most frequent complication was persisting sepsis (n=11, 39%), mainly due to pulmonary infections (n=8, 29%). Notably, the postoperative course was complicated by early occlusions of Omniflow® II bypasses in 2 patients (7%). One of those was the above-mentioned case of mesenteric ischemia and in the other patient this was the result of an impaired run-off due to peripheral arterial disease. Six patients (21%) had an uncomplicated postoperative course.

Late outcomes and reinterventions

Median estimated FU was 14 months (95% confidence interval: 9–19 months). Two patients were lost to FU and 2 of the remaining 17 patients died during FU due to non-aortic causes, one patient 15 months after discharge and the other 33 months after discharge. *Figure 4* shows the Kaplan-Meier estimate of over-all survival. The estimated overall survival was 61%.

None of the patients required aortic reoperations during FU. and there was no evidence for reinfection, based on clinical and laboratory examinations, routine ultrasound and CTA controls, neither among the surviving nor among the deceased patients. The only non-aortic surgical intervention was an incisional hernia repair in a patient following juxtarenal aortic repair.

The patient who had undergone xenogeneic infrarenal aortic reconstruction with reconstruction of the ureter and temporary percutaneous nephrostomy for an iatrogenic ureteral fistula complained of persisting weakness, weight loss and diarrhea 4 weeks postoperatively. A campylobacter jejuni infection and a urinary infection with *Enterococcus faecium* were found as cause although no bacteria had been detected before and during the initial surgery. After completion of the antibiotic treatment, which was complicated by a mild candida esophagitis, his symptoms resolved. In all other patients the FU was uncomplicated. Thus, the hospital readmission rate was 13% (2/15).

Table S1 gives a detailed case by case overview over the included patients and procedures, microorganisms and outcomes.

Discussion

This study shows that xenogeneic orthotopic reconstructions

Table 3 Clinical presentation

Clinical aspect	Overall (n=28)	Subgroup death (n=11)
Symptoms		
Asymptomatic	4 [14]	1 [9]
Symptomatic	24 [86]	10 [91]
Unspecific/fatigue	3 [11]	2 [18]
Recurrent fever	2 [7]	1 [9]
Pain	1 [4]	0 [0]
Sepsis	4 [14]	1 [9]
Recurrent GI bleeding	1 [4]	1 [9]
Contained rupture	8 [29]	3 [27]
Hemorrhagic shock	3 [11]	1 [9]
Tracheal compression	1 [4]	1 [9]
Chronic cutaneous fistula	1 [4]	0 [0]
Laboratory parameters		
WBC/nL	11 [4–22]	17 [6–22]
CRP mg/L	61 [16–350]	81 [16–350]
PCT mg/mL	0.1 [0–12]	0.8 [0–12]
Hb g/dL	10 [6–15]	9 [6–15]
Hct %	30 [18–44]	27 [18–41]

Data are presented as n [%] or median [range]. WBC, white blood cell count; CRP, C-reactive protein; PCT, procalcitonin; Hb, hemoglobin; Hct, hematocrit.

can be performed at all aortic levels for aortic graft and native AIs leading to reasonable outcomes during early to mid-term FU. Both of the herein used graft materials, bovine pericardium and the Omniflow® II graft, show good results with 100% freedom from reinfection and from aortic reintervention. The combination of both materials can be useful for reconstructing the aortic bifurcation and the viscerorenal or supra-aortic branches. Nonetheless, aortic graft and native infections (AI) are challenging conditions that are associated with relevant morbidity and mortality rates even in a specialized center.

Diagnosis and treatment of patients with AI is complex and requires multidisciplinary expertise (1,2). Rifampicin-soaked grafts or silver impregnated graft have been used traditionally for *in situ* reconstructions for AI in the past, however it has been found that the duration of the anti-infective effect is limited. Thus, they can still represent an option for treating low grade infections, but do not represent the favored material (1). Instead, orthotopic reconstruction with non-prosthetic materials is nowadays recommended as the treatment of choice in fit patients (1,4,21). Autologous vein has shown the best outcomes in terms of infection resistance and survival and, therefore, is recommended as the first choice graft material (1). However, when large caliber reconstructions are required as in abdominal AIs, only the deep femoropopliteal veins are available as autologous material. Although superior survival rates have been reported compared to antibiotic-soaked or standard prosthetic graft reconstructions (22), femoropopliteal vein harvesting can cause chronic venous hypertension in up to 15% of the patients, leads to significantly longer operating times and, ideally, requires two operating teams (4,22,23). This reduces the suitability of this technique in urgent or emergent settings which was the case in 78% of the herein reported procedures. Moreover, the deep femoral veins are not suitable for reconstructing the thoracic aorta. In this localization, cryopreserved homografts represent traditionally the only

Table 4 Procedural characteristics

Procedural characteristics	Overall (n=28)	Subgroup death (n=11)
Extent of procedure		
Infrarenal repair	11 [39]	3 [27]
Juxtarenal repair	7 [25]	3 [27]
+ left renal bypass	1 [4]	0 [0]
TAAA Type IV repair	1 [4]	0 [0]
TAAA Type V repair	3 [11]	3 [27]
TAA repair	4 [14]	1 [9]
+ left subclavian bypass	1 [4]	0 [0]
Ascending + arch + proximal descending	1 [4]	0 [0]
Ascending + left carotid and left subclavian bypass	1 [4]	1 [9]
Urgency of procedure		
Elective	7 [25]	2 [18]
Urgent	10 [36]	5 [45]
Emergent	11 [39]	4 [36]
Duration of procedure		
Operating time (minutes)	383 [247–585]	385 [245–541]

Data are presented as n [%] or median [range]. TAAA, thoracoabdominal aortic aneurysm; TAA, thoracic aortic aneurysm.

non-prosthetic alternative. However, the availability (4,6), as well as the risk for re-infection, degeneration and bleeding (4,21,24) as well as the still lacking long-term results (1) remain a relevant limitation of aortic reconstructions with this type of graft material. Therefore, readily available non-prosthetic materials are particularly attractive for treating AI.

Several studies have reported very good early to midterm results with self-made bovine pericardial grafts for aortic reconstructions at different levels (5,7-9,25,26). In particular, the repeatedly observed high resistance to infection (freedom from reinfection up to 100%) combined with good patency and low reintervention rates distinguish bovine pericardium from other available graft materials when used for aortic reconstructions in case of infection (7). Indeed, the high resistance of bovine pericardium to bacterial colonization has also been confirmed *in vitro* (27). Accordingly, no aortic reinfections or reinterventions were observed in the present study. Based on these positive properties of bovine pericardium, an off-the-shelf bifurcated pericardium graft that can be used for aortoiliac reconstructions has recently become available and two studies have reported promising results during early to midterm follow-up (28,29).

In addition to reconstructing the aorta itself, 5 patients (18%) in this study required reconstruction of the viscerorenal vessels and 2 patients (7%) of the supra-aortic branches. Although the reconstruction of the viscerorenal aortic segment and its branches using only bovine pericardium as graft material is feasible (9), manufacturing multiple pericardium tubes intraoperatively is certainly time-consuming and, therefore, less convenient in these already highly complex procedures. The Omniflow® II graft, consisting of an ovine collagen matrix on a polyester mesh, seems to be a promising alternative for such cases. Although concerns about its resistance to bacterial colonization have been raised in an *in vitro* study (27), results from clinical practice, most of which regard peripheral arterial reconstructions, have shown a good infection resistance so far (10-12,30). Moreover, excellent early to midterm patency without reinfection has been reported in a case series using the Omniflow® II graft for reconstruction of the aortic bifurcation alone or in combination with a bovine pericardium tube (31) and its usefulness in reconstructing the aortic arch in the event of infection has also been demonstrated (8).

The present study confirms these positive results using

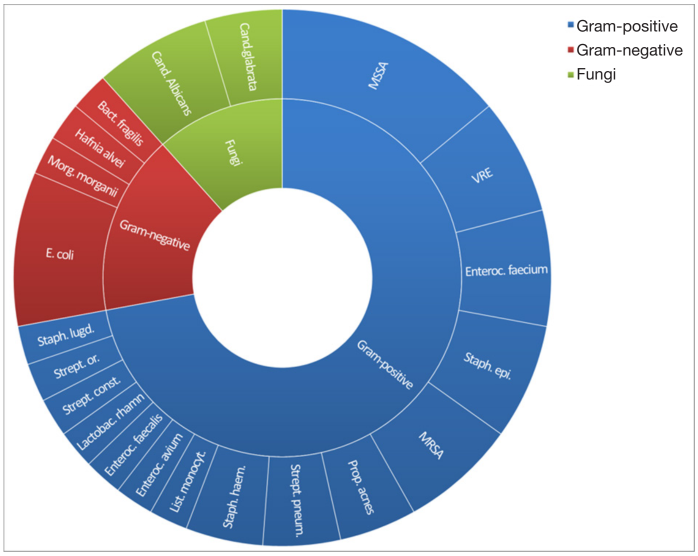

Figure 3 Overview over detected pathogens. Cand., Candida; E. coli, Eschericia coli; Bact., Bacteroides; Morg., Morganella; Staph.lugd., Stapylococcus lugdunensis; Staph. const., Stapylococcus constellatus; Staph. haem., staphylococcus haemolyticus; Staph.epi., Staphylococcus epidermidis; Strept.or., Streptococcus oralis; Strept. pneum., Streptococcus pneumonia; Lactobac.rhamn, Lactobacillus rhamnosus; Enteroc., Enterococcus; List.moncyt., Listeria monocytogenes; Prop., Propionibacterium; MSSA, methicillin-sensitive staphylococcus aureus; MRSA, methicillin-resistant staphylococcus aureus; VRE, vancomycin-resistant enterococcus.

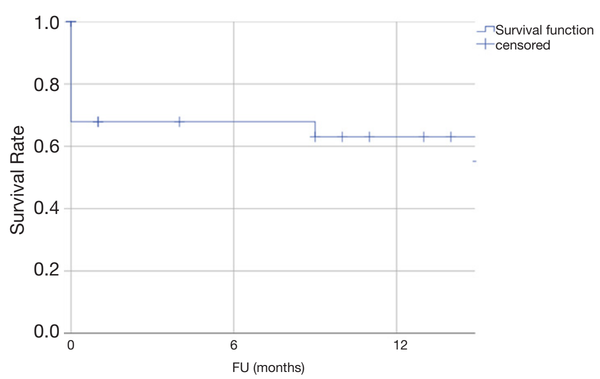

Figure 4 Kaplan-Meier analysis of overall survival. A 10% standard error was used as cut-off point.

the Omniflow® II graft for the afore-mentioned indications and is the first to describe its use for replacement of the viscerorenal aortic branches. However, in one of those patients an early mesenteric bypass occlusion occurred with subsequent mesenteric ischemia requiring extensive bowel resection. Since no technical problem was found during the revision surgery, the lower resistance to kinking as well as the initially higher thrombogenicity of this graft (6) may have caused this early complication. They should be kept in mind when implanting the Omniflow® II graft and, in addition to precisely following the manufacturers guidelines on appropriate graft rinsing with heparin prior to implantation, a higher anticoagulation regime in the early postoperative period might be considered. However, this has to be weighed individually against the bleeding risk, which represented a relevant complication in this series.

Despite the good technical outcomes in this study, the 32% early and 39% overall mortality rates are relevant. Mortality rates of patients with AI can vary significantly depending on multiple factors, i.e., the clinical presentation of the patient or rather the urgency of repair combined with the type and extent of treatment (1). Our results are in accordance with those of most other authors (4,8,21) and reflect the severity of disease in this specific patient cohort in addition to the seriousness of AI in general. Ongoing sepsis with subsequent multi-organ failure has been reported as a major cause of death in patients after xenogeneic orthotopic aortic reconstructions in AI patients (4). This was also the main cause of death in the majority of the patients in the present study and is also reflected by the higher levels of leukocytes, CRP and PCT in the subgroup of patients who died during the hospital stay. Moreover, comorbidities that are known to increase the

Table 5 Early complications

Complication	Overall (n=28)	Subgroup in-hospital death (n=9)
No complication	6 [21]	0 [0]
Major bleeding	4 [14]	4 [44]
Acute cardiac insufficiency/severe arrhythmia	2 [7]	2 [22]
Pneumonia/pleural empyema	8 [29]	5 [56]
Sepsis	11 [39]	8 [89]
Transient dialysis	12 [43]	0 [0]
Death while on dialysis	7 [21]	7 [78]
Stroke	1 [4]	0 [0]
Minor subarachnoideal bleeding	1 [4]	1 [11]
Paraparesis	1 [4]	0 [0]
Extremity ischemia	2 [7]	1 [11]
Gluteal ischemia	1 [4]	0 [0]
Mesenteric ischemia	1 [4]	1 [11]
Compartment syndrome calf	2 [7]	1 [11]
Transient liver failure	1 [4]	0 [0]
Malignant hypertension due to stenosis distal anastomosis	1 [4]	0 [0]
Deep venous thrombosis	1 [4]	0 [0]
Anastomotic insufficiency of gastric esophagoplasty	1 [4]	0 [0]
Endokarditis	1 [4]	1 [11]

Data are presented as n [%].

operative risk such as chronic renal insufficiency, COPD and immunosuppression were more frequent in this subgroup of patients. Bleeding complications, mostly diffuse, represent another important aspect contributing to the early morbidity and mortality in the present cohort. The high proportions of patients presenting with contained rupture (29%), of patients with prior aortic (64%) and prior abdominal non-aortic surgery (14%) are a relevant risk factor in this regard.

Limitations

The retrospective nature of this study as well as the heterogeneity of the procedures including aortic reconstructions at all levels are the main study limitations. However, AIs are rare and the clinical presentation of patients can vary significantly. In addition to presenting our overall experience with these procedures, it was also the aim of this study to point out the applicability of the reported technique for different types of aortic reconstruction thereby increasing the transferability of our findings to similar clinical situations. Finally, in view of the relatively small study population, the lack of FU data after discharge for two patients is also a limitation of this study.

Conclusions

Treating patients with AIs is challenging and, as recommended also in the recent guidelines, multidisciplinary expertise is mandatory. Among the available graft materials for aortic reconstruction, bovine pericardium und the biosynthetic Omniflow® II graft represent valuable and versatile alternatives to autologous vein or cryopreserved homografts, especially in case of urgent or emergent procedures. Long-term data are desirable to validate these findings.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Ethical board approval was obtained (EK 20-031), individual consent was waived due to the retrospective study design.

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Supplementary

Table S1 Case by case overview over the patients including data on basic demographics, diagnoses, procedures, bacteria and outcomes

Patient number	Age (years)	Gender	Diagnosis	Symptoms	Type of previous aortic surgery	Previous non-aortic open surgery	Pathogen	Type of repair	Material used for reconstruction	Early complications	Complications during follow-up	Death (yes/no)
1	66	M	AEF	Bleeding	TEVAR	Esophagectomy	Enterococcus faecium	TAA	Bovine			No
2	72	M	Mycotic infrarenal PAU	Contained rupture	None		SA	Infrarenal	Bovine			No
3	62	M	PAD Fontaine IV, TAAA type III (endovascular repair planned)	Chronical cutaneous fistula greater trochanter + ischium	infrarenal bifurcated graft (aortobiiliac)	Anus praeter, interposition graft for SMA aneurysm	Enterococcus faecalis, Corynebacterium tuberculosteari-cum, Bacteroides fragilis, Staphylococcus epidermidis	Infrarenal	Bovine+ Omniflow® II	Gluteal ischemia		No
4	68	M	Infected EVAR due to access psoas muscle	Recurrent fever	EVAR		SA, Staphylococcus haemolyticus	Juxtarenal	Bovine+ Omniflow® II	Pneumonia, sepsis, bleedig, death while on dialysis		Yes
5	84	M	Mycotic infrarenal AAA + iliac artery aneurysm	Contained rupture, sepsis			SA	Infrarenal	Bovine	Endocarditis -> refractory ventricular fibrillation, death while on dialysis		Yes
6	78	M	TAAA type IV	Contained rupture, sepsis	EVAR		Escherichia coli	TAAA type IV	Bovine + Omniflow® II	Pneumonia, sepsis, transient liver failure, transient dialy-sis		No
7	76	F	Large periprosthetic fluid collections	None	Infrarenal bifurcated graft (aortobifemoral)		Staphylococcus lugdunensis	infrarenal	Omniflow® II			No
8	52	M	Inflammatory TAAA type IV	None		Partial resection of ileum for perforation due to foreign body ingestion	Initially: none; after revision for paralytic ileus: Escherichia coli + VRE	TAAA type V	Bovine+ Omniflow® II			Yes
9	72	M	Mycotic infrarenal AAA	Abdominal pain			Listeria monocytogenes	Infrarenal	Omniflow® II			No
10	70	M	Type Ia endoleak, Aortitis	Unspecific symptoms/fatigue	BEVAR		Staphylococcus epidermidis	TAA	Bovine	Acute cardiac insufficiency		Yes
11	42	F	AEF, mediastinitis	Recurrent respiratory infections, cough, thoracic pain	Supracoronary repair of aortic arch and ascending aorta with reconstruction of aortic valve		Lactobacillus rhamnosus	ascending, arch + proximal descending	Bovine	Pneumonia, sepsis, transient dialysis, stroke, anasto-motic insufficiency (gastric esophagoplasty)		No
12	67	M	Mycotic TAAA type V	Rupture, septic shock	TEVAR + Chimney celiac trunc		MRSA	TAAA type V	Bovine	Bleeding, sepsis, death while on dialysis		Yes
13	73	M	Infected EVAR	Unspecific symptoms/fatigue	EVAR		Propionibacterium acnes	Juxtarenal	Bovine+ Omniflow® II	Pneumonia, sepsis, transient dialysis	Repair of incisional hernia	Yes
14	69	M	Infected EVAR	Recurrent fever, sepsis	EVAR		Referring hospital: MRSA; authors' institution: Staphylococ-cus epidermidis	INFRARENAL	BOVINE+ OMNIFLOW® II			No
15	66	M	ADF	Recurrent gastrointestinal bleeding requiring blood transfusion	Infrarenal tube graft (x2)		Initially: Escherichia coli; Candida glabrata; during relaparo-tomy after 3 weeks: VRE	Juxtarenal	Bovine	Bleeding, sepsis, extremity ischemia, compartment syn-drome calf, death while on dialysis		Yes
16	53	M	Infected TEVAR	Sepsis	TEVAR + Chimney left subclavian artery		SA	TAA + left subclavian bypass	Bovine+ Omniflow® II	Pneumonia, sepsis, malignant hypertension due to stenosis distal anastomosis		No
17	28	F	High-grade carcinoma of felopian tube	Hemorrhagic shock		extensive abdominal tumor resection (total exenteration, deperitonealization, lymphadenectomy, ileum conduit, ko-lostoma endst.), two revisions for bleeding 7 and 8 days postoperatively	initially: Candida albicans, during revision surgery: VRE	infrarenal	Omniflow® II	bleeding, minor subarachnoideal bleeding, deep venous thrombosis, death while on dialysis		Yes
18	62	M	Ureteral fistula	Weight loss, nausea, unspecific abdominal pain	Infrarenal bifurcated graft (aortobiiliac)		None	Infrarenal	Omniflow® II		Campylobacter jejuni infection, urinary infec-tion with Enterococcus faecium	No
19	45	M	Inflammatory infrarenal PAU	Contained rupture			None	Juxtarenal	Omniflow® II			No
20	77	M	mycotic aneurysm brachiocephalic trunc	sepsis, tracheal compression			SA, Enterococcus faecium	ascending + right carotid and right subclavian bypass	bovine+ Omniflow® II	pneumonia, sepsis		Yes
21	72	M	ADF	Sepsis	Infrarenal bifurcated graft (aortobiiliac)		Streptococcus constellatus ; Streptococcus oralis	Infrarenal	bovine+ Omniflow® II			No
22	58	M	Mycotic juxtarenal plaque rupture	Rupture			Streptococcus pneumoniae	Juxtarenal	bovine+ Omniflow® II			No
23	57	M	Infected aortobifemoral graft	Sepsis	Infrarenal bifurcated graft (aorto-biiliac), infrarenal bifurcated graft (aortobifemoral)		Candida albicans, Candida glabrata, Hafnia alvei	Infrarenal	Omniflow® II	Bleeding, sepsis, death while on dialysis		Yes
24	76	M	Infected EVAR, Type I EL		EVAR		Propionibacterium acnes; Staph. Haemolyticus	Infrarenal	Omniflow® II			No
25	71	F	TAAA Type V	Contained rupture			Strept. Pneumoniae	TAAA type V	bovine+ Omniflow® II	Mesenteric ischemia, death while on dialysis		Yes
26	71	F	Infected aortobifemoral graft	None	Infrarenal aortobifemoral		None	Juxtarenal	Omniflow® II			No
27	61	M	Infrarenal AAA + juxtarenal PAU	Contained rupture			SA; C. alb., E. coli, Enterococcus avium, Morg, morganii, Enterococc faecium	Juxtarenal	bovine+ Omniflow® II	Pneumonia, sepsis, extremity ischemia, compartment syndrome calf, transient dialysis		No
28	59	M	AEF	Bleeding, sepsis	TEVAR		MRSA, VRE	TAA	Bovine	Pneumonia, sepsis, parapersis, transient dialysis		No

AAA, abdominal aortic aneurysm; ADF, aortoduodenal fistula; AEF, aortoesophageal fistula; ATBAD, acute type B aortic dissection; BEVAR, branched endovascular aortic rpair; C. alb., Candida albicans; E. coli, Escherichia coli; EL, endoleak; EVAR, endovascular aortic repair; f, female; m, male; Morg. Morganii, Morganella morganii; MRSA, multi-resistant staphylococcus aureus; PAU, penetrating aortic ulcer; SA, staphylococcus aureus; Strept., streptococcus; TAA, thoracic aortic aneurysm; TAAA, thoracoabdominal aortic aneurysm; TEVAR, thoracic endovascular aortic repair; VRE, vancomycin-resistant enterococcus.

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