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Open Surgical Treatment for Chronic Mesenteric Ischemia - Revascularization Techniques, Operative and Clinical Outcomes

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Abstract

Chronic mesenteric ischemia represents a special challenge in its management. For an optimal revascularization, it requires a great expertise in choosing and carrying out the indicated mesenteric reconstruction. Because of its insidious course, appropriate diagnosis-finding of chronic mesenteric ischemia is not always easy. In its later stages the patients complain of abdominal angina, marked weight loss and ischemic colitis. The clear indication for a vascularsurgical therapy of chronic mesenteric ischemia exists only if there is a stenosis or occlusion of at least 2 of the 3 mesenteric arteries. There are several diagnostic modalities for the diagnosis of mesenteric ischemia such as Duplex-ultrasonography, CTA, MRA and DSA. In principle, there are several reconstruction procedures for the mesenteric vessels. According to the origin of bypass and the direction of arterial flow (compared to the aorta), there are antegrade and retrograde reconstructions. Other surgical techniques such as thrombendarteriectomy and decompression of median arcuate ligament could also be used in some special cases if indicated. The antegrade versus retrograde group offers more primary patency rates perioperatively (90.5 % vs. 70.6 %), this difference was not found at longer follow-up, such as at one year and five years. The benefits of complete revascularization, however, were obtained at the expense of a tendency of more early postoperative complications (83.3 % vs. 55 %). The mortality in the perioperative period was significantly higher in the 2-vessel group (27.8 % vs. 0 %, p=0.017). The vascular surgeon should be prepared to perform various techniques of mesenteric reconstruction (antegrade and retrograde, single or multiple vessels, autologous or alloplastic etc.).

Key words

Chronic mesenteric ischemia – Visceral/Mesenteric arteries - Risk factors – Bypass – Pre-/Intra-/Peri-/Post-operative –open reconstruction – single vessel – multiple vessels – antegrade – retrograde – Therombaretriectomy – Venous graft – Prosthesis – PTFE – Dacron – Image-guided radiology

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List of Abbreviations

ACR	American College of Radiology
ANCA	Antineutrophilic cytoplasmic antibody
BMI	Body mass index
CA	Celiac axis
CE-MRA	Contract enhanced magnetic resonance angiography
CHA	Common hepatic artery
CHD	Coronary heart disease
CHF	Congestive chronic heart failure
CMI	Chronic mesenteric ischemia
CRF	Chronic renal failure
CTA	Computed tomography angiography
CVD	Cerebrovascular disease
DSA	Digital subtraction angiography
DM	Diabetes mellitus
EDV	End-diastolic velocity
ePTFE	Expanded polytetrafluoroethylene
GDA	Gastroduodenal artery
GP	General practioner
GSV	Great saphenous vein
HLP	Hyperlipoproteinemia
ICU	Intensive care unit
IMA	Inferior mesenteric artery
IMV	Inferior mesenteric vein
LGA	Left gastric artery
MAL	Median arcuate ligament
MALS	Median arcuate ligament syndrome
MRA	Magnetic resonance angiography
MVO	Mesenteric vascular occlusion
NIS	Nationwide inpatient sample
NOMI	Non-occlusive mesenteric ischemia
OP	Operation
PAD	Peripheral arterial disease
PSV	Peak systolic velocity
PTA	Percutaneous transluminal angioplasty
RBCs	Red blood cells
RVD	Renovascular disease
SA	Splenic artery
SMA	Superior mesenteric artery
SMV	Superior mesenteric vein
SSI	Surgical site infection
SV	Splenic vein
TPN	Total parenteral nutrition

UFH	Unfractionated heparin
UTI	Urinary tract infection

1. Introduction

1.1. Definitions

Mesenteric ischemia is a rare but severe disease, which is encountered during the vascular surgery practice. It represents a failure of perfusion of visceral organs to meet the usual metabolic requirements.(1) (2) This disorder is either acute or chronic based on the acuity and duration of emerging symptoms. Acute mesenteric ischemia occurs rapidly over a few hours and frequently leads to acute intestinal infarction requiring resection as well as consideration of recanalization. It can be associated with a high mortality. Chronic mesenteric ischemia (CMI) is a more chronic and insidious process, which usually progresses over several months or even years. In many cases, it may be misdiagnosed as a gastrointestinal disorder. Those patients usually have undergone an extensive diagnostic workup for other suspected etiologies. The patients with CMI often complain of subtle or even nonspecific manifestations of physical findings, which may not be remarkable. To be aware of this clinical entity by the physician, this is essential for its recognition and subsequent medical management. Unrecognized and untreated, CMI has the potential to worsen and even develop into acute intestinal ischemia with bowel infarction.

1.2. History

"Occlusion of the mesenteric vessels is to be regarded as one of those condition of which . . .

- the diagnosis is impossible,
- the prognosis hopeless (and)
- the treatment almost useless".

This pessimism expressed by Cokkinis more than 90 years ago concerning mesenteric ischemia is, unfortunately, still shared by many physicians today. (3) The first description of mesenteric vascular occlusion was attributed to the pathologist Antonio Beniviene from Florence in the latter part of the fifteenth century. (4) The medical profession became interested in this condition so that other cases were reported by Tiedman in 1843 (5) and later by Virchow in 1854 (6). CMI secondary to arterial insufficiency was first recognized and described by Chienne in 1868 (7) followed by Councilman (8) in 1894 with the anatomical description of the celiac trunk and superior mesenteric artery (SMA) occlusions. In 1901, Schnitzler described a patient with postprandial pain who had infarction of the small bowel from a thrombus superimposed on atherosclerosis of the SMA at autopsy. (9) CMI was first described as ‘abdominal angina’ in 1918 by Goodman. (10) (11) In his famous report in 1926, Cokkinis described the symptoms of CMI accurately. He wrote: “Among the commonest of these are a colicky abdominal pain, which may have some relation to food ... The symptoms are colicky abdominal pain, 1 ½ to 2 h after meals, nausea, and vomiting ... they may last for years, and then arterial thrombosis supervenes and leads to infarction ...” (3) Dunphy correlated the chronic abdominal pain to subsequent mesenteric artery occlusion and gut infarction in his report in 1936. (12)

In 1958, the first successful open repair for CMI was performed by Shaw and Maynard, they reported two cases successfully treated using thromboendarterectomy, (13) and since then, the open surgical repair has been the standard treatment. Technically, more successful procedures, such as Dacron bypass grafting from the infrarenal aorta to the SMA, were described in 1962 by Morris *et al*. (14) Moreover, antegrade aortovisceral bypass and transaortic visceral thromboendarterectomy were described in 1966 by Stoney and Wylie. (15) Antegrade reconstruction has been considered to be the gold standard of repair since then; but clamping of the paravisceral aorta was not without risk, especially in elderly patients with coronary artery disease, associated renal artery disease and aortoiliac occlusive disease. (16)

Baur *et al*. from Oregon modified infrarenal or retrograde bypass to bring the distal end of the graft in a curving manner such that the visceral artery anastomosis was constructed in an antegrade manner, to decrease turbulence of flow. (17) Gentile *et al*. revealed that SMA reconstruction alone was satisfactory. (18) The French advanced a new technique to revascularize the SMA, often in association with a reconstruction of the infrarenal aorta using retrograde bypass in a left retroperitoneal of transperitoneal C-shaped route behind the renal pedicle to revascularize the SMA in an antegrade manner. It is often called ‘French Bypass'. (19) Keese *et al*. have demonstrated that these patients are fit for open surgery and, if treated by open revascularization, will experience long-term relief from the symptoms, a better quality of life and better overall survival. (20)

As an alternative to open surgery for CMI, mesenteric endovascular revascularization was first described in 1980. (21) It is used in the majority of patients today, as its mortality is less in the hands of most practitioners than open repair (22) (23) (24). Further studies from the Mayo Clinic by Oderich *et al*. detailing 229 patients, on the other hand, have shown that the mortality from open repair is less than 3 % and is equal to that of endovascular repair. Nonetheless, these are retrospective studies from a high-volume institution with a long-standing interest in the problem, and the patients are carefully selected. (25) (26)

1.3. Epidemiology

Among all ischemic intestinal disorders, CMI is fairly uncommon accounting for only 5 % of all cases of ischemic disorders of the gastrointestinal tract. (27) Since the majority of patients with mesenteric occlusive disease manifest no symptoms, the exact incidence of CMI is not known. The prevalence is estimated at 1 in 100,000 individuals. (28) Wilson *et al*. found that 17.5 % of elderly patients examined with duplex ultrasonography had critical stenosis of at least one visceral vessel. (29) Mesenteric vascular disease as a part of generalized atherosclerosis is often associated with atherosclerotic manifestations of other organs. (30) A study of the Veterans Affairs system reviewed 205 consecutive angiograms of patients with aneurysmatic or occlusive disease. It was found that asymptomatic stenosis of mesenteric vessels occurs in 40 % of patients with abdominal aortic aneurysms, 29 % of patients with the aortoiliac occlusive disease, and 25 % of patients with the peripheral arterial disease (PAD). (31) The mean age was 75 years and the female to male ratio was reported to be 3:1. (32) CMI occurs relatively rarely, with a frequency of 2-4 out of 100,000 people. (33) A report by Oderich and colleagues on 229 patients undergoing revascularization for CMI showed that 57 % (*n*=131/229) had the three-vessel disease, 41 % (*n*=93/229) had the two-vessel disease, while only 2 % (*n*=5/229) had the single-vessel disease. While multivessel mesenteric stenosis was found in 1 to 7 % of asymptomatic patients, it appears that the clinical manifestations of CMI are much rarer, though possibly increasing over time. (25)

1.4. Anatomy

1.4.1. Arterial supply of viscera

The three main arteries, which supply the viscera originate from the abdominal aorta and include the celiac axis (CA), superior mesenteric (SMA) and inferior mesenteric (IMA) arteries. The foregut is supplied by the CA, which in turn divides normally into three major branches: the splenic artery, the common hepatic artery, and the left gastric artery. (34) The midgut receives arterial supply from the SMA, which arises from the aorta very close to the CA at approximately 1 cm caudally. Branches include the middle, right, and ileocolic arteries as well as jejunal and ileal arteries and arterioles. (34) Thus, the SMA and its branches are responsible for blood supply to the vast majority of the jejunum, ileum, and the ascending, transverse and splenic flexure portions of the colon. The IMA arises 3-5 cm above the aortic bifurcation and divides into ascending and descending branches. Branches include the left colic, marginal artery of Drummond and sigmoid arteries to supply the region from the splenic flexure until the superior portion of the rectum. (34) (35) (36)

1.4.2. Venous drainage of viscera

Venous drainage of the splanchnic system involves mainly the portal circulation, along with several tributaries, which drain the blood into the portal vein including the splenic vein (SV), inferior mesenteric vein (IMV), superior mesenteric vein (SMV), left gastric, right gastric, and cystic veins. The superior rectal, sigmoid, and left colic veins drain into the IMV. The IMV subsequently drains directly into the SV along with the pancreatic, gastroepiploic and short gastric veins. The SMV and SV join together and form the portal vein confluence adjacent to the pancreatic head. The portal vein continues onward to drain blood into the sinusoids of the liver.

1.4.3. Collaterals

The mesenteric circulation has an extensive collateral vascular pathway. These mesenteric collaterals, embryonic remnants of vessels connecting the CA, SMA, and IMA, can develop within one mesenteric artery outflow, between two mesenteric arteries, or between mesenteric and parietal or body wall vessels. The most common collateral pathways found between the CA and the SMA are the pancreaticoduodenal arcades and occasionally the arc of Buhler. Common connections between the SMA and the IMA include the marginal artery of Drummond and the more centrally located arc of Riolan. (37)

1.5. Etiology

CMI is usually caused by atherosclerotic changes of the three mesenteric arteries. However, as mentioned earlier, most patients have an involvement of at least two vessels to cause clinically evident disease. According to some estimations, up to 95 % of cases of CMI are due to atherosclerosis. (38) (39) Non-atherosclerotic causes account for 5‑10 % of all cases of CMI. (36) Examples for unusual causes of mesenteric ischemia are summarized in table 1. (40)

Table 1: Unusual causes of mesenteric ischemia

1. **Mechanical**	Arterial dissection, median arcuate ligament syndrome, retroperitoneal fibrosis and trauma
2. **Drugs**	Digitalis, ergotamine and cocaine
3. **Hematologic**	Thrombocytosis, amyloidosis, disseminated intravascular coagulation and polycythemia
4. **Vasculopathies**	PAN, Takayasu arteriitis and Behçet disease
5. **Anomalies**	Fibromuscular dysplasia and coarctation of abdominal aorta

- Modified by Krupski *et al*. (40)

1.6. Pathophysiology

The symptoms are attributed to a gradual reduction in blood flow to the intestine. (41) Since blood flow to the bowel can vary from 20 % when fasting to 35 % after eating, symptoms occur with increased demand for blood flow, analog to claudication symptoms after exercise in case of the peripheral arterial occlusion disease. Many patients have adequate collaterals which usually provide sufficient flow to prevent ischemic symptoms. Frequently, angiography will demonstrate a large meandering mesenteric artery, which is an essential vessel in the collateral circulation from the IMA. Symptoms can usually occur if two or more vessels are occluded. (42) (43) The clinical significance of the mesenteric ischemia correlates to several factors: the extent of disease, the adequacy of collateral pathways and acuteness of symptoms. Approximately 2‑10 % of patients with CMI have the single-vessel disease, which affects primarily the SMA but in the majority with no burden of complaint. Patients with poorly developed collaterals or more acute presentation might be predicted from the postprandial hyperemic response. (25)

1.7. Risk factors

The well-known risk factors for atherosclerotic disease are also applicable to CMI. The majority of patients (75 %) are smokers. In contrast to other vascular syndromes, females are affected more than males. About one-third of patients has hypertension and hyperlipidemia. Ten % of patients are diabetic. (44)

1.8. Natural history

Patients with asymptomatic mesenteric stenosis usually have a benign course. Nonetheless, 15 % to 50 % of patients who present with bowel gangrene have thrombosis of preexisting lesions with no antecedent warning signs. (45) Thomas *et al*. reviewed 980 aortograms and found 60 patients (6 %) with significant mesenteric artery disease. Of these, 15 patients had involvement of all three visceral arteries. During follow-up of 2.6 years, four patients (27 %) developed symptoms; three had successful revascularization, but one died from acute ischemia. (46)

1.9. Diagnosis

1.9.1. Clinical features

Clinically, the classic symptoms of CMI include abdominal pain, weight loss, and "food fear. (47) " There is usually postprandial abdominal pain, which begins within 30 minutes after meals. It often persists for as long as 5 to 6 hours. (48) Typically, patients with CMI undergo an extensive diagnostic work-up to rule out other causes of chronic abdominal pain and weight loss, including inflammatory, infectious, and malignant diseases. The investigation includes upper and lower gastrointestinal endoscopy and cross-sectional studies of the abdomen as CT and MRI. (36) (49) The finding of mesenteric artery stenosis in an imaging study is the first clue to the correct diagnosis.

1.9.2. Duplex ultrasonography

The main clinical application of mesenteric ultrasonography is to identify proximal stenosis of the SMA, and CA appreciated from both anatomic and hemodynamic changes. The ultrasonography of mesenteric artery stenosis beyond the artery's origin is limited due patient's body habitus or overlaying bowel gas. Moreover, ultrasonography is operator-dependent and should, therefore, be performed by an experienced sonographer. Interpretability of duplex ultrasonography of the CA and the SMA varies between 68 % of good and 11 % of moderate interpretability. (50)

For the SMA: the PSV (peak systolic velocity) threshold, which has the highest accuracy for detecting > 50 % SMA stenosis, is > 295 cm/s (sensitivity, 87 %; specificity, 89 %); and for detecting > 70 % SMA, it is > 400 cm/s (sensitivity, 72 %; specificity, 93 %). The EDV (end diastolic velocity) threshold that provides the highest accuracy for detecting > 50 % stenosis is > 45 cm/s (sensitivity, 79 %; specificity, 79 %); and for > 70 % stenosis, it is > 70 cm/s (sensitivity, 65 %; specificity, 95 %). For CA: the PSV threshold that provides the highest accuracy for > 50 % stenosis is > 240 cm/s (sensitivity, 87 %; specificity, 83 %); and for > 70 % stenosis, it is > 320 cm/s (sensitivity, 80 %; specificity, 89 %). The EDV threshold that provided the highest accuracy for > 50 % stenosis was > 40 cm/s (sensitivity, 84 %; specificity, 48 %); and for > 70 % stenosis, it was > 100 cm/s (sensitivity, 58 %; specificity, 91 %). (51) In daily practice, duplex ultrasonography should be performed under fasting conditions. Some publications suggest measurement of PSV and EDV after test-meals because the augmentation of blood-flow following meal is suppressed in patients with CMI compared to subjects with normal vessels. (52)

1.9.3. Magnetic resonance angiography (MRA)

Using contrast-enhanced (CE)-MRA, it is possible to identify mesenteric artery stenosis and even existing collaterals. Kolkman *et al*. observed a significant inter- and intra-observer variation in grading of stenosis in 45 % of the cases. (52) Although, it is on a large scale used, we cannot consider it a gold-standard investigative procedure to assess the vessel anatomy. The main advantage of MRA is its ability to measure the actual blood-flow through the splanchnic and portal circulations (53) and to be considered in patients with renal insufficiency. A serious limitation is that MRA cannot be used in patients with certain devices or claustrophobia.

1.9.4. Computed tomography angiography (CTA)

After the introduction of multi-slice CT, a detailed scan of the abdominal arteries has become possible. Several studies show that CT angiography is an accurate way to image the mesenteric arteries, veins, and collaterals (Figure 2). (54) (55) It is essential to use multi-slice scanners with slice thicknesses of 2 mm at most (preferably, 1 mm or less) in order to visualize the mesenteric arteries and their collaterals. With the state-of-the-art technology, CT-scanning in inspiration and expiration is now possible and even presents a prerequisite if there is suspicion of CA compression syndrome. (56) Although, CTA is currently recommended as first-line imaging in the diagnostic work-up of mesenteric vascular disease, it does have some limitations as using ionizing radiation, which has potential carcinogenic effects. (57) The need for multiphase imaging in arterial and venous phases of enhancement increases the radiation exposure compared to a routine abdomen and pelvis CT scan for the further assessment of nonspecific abdominal pain. Interestingly, the "American College of Radiology" estimates the effective dose for an adult on the range of 1-10 mSv for CTA of the abdomen. (58)

1.9.5. Digital Subtraction Angiography (DSA)

Intra-arterial digital subtraction angiography (DSA) of the mesenteric arteries can be used to confirm former CTA findings and/or perform endovascular therapeutic procedures in the same session, including an infusion of papaverine and angioplasty or stenting of stenosis. Its high diagnostic accuracy and its possibility to do interventions simultaneously, makes angiography the procedure of choice in patients suspected of CMI. It usually involves a non-selective anteroposterior and lateral aortic angiography, followed by a selective angiography of the three mesenteric arteries, to allow obtaining a detailed view of the vascular anatomy, stenosis, and relevant *anatomical* variations. (59) CT and MR angiographies are gaining acceptance as the primary diagnostic modalities for mesenteric vessel anatomy. (60) However, detailed angiographic information of anatomy, stenosis, collaterals, and anatomical variations is essential in the preparation of an optimal revascularization strategy, which is best obtained using intraarterial DSA. (52)

1.9.6. Endoscopy

Endoscopy can detect ischemic changes, most noticeable such as erosive ischemic gastritis, gastroduodenitis, or ischemic colitis of the (in particular, right) colon. (61) Gastric tonometry can also be used to examine intestinal perfusion. (62) (63) Another noninvasive measurement of mucosal capillary hemoglobin oxygen saturation during endoscopy is the visible light spectroscopy using white light from a fiber-optic probe. (64)

1.10. Therapy

Treatment of CMI is focused on the mechanical relief of occlusive lesions and restoration of blood flow. Open surgical treatment using bypass has been the gold standard of treatment in the past. However, the endovascular treatment, consisting of percutaneous transluminal angioplasty and stenting, has emerged recently as an alternative treatment modality for CMI. (65) (66) (67) The Nationwide Inpatient Sample (NIS), which is the largest publicly available all-payer inpatient healthcare database in the United States, demonstrated from 1988 to 2006 that although there were 6,342 cases of endovascular intervention and 16,071 open surgical repairs for all causes of mesenteric ischemia (both acute and chronic), patients with CMI were more frequently treated endovascularly than with open bypass (62 % *vs*. 38 %). Reasons for this trend were attributed to lower cardiac and pulmonary morbidity and mortality rate, (32) although some major academic centers have demonstrated comparable outcomes for both open and endovascular repairs. (25, 68) In 2009, Oderich *et al*. from the Mayo Clinic published an analysis of risk-stratified outcomes in a retrospective review of 229 open or endovascular treated CMI patients. Patients who underwent percutaneous endovascular (PTA) and stent-angioplasty were significantly older and of higher risk. Interestingly, the mortality rate was not statistically different, although open surgical patients had higher cardiac and pulmonary complication rates (36 % *vs*. 18 %) and longer hospital stays (12±8 *vs*. 3±5 days). (25)

Despite these documented advantages of percutaneous therapy, open surgical repair has shown to have up to date superior durability with fewer symptom recurrences in long-term results. (36) Therefore, the choice of therapy should be tailored to the patient’s comorbidities and disease process. In general, endovascular therapy is associated with fewer complications but it does demonstrate lower primary patency rates and a greater need for earlier reintervention. (25) (68) (69) One of the largest series with intermediate-term (3 years) follow-up describes 49 patients treated endovascularly for symptomatic CMI. Primary patency was 63.9 ± 8.5 %; approximately 30 % of patients required reintervention with a mean time to the first reintervention of 15.5 ± 4.3 months. The large plaque burden from aortic atherosclerosis has been proposed as the principal mechanism for the high restenosis rate. (70)

Surgical revascularization remains the most durable treatment for CMI. (36) Several studies recommend single-vessel reconstruction using autologous vein and a retrograde approach with bypass grafts originating from the infrarenal aorta. (71) (72) (73) Although this procedure avoids supraceliac aortic dissection and clamping, the geometry of a retrograde bypass is theoretically unfavorable, with the potential for compression by the overlying abdominal viscera. In the modern era, antegrade bypass using grafts originating from the supraceliac segment of the aorta has become the preferred surgical technique. (74) Regardless of the method of revascularization, the proper patient selection is critical to optimize results.

Considering the generalized atherosclerosis, patients with concurrent extracranial carotid and coronary artery disease should be detected and treated during preoperative setting appropriately. Medical and percutaneous treatments for myocardial ischemia are also preferred before mesenteric revascularization, because patients with CMI are at increased risk for intestinal infarction during and after coronary artery revascularization. (75)

Although hypoproteinemia and malnutrition with cachexia frequently accompany CMI, postponement of the operative therapy to nourish the patient is rarely helpful. The risk of intestinal infarction during the preoperative period is significant and is often associated with catastrophic results. (76) In patients with life-threatening malnutrition, endovascular therapy should be considered as a temporary measurement before surgical therapy.

2. Aim of study

In this study, the aim is to review more than 12-years' experience from a single institution of open surgical treatment of patients with CMI, depending on the mesenteric revascularization technique and to evaluate contemporary short- and long-term outcomes of patients, who underwent surgical vascular reconstruction for CMI, which often remains a clinical challenge, with specific attention given to

- postoperative outcome,
- short- and long-term graft patency rate (and)
- symptom-free and survival rates

aiming at optimizing the patients' selection process.

The following revascularization techniques were, in particular, investigated:

1. Single-vessel or two-vessel reconstruction?
2. Antegrade or retrograde directionality (flow direction) for revascularization of mesenteric arteries?

3. Patients and Methods

3.1. Study design

All patients, who had undergone an elective open vascular reconstruction of CMI by the vascularsurgical team at Magdeburg's University Hospital (Germany) over a defined time period, were documented and enroled into this systematic retrospective unicenter observational study (design) for quality assurance as contribution to research on clinical care to reflect daily vascularsurgical work and practice as indicated. Data were documented in a clinical access-based database (Access, Microsoft Office 365, Microsoft Corporation, Redmond/Washington, USA). The list of the patients was compiled initially from the surgical department computer system based on the hospital's coding system, coding of CMI as a diagnosis from the ICD-coding system (International Classification of Diseases) overlapped with the treatment code as an open vascular reconstruction for mesenteric arteries from OPS ("Operations- und Prozedurenschlüssel") coding system.

3.2. Patients' groups

Any form of CMI was considered, including patients with mechanical compression of the CA by the median arcuate ligament (inclusion criteria). Non-occlusive mesenteric ischemia (NOMI), mesenteric venous occlusion (MVO), acute mesenteric ischemia or visceral artery reconstructions for the aneurysmatic disease were excluded (exclusion criteria). Only patients treated electively for CMI were enrolled. Mesenteric artery repair was defined based on the orientation of inflow. Repairs utilizing bypass conduit originating from the supraceliac aortic or transaortic endarterectomy were considered “antegrade”. Inflow originating from the distal aorta or iliac artery was considered “retrograde”. These criteria produced a particular cohort group of patients. Further factors were analyzed regarding the number of revascularized vessels either single-vessel or two-vessel reconstruction.

3.3. Patients’ data and follow-up

The patients’ files were retrieved and checked up individually to fill in the database. The cohort was followed up, either through the hospital's computer system and the files themselves. Clinical follow-up was performed initially at three months and then once yearly. The presence or absence of change(s) in clinical symptoms including postprandial abdominal pain, weight loss, and food fear was determined. Mesenteric duplex ultrasonography was the first diagnostic tool to consider if there was a clinical suspicion of recurrent symptoms. All patients have undergone a radiological imaging either CTA or MRA. DSA has been considered in some patients, with unclear diagnosis, usually in combination with an endovascular intervention.

After acquiring a permission from ethics committee, the patients’ data from records could be collected for the retrograde case series study. The follow-up endpoint was either 5-year time period postoperatively, loss from follow-up or death. We stopped collecting the data on 12/31/2018.

A computerized database (based on Excel, Microsoft Office 365, Microsoft Corporation, Redmond/WA, USA) was designed according to the study protocol to include all the relevant information. The medical records of these patients, including both inpatient and outpatient notes, have been reviewed retrospectively to determine the presenting symptoms, preoperative evaluation, operative procedure, and postoperative outcome. Multiplanar and 3-D reconstructions of CTA were done using OsiriX-MD® software (Pixmeo SARL, Bernex, Switzerland). Follow-up was accomplished in all patients by return visit, patient or physician correspondence or telephone conversation. The author documented the standard postoperative complications, as listed in table 2 (right column).

3.4. Studied risk factors

The risk factors, which had been expected to be relevant in this study, were integrated, as listed in table 2, so that, at least a basis for a more advanced multicenter study in the near future could be provided. Published articles and studies were reviewed evaluating the open mesenteric reconstruction of CMI and the importance of visceral reconstruction regarding pathoanatomic and pre-operative risk factors for CMI as well as intra- and perioperative risk factors (as listed in table 2) as the main determinant of postoperative outcome in these patients. This review will be used to produce the main questions to be answered and to generate a comparison with our own more than ten years' experience at the Magdeburg's University Hospital.

A Medline/PubMed search from early 1990 through 2020 was conducted, depending upon search criteria of chronic mesenteric ischemia (CMI), risk factors, bypass, pre-operative, intra-operative, open reconstruction. This search yielded around 96 articles meeting our primary interest. Every study or article were included presenting any form of at least one risk factor correlation with clinical outcome after open mesenteric reconstruction of CMI. Other studies/articles not presenting clinical outcome-risk factors relation, on the other hand, were excluded. Depending on this literature review, the author worked out the main group of risk factors to be checked up, which are illustrated in table 2.

Table 2: Pre-, intra- and postoperative risk factors and related clinical outcomes

Preoperative risk factors	**Intraoperative risk factors**	**Postoperative risk factors**	**Clinical outcome**
- Weight loss - Age - Abdominal angina - BMI - DM - Arterial hypertension - Hyperlipidemia - Smoking history - Preoperative TPN - PAD - CVD - RVD - CHD - CHF - CRF - Previous malignancy - Previous surgeries: - abdominal - bowel - peripheral vascular - aortic - cardiac - mesenteric - Pathology of CA, SMA, and IMA (obstruction/stenosis) - Therapy: antiplatelet/ anticoagulation	- Duration of OP - Duration of aortic cross-clamping - Approach used - Inflow vessel - Outflow vessel(s) - Number of vessels reconstructed - Combination with other constructions - Perioperative antibiotic prophylaxis - Type of material used for the reconstruction	- Length of ICU stay - Length of hospital stay - Reoperation(s) / Re-intervention(s)	- Morbidity - Patency (primary, clinical and secondary) - Graft obstruction - Graft infection - Intestinal ischemia - Intestinal obstruction - Cardiovascular complications - Heart failure - Myocardial infarction - Respiratory complications - Cerebrovascular complications - Stroke - Delirium - Renal failure - Hepatobiliary complications - UTI - Wound infection - Lymphocele - Postoperative bleeding - Gastrointestinal bleeding - Mortality - Survival rate

BMI: body mass index, *DM*: diabetes mellitus, *TPN*: total parenteral nutrition, *PAD*: peripheral arterial disease, *CVD*: cerebrovascular disease, *RVD*: renovascular disease, *CHD*: coronary heart disease, *CHF*: congestive chronic heart failure, *CRF*: chronic renal failure, *CA*: celiac axis, *SMA*: superior mesenteric artery, *IMA*: inferior mesenteric artery, *ICU*: intensive care unit, *UTI*: urinary tract infection

3.5. Preoperative diagnostic modalities

3.5.1. Diagnostic imaging

The diagnosis of CMI is based primarily on clinical symptoms and supported by imaging findings, following the exclusion of other potential intestinal disorders. CT accurately demonstrates calcified and non-calcified plaques causing arterial stenosis or occlusion, typically in the proximal segments of CA and SMA. (54) Small, attenuated vessels and large collateral vessels are essential supportive findings. For the diagnosis of CMI, an occlusion or severe stenosis in at least two major mesenteric arteries was mandatory. (77) Figure 1 demonstrates a high-grade stenosis of CA at its origin and occlusion of the proximal SMA.

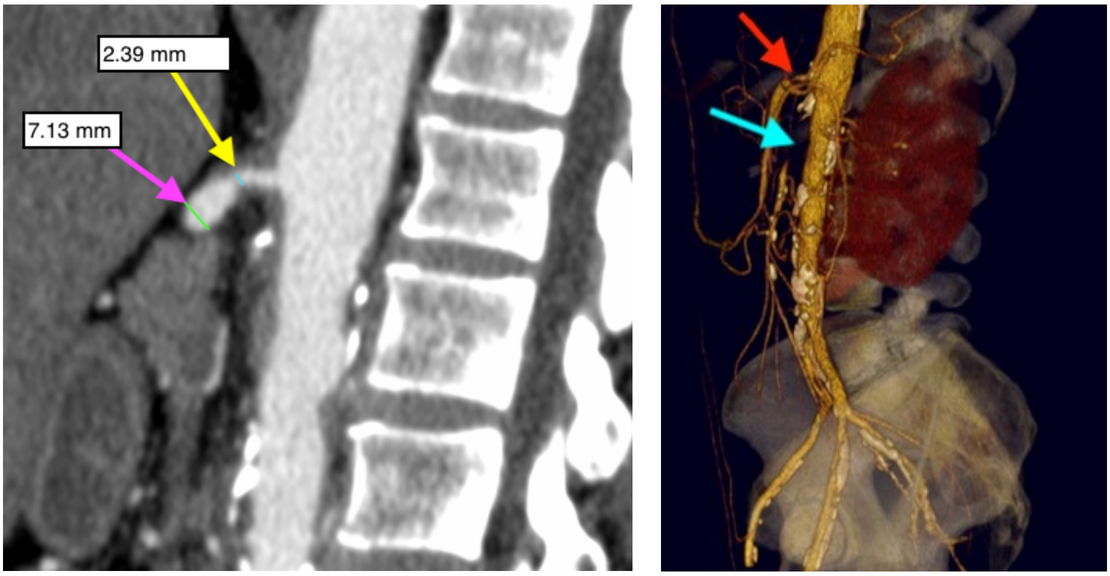

Figure 1: Contrast-enhanced multislice CT showing a CT-slice of a sagittal reconstruction in a patient with high-grade stenosis of CA at origin (> 70 % reduction of arterial diameter) and occlusion of the proximal SMA (left) and a 3-D reconstruction of the same patient (right) - red arrow represents the CA-stenosis and light blue arrow represents the SMA-occlusion (from Department of Radiology, University Hospital Magdeburg)

Once intestinal ischemia was suspected, the diagnosis of the chronic mesenteric arterial occlusive disease was made by abdominal duplex ultrasonography scanning of the celiac axis (CA) and superior mesenteric artery (SMA). Most patients had undergone previous radiologic and endoscopic procedures in an attempt to define a primary gastrointestinal problem as the cause for weight loss and abdominal pain. As a part of preoperative planning, all patients underwent usually a CTA or less MRA. DSA has been used in case of non-conclusive diagnosis using CTA or MRA.

3.5.2. Radiological pathology of mesenteric arteries

All three mesenteric arteries ‘CA, SMA and IMA’ were assessed either as obstructed or stenotic. High-grade stenosis of mesenteric arteries was defined as decreased the vessel diameter of more than 70 %. (78) Patients who were fit for surgery and having non-calcified supraceliac aorta and/or iliac arteries have been subjected for open surgical treatment rather than endovascular.

3.6. Operative techniques

3.6.1. Choice of procedure

There are several techniques used to reconstruct the mesenteric arteries. In patients who were fit for surgery and had favorable anatomy, a surgical approach was considered; otherwise, those patients underwent endovascular reconstruction through the interventional radiology team. All preoperative interventional scans were reviewed by both radiology staff and a vascular surgeon directly, as a part of the interdisciplinary conference to plan the vascular procedure and were re-reviewed at the time of data collection by the author.

The assessment based on a comparison of pre- and post-injection imaging findings, which were used to exclude and distinguish high-grade stenosis from complete obstruction as a result of atherosclerosis. High-grade stenosis was defined as a reduction of the diameter of the mesenteric artery at its origin of more than 70 %, with apparent mesenteric collateral circulation.

Several techniques were used to reconstruct the diseased mesenteric vessels either by single or multiple mesenteric repairs. The reconstruction was performed either in an antegrade or retrograde fashion. The choice of reconstruction method has been decided by the surgeon. Usually an antegrade bypass has been used in patients without supraceliac calcification and those who were fit for supracoelic clamping. All patients received a prophylactic antibiotic preoperatively usually using Cefuroxime as a second-generation cephalosporin. In case of penicillin allergy known or reported from the patient’s individual medical history, an alternative antibiotic was used.

3.6.2. Operative technique

3.6.2.1. Transperitoneal exposure

The patient was placed in the supine position, then the entire abdomen and lower chest were prepped and draped. A longitudinal incision was made in the midline, extending from the xiphoid process to the umbilicus or down to symphysis pubis, according to the procedure. The wound was deepened through subcutaneous tissue; the linea alba was incised, then the peritoneum was entered under direct vision. After routine exploration of peritoneal contents, the wound edges were retracted using a self-retaining retractor.

3.6.2.1.1. Exposure *of* CA

The left triangular ligament of the liver was incised, allowing mobilization and retraction to the right of the lateral segment of the left hepatic lobe. The gastrohepatic ligament was opened from the gastroesophageal junction to the pylorus, preserving the vagal nerve near the lesser curvature. Then, gentle retraction of the lower esophagus and lesser curvature to the patient's left to expose the CA and its primary branches lying deep to the posterior parietal peritoneum.

The distal thoracic aorta was exposed by opening the posterior peritoneum and vertically dividing the median arcuate ligament and interdigitating fibers of the left and right crura over the anterior aortic surface. A nasogastric tube helped to precisely identify and subsequently protect the esophagus. Further exposure of the CA was accomplished by dividing the celiac ganglion (Figure 5). Approximately 6-8 cm of the aorta was dissected to free it from adhesions. If a two-vessel antegrade reconstruction was considered, then the CA was isolated by exposing the common hepatic artery above the pancreas, then following it to the celiac trifurcation. Then, the splenic artery was isolated, allowing a circumferential dissection of its origin at CA. The left gastric artery was often ligated and divided facilitating a pre-pancreatic tunnel for a SMA graft limb. So, we avoided a retropancreatic tunneling to reduce the risk of bleeding from the retropancreatic venous plexus and to avoid the injury of the pancreas. Complete preparation and isolation of the CA were only needed if CA was the target for bypass. The celiac trunk was not isolated if the target for the bypass was the common hepatic artery.

3.6.2.1.2. Exposure of SMA

The origin of SMA was exposed by mobilizing the superior border of the pancreas and continuing the dissection on the anterior surface of the aorta caudally to the CA. The dissection continued between the superior edge of the pancreas and the hepatic and splenic artery branches. Lateral dissection of the superior pancreatic border to the left of the aorta was avoided, to prevent avulsing pancreatic branches of the splenic artery. The origin of the SMA was exposed posterior to the neck of the pancreas, which was mobilized and retracted anteriorly along with the splenic vein (Figure 2). (79)

The SMA can be exposed distally to the inferior border of the pancreas using a lateral approach. The fourth portion of the duodenum was mobilized be dividing Treitz’s ligament. SMA can be dissected and isolated proximally to the duodenum, which can be enhanced by retracting the inferior border of the pancreas to the level of the left renal vein (Figure 2). (79)

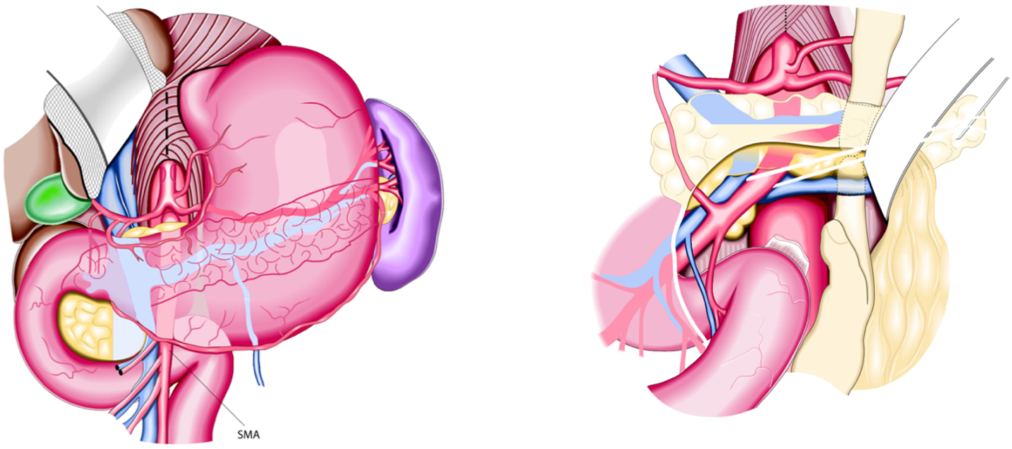

Figure 2: Dissection of the CA and SMA at the Origin (left) and distal SMA (right) (79)

3.6.2.2. Antegrade bypass

After preparation of the supraceliac segment of the aorta, then the aorta could either be partly or entirely cross-clamped. A complete cross-clamping was usually favored in obese patients with a deep operative field or in those with a plaque in the aorta, at the aortic wall. The proximal supraceliac aorta could be clamped using a straight or mildly angled aortic clamp whereas a hypogastric clamp had been used for the lower supraceliac aorta (two clamp technique). Partial aortic occlusion was considered, if necessary. UFH (70-100 IU/kg) was routinely admitted before aortic cross-clamping. The vascular anastomosis was considered to be done within 20 minutes in order to reduce the risk of renal and mesenteric ischemia because of aortic cross-clamping. Through adequate anesthesia management, the cardiac risk from increased afterload with complete aortic clamping was held low intraoperatively.

Graft size was based on the diameter of CA and SMA. If reconstruction of CA and SMA was planned, a preformed Y-graft was used. Prostheses from several manufacturers were used, according to availability at the time of operation and surgeon’s preference: ‘Dialine II®, Bard/New Jersey, USA’; ‘Gelsoft™ Plus, VASCUTEK, Terumo Corporation, Tokyo, Japan’; ‘Goretex®, W. L. Gore & Associates, Newark/Delaware, USA’ or ‘Silver Graft®, B. Braun, Melsungen, Germany’. The proximal anastomosis to the aorta was performed in a side-to-end fashion using running polypropylene suture (Prolene®, Ethicon Inc., Bridgewater/NJ, USA) with or without parachute technique. The proximal anastomosis was then tested by infusing saline into the graft with clamps still in place. Blood flow was restored slowly through the native aorta after back-bleeding and fore-bleeding through the limbs had been done. The limbs of the graft were clamped at their origins. The celiac anastomosis was done using either end-to-side or end-to-end techniques with ligation of the native artery at its proximal site. So, a functional end-to-end anastomosis was created. If the entire CA was occluded or diseased, the preferred target artery was the common hepatic artery. This anastomosis was end-to-side on the superior margin of the artery. Before completion of the distal anastomosis, back-bleeding was allowed from the CA branches or hepatic artery with the distal graft limb clamped. Fore-bleeding was permitted through the SMA graft limb; it was flushed with saline, and any blood and fibrin within it was removed with suction. The SMA limb was clamped at its origin, and blood flow was restored into the branches of CA. For positioning of the SMA graft limb, it has been passed through a tunnel to the infracolic position. This anastomosis was performed in an end-to-side fashion with the arteriotomy often on the left lateral or anterolateral side of the artery. It was essential to gently relax the small bowel to be sure the graft was cut to appropriate length (Figure 3). (79) (80) A mesenteric bypass was used using a venous graft in some cases if an appropriate venous material was available either a mesenteric vein or more commonly great saphenous vein, and those patients had elevated risk for wound infection.

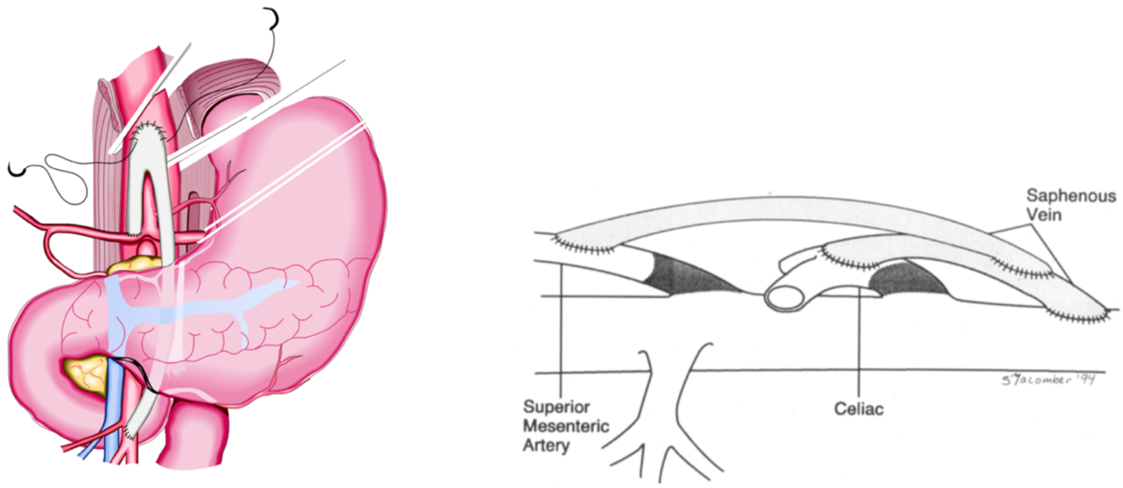

Figure 3: Antegrade bypass from the supraceliac aorta to the CA and SMA using a bifurcated prosthetic graft (left) and using saphenous vein (right). (79, 80)

3.6.2.3. Retrograde bypass

A retrograde reconstruction was considered for patients with high risk for cardiovascular events during aortic cross-clamping and for those with extensive calcification of supraceliac aorta. The retrograde bypass originated either from the iliac artery, the infrarenal aortic prosthesis or infrarenal aorta (Figure 4). (19), (81). Either a polyester or venous graft was chosen for the bypass, according the surgeon’s preference. It was either directly from the infrarenal aorta or in a C-shape configuration. Rarely, a two-vessel reconstruction was done to the SMA and common hepatic arteries. In this case, the graft was connected to the SMA in a side-to-side fashion, then passed through a retropancreatic tunnel or on top of the pancreas, gently curved and anastomosed to the common hepatic artery in an end-to-side manner. The C-shaped configuration originating from the iliac artery and passing behind the renal artery and vein was called "French bypass" (Figure 4). (19) (81) (82) If the bypass was carried straight to the SMA, the iliac artery anastomosis was performed first using end-to-side and the proximal anastomosis using side-to-end technique. If a C-configuration was performed, either the proximal or distal anastomosis was performed according to the surgeon's preference.

An inflow source from the right iliac artery was preferable than from the left iliac artery. The later was used, if it was less diseased than the right one. The author's preference was to sew the distal anastomosis end-to-side to the SMA first, let the bowel relax, and then to fill the graft with saline to properly position it in a C-shape. The graft was then cut to length, spatulated, and sewn side-to-end to the iliac artery. The advantage of the C-shape was that blood flow is antegrade vis-à-vis the SMA. It could also avoid a suprarenal clamping of the aorta and prevent kinking of the bypass through the intestine. (82)

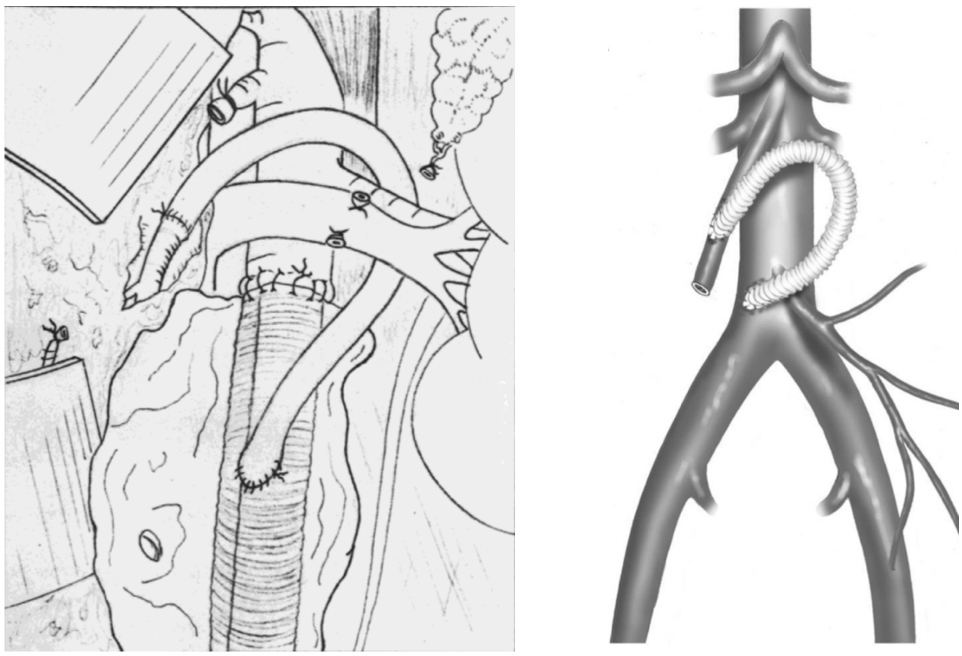

Figure 4: Retrograde prosthetico-mesenteric bypass is passing behind the pedicle of the kidney (left) and aortomesenteric bypass using a prosthetic graft. (19), (81)

3.6.2.4. Transaortic mesenteric endarterectomy

The aorta was usually exposed using medial visceral rotation with the left kidney remaining in its bed, and dissection was done anterior to the renal vein, or even with medial rotation of the left kidney after dividing the left renal vein. The diaphragmatic crura were transected longitudinally, allowing exposure of the left anterior-lateral wall of the aorta and origins of the SMA and CA. After systemic heparin administration and a double clamping of the supraceliac and infrarenal aorta, a trapdoor aortotomy was performed, starting at the level of the renal arteries up to just above the origin of CA. Endarterectomy of the segment IV of aorta including the CA and SMA was performed, ending at the renal artery orifices. Rarely, an endarterectomy of renal arteries was required in symptomatic patients. Finally, the aortotomy was closed longitudinally and rarely required a patch. Here, a xenogenic patch ‘XenoSure® Biologic Vascular Patch, LeMaitre Vascular, Burlington/MA, USA’ was used. If a longitudinal arteriotomy was done, this could be closed with a patch (Figure 5). (79)

3.6.2.5. Decompression

After entering the lesser sac and dissection of CA, the aortic dissection extended up to about five centimeters proximally to the origin of the CA to ensure a complete division of the celiac plexus. The dissection extended to the prevertebral fascia on the right of the aorta and the suspensory ligament of the fourth portion of the duodenum. All ganglionic fibers that had been visualized were divided with the electrocautery or ultrasonic scalpel. Currently, most surgeons agree that laparoscopic division of the MAL and the associated celiac ganglion tissue are critical for successful treatment (Figure 6). (1)

3.6.2.6. Combination with other reconstructions

A reconstruction of a CMI could take place as a part of extensive abdominal vascular reconstruction as concomitant with the aortic reconstruction of severe PAD (Figure 4) and sometimes combines with renal arterial reconstruction. (83)

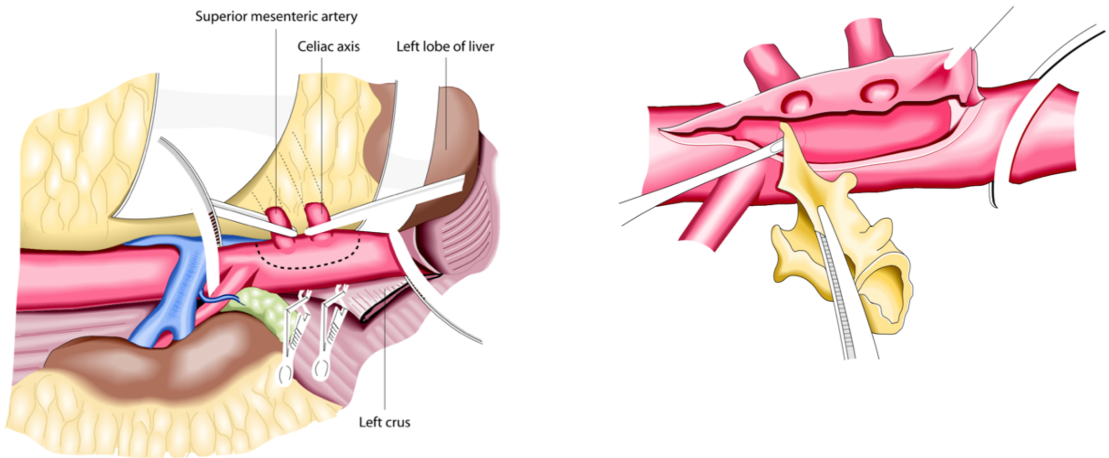

Figure 5: Diagrammatic presentation showing a trap-door aortotomy (right) and endarterectomy (left) of CA and SMA (79)

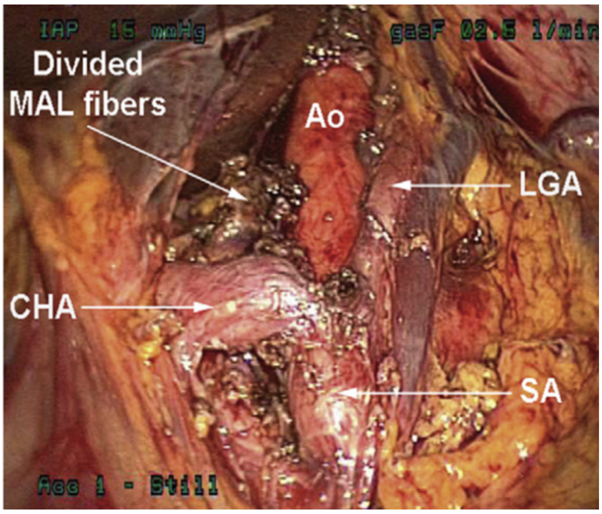

Figure 6: Intraoperative image shows the divided fibers of the MAL and the three terminal branches of the CA. *Ao*, aorta; *CHA*, common hepatic artery; *LGA*, left gastric artery; *SA*, splenic artery; *MAL*, median arcuate ligament (1)

3.7. Postoperative assessment

3.7.1. General concepts and definitions

In the postoperative period, the patients usually received low dose intravenous UFH with intravenous heparin (500 units per hour) for 24 hours. All patients who survived the operation received antiplatelet therapy postoperatively, except those who needed oral anticoagulation, this could be continued postoperatively.

Primary patency was defined as symptom relief and was considered the sole determinant of successful therapy. However, mesenteric artery occlusion could occur without recurrent symptoms. Clinical patency was regarded as asymptomatic patients postoperatively, independent of graft patency, which might be proven radiologically to be occluded. Secondary patency was defined as a symptom relief after secondary intervention following the primary operative procedure in the follow-up period. The graft patency was documented early postoperatively using CTA and late postoperatively either using CTA or colored duplex ultrasonography of mesenteric vessels.

3.7.2. Peri- and postoperative morbidity and mortality

The possible perioperative complications were considered part of perioperative morbidity, which occurred from the first postoperative period until the discharge of patients, as listed in table 2. Any bleeding which required a massive blood transfusion more than four packed RBCs units, reintervention or surgical revision postoperatively was considered major bleeding. The data were collected in two separate sessions, with the numerical coding of the patients, the pre-operative assessment and the post-operative data were separately documented in the databank to prevent bias. Post-procedural CTA scans were also performed in case of suspected graft obstruction or deterioration of general condition to exclude significant complications or active bleeding.

In this cohort, the cause of death, whether it was related to the mesenteric reconstruction or not, was clear from the clinical course, GP, or medical documentation, no patient underwent an autopsy. Cardiac complications were defined by occurrence of one or more of the following: Arrhythmia requiring chemical or electrical cardioversion, heart failure leading to low-output syndrome or cardiac insufficiency after myocardial infarction. Pulmonary complications were defined by occurrence of one or more of the following: pneumonia, pleural effusion requiring drainage or lung failure requiring intubation. Cerebrovascular complications were defined by occurrence of one or more of the following: Delirium or transient confusion, transient ischemic attacks, ischemic stroke or brain hemorrhage. Hepatobiliary complications were defined by occurrence of one or more of the following: hepatitis leading to hepatic failure or pancreatitis.

3.7.3. Survival and follow up

Survival was noted from the first postoperative day until the last visit of the patient. Late complications including graft obstruction and infections were reported within the follow-up period.

3.8. Statistical methods

The statistical evaluation was carried out using the software SPSS Statistics version 24.0 (SPSS Inc., Chicago/IL, USA). Because of the small sample size non-parametric tests were performed to determine whether there was a significant difference between the findings and the individual variables. Survival and patency rates were calculated using the Kaplan-Meier method. Univariate statistical comparisons using contingency table analysis (Pearson's chi-square test) was made between each of the directionality of reconstruction (antegrade or retrograde) and the number of reconstructed vessels (either one or two vessels) regarding the development of complications postoperatively as appropriate. The statistical tests have been done considering the recommendations of colleagues at the institute of biometry and medical informatics in Magdeburg. Statistical significance was ascribed to a *p*-value of < 0.05.

3.9. Conflict of Interest

The author declares no conflicts of interest. This study did not receive any specific grant from funding agencies in the public, commercial, or non-profit organisation sectors.

3.10. Ethical Statement

Data generation, documentation and evaluation was performed according to prerequisites of data protection law of the German district Saxony-Anhalt and according to the federal law.

Study was performed according to the requirements of the ‘Declaration of Helsinki for Biomedical Research from 1964’ by the World’s Medical Association and its further amendments as well as the policy of the institutional ethic committee. All patients signed a consent form after preceeding extensive explanation on the surgical intervention including relevant complications as well as with regard to the enrollment in the study.

3.11. Study Registration

The study was officially registered at German Clinical Trials Register under the registration number DRKS00020830

4. Results

4.1. Demographic data

From 2005 to 2018, 48 patients were identified who had undergone mesenteric revascularization for CMI. Eight patients who received revascularization of acute on top of chronic mesenteric ischemia were excluded. Mesenteric reconstruction because of other causes was also excluded: aneurysm of SMA (*n*=2), aneurysm of the hepatic artery (*n*=1) and debranching of the celiac trunk and SMA because of the thoracoabdominal aortic aneurysm (*n*=1). Thus, 36 patients remained for final study-related analysis. Two patients underwent second mesenteric revascularization as a result of recurrent symptoms and graft failure, so we had a total procedure’s number of 38.

The mesenteric reconstruction was performed more commonly in women (*n*=20, 53 %) than men (*n*=18, 47 %). The mean age of patients (mean ± S_D) was 64 ± 13 ranging from 32-83 years.

4.2. Preoperative characteristics and comorbidities

Atherosclerosis was the primary cause in 35 patients, median arcuate ligament compression syndrome in two patients and radiation-induced mesenteric ischemia in one patient. The most frequently reported symptoms were postprandial abdominal pain in all patients (100 %) and loss of body weight of more than 10 % in the last six months (32 patients, 84 %) with a mean ± SD of BMI: 20.99 ± 4.14 kg/m^2. Only two patients presented with gastrointestinal bleeding.

Among the preoperative characteristics, 8 patients (21.1 %) had diabetes, 35 patients (92.1 %) had a history of smoking, 30 patients (78.9 %) were active smokers until the time of admission, 30 patients (78.9 %) were treated for hypertension, 18 patients (47.4 %) were treated for hyperlipidemia. Ten patients (26.3 %) had coronary artery disease, with 4 patients (10.5 %) having undergone coronary artery bypass grafting. Carotid artery disease was noted in 16 patients (42.1 %) with 3 patients (7.9 %) having undergone cerebrovascular reconstruction. Twenty-seven patients (71.1 %) received preoperatively antithrombotic therapy. Only five patients (13.2 %) were treated preoperatively with an oral anticoagulant. Twenty-three patients (60.5 %) had peripheral arterial disease; most of them (83.3 %) were PAD stage II (according to Fontaine's staging system). Other prevalent risk factors included chronic renal failure (*n*=17, 44.7 %), of those only one patient had end-stage renal disease. Renovascular disease in only 3 patients (7.8 %) was less common. Congestive chronic heart failure and atrial fibrillation were noted in 13.2 % of the patients (*n*=5). Most patients had normal thyroid function. Only one patient had hyperthyroidism (2.6 %), and four patients had hypothyroidism (10.5 %). About 40 % of patients received TPN preoperatively. Two patients (5.3 %) were noted to have a hypercoagulability state; one of them had hyperhomocysteinemia and the other ANCA-negative vasculitis by retroperitoneal fibrosis (Ormond's disease). Preoperative abdominal surgeries were common in 26 of the patients (68.4 %), previous bowel surgery in half of the patients, previous mesenteric surgery in 4 patients (10.5 %), previous aortic surgery in 10 patients (26.3 %), and previous peripheral vascular reconstruction in 9 patients (23.7 %). There is no statistical significance regarding the distribution of preoperative risk factors among males and females, as listed in table 3.

Table 3: Distribution of preoperative risk factors among males and females.

Risk factor	**No. of patients (%) having the risk factor**			***p*-value**
	Males	Females	In total	
Weight loss	13 (72.2 %)	18 (95 %)	32 (84.2 %)	0.055
Gastrointestinal bleeding	2 (11.1 %)	0 (0 %)	2 (5.3 %)	0.218
Diabetes mellitus	4 (22.2 %)	4 (20 %)	8 (21.1 %)	0.867
Arterial hypertension	14 (77.8 %)	16 (80 %)	30 (78.9 %)	0.867
HLP	8 (44.4 %)	10 (50 %)	18 (47.4 %)	0.732
History of smoking	18 (100 %)	17 (85 %)	35 (92.1 %)	0.087
Active smoker	15 (83.3 %)	15 (75 %)	30 (78.9 %)	0.529
PAD	12 (66.7 %)	11 (55 %)	23 (60.5 %)	0.463
CVD	8 (44.4 %)	8 (40 %)	16 (42.1 %)	0.782
RVD	2 (11.1 %)	1 (5 %)	3 (7.8 %)	0.485
CHD	7 (38.9 %)	3 (15 %)	10 (26.3 %)	0.095
Atrial fibrillation	4 (22.2 %)	1 (5 %)	5 (13.2 %)	0.117
CHF	3 (16.7 %)	2 (10 %)	5 (13.2 %)	0.544
CRF	8 (44.4 %)	9 (45 %)	17 (44.7 %)	0.973
Previous abdominal surgery	11 (61.1 %)	15 (75 %)	26 (68.4 %)	0.358
Previous bowel surgery	10 (55.6 %)	9 (45 %)	19 (50.0 %)	0.516
Previous peripheral vascular surgery	5 (27.8 %)	4 (20 %)	9 (23.7 %)	0.573
Previous carotid surgery	1 (5.6 %)	2 (10 %)	3 (7.9 %)	0.612
Previous aortic surgery	5 (27.8 %)	5 (25 %)	10 (26.3 %)	0.846
Previous cardiac surgery	3 (16.7 %)	1 (5 %)	4 (10.5 %)	0.242

Previous mesenteric surgery	2 (11.1 %)	2 (10 %)	4 (10.5 %)	0.911
HLP: hyperlipoproteinemia, *PAD*: peripheral arterial disease, *CVD*: cerebrovascular disease, *RVD*: renovascular disease, *CHD*: coronary heart disease, *CHF*: congestive heart failure, *CRF*: chronic renal failure				

4.3. Pathological and anatomical features

Critical stenosis or occlusion of celiac artery (CA) was noted in 81.5 % of patients (*n*=31), SMA in 94.7 % of patients (*n*=36). The only two patients who did not have a pathological affection of SMA had medial arcuate ligament syndrome (MALS) with compression of the CA. The IMA was affected in 50 % of patients. Critical stenosis or occlusion of all three mesenteric vessels (CA, SMA, and IMA) was found in one-third of patients (*n*=12). Lesions were localized to only the CA and SMA in 44.4 % of patients (*n*=16). Lesions were localized to only the SMA and IMA in 15.8 % of patients (*n*=6). Affection of CA and IMA was found in only one patient. The author did not report any patient with symptomatic CMI with a pathological affection of only the SMA. Two patients were reported having stenosis of CA as a result of MALS

4.4. Operative details

Patients were evaluated based on the type of directionality in the reconstruction (direction of inflow) and number of reconstructed vessels. Twenty one patients (55.3 %) underwent antegrade revascularization either by use of an antegrade bypass from the supraceliac aorta to the SMA and/or CA (44.7%) or direct reconstruction of CA; the remaining 44.7 % of patients (*n*=17) underwent retrograde reconstructions that originated from the infrarenal aorta (15.8 %), a prosthetic graft (23.7 %) or iliac axis (7.9 %).

A composite reconstruction was performed in five patients (13.2 %), in whom one patient (2.6 %) underwent combined renal and mesenteric reconstruction and the other four patients (10.2 %) underwent mesenteric reconstruction in association with peripheral vascular reconstruction using implantation of an aortic graft.

The transperitoneal approach was used in almost all patients (*n*=37, 97.4 %) except in one patient, in whom a retroperitoneal approach using a Crawford incision was executed. This patient was subjected to a thrombendarterectomy of the segment IV of the aorta including CA and SMA. One patient underwent a revascularization of the common hepatic artery via the left common iliac artery using venous conduit bypass. An extension of the bypass to SMA was not attempted during the first operation due to the high operative risk because of the septic condition of the patient as well as the extensive mesenteric collaterals through the arc of Riolan and Drummond. Afterwards, because of the extensive small intestine necrosis, it was essential to revascularize the SMA. After that, the patient has undergone graft failure with subsequent resection of the small intestine. The patient survived with a short-bowel-syndrome.

The most commonly used material for vascular reconstruction was Dacron (Polyester) in 18 patients (47.4 %). Expanded polytetrafluoroethylene (ePTFE, Goretex®, W. L. Gore & Associates, Newark/Delaware, USA) was used in 11 patients (28.9 %), the autologous vein in 4 patients. One patient underwent a combined reconstruction using Dacron as a bypass material and thrombendarterectomy of IMA and its closure using the biological material. Thrombendarterectomy and closure using biological material (xenogenic patch, XenoSure® Biologic Vascular Patch, LeMaitre Vascular, Burlington/MA, USA) were used in 2 patients. One patient underwent only a decompression of MAL and another patient a direct closure after Crawford incision and thrombendarterectomy of segment IV of the aorta.

One-vessel reconstruction was used in 53 % of patients (*n*=20), whereas the two-vessel reconstruction in the remaining 47 % of patients (*n*=18). The mean duration (mean ± SD) for cross-clamping of the aorta was 13.6±9.2 minutes and 9.8±10.2 minutes for cross-clamping of the supraceliac aorta. The average length of operation (mean ± SD) was 196±70 minutes ranging from 70-350 minutes.

4.5. Postoperative outcome

The mean hospital stay was 37.9 days while the mean intensive care unit (ICU) stay was 17.5 days. Most patients were extubated within the first 24 hours. Totally, 12 patients (31.6 %) required reoperation during the postoperative period after the first performed reconstruction. Seven patients (18.4 %) had a failure of their bypass graft in the postoperative period.

After the first reconstruction, 12 patients underwent further revisions, with a mean of totally performed operations of 2.45 (ranging from 1-17). During the postoperative period, the primary patency rate was 81.6 % (*n*=31) whereas the clinical patency rate was 89.5 % (*n*=34) and the secondary patency rate was documented in 5 from 6 patients.

Graft obstruction was noted in 18.4 % of patients (*n*=7); 6 patients in the early postoperative period during the same admission, of those four patients, required partial intestinal resection as a result of intestinal ischemia whereas a symptomatic graft obstruction was found in one patient within the first follow-up year. This patient underwent a further reconstruction of the CMI electively. After five years, the primary and clinical patency rates were reported to be 55.3 % of the patients' group (*n*=21) whereas six patients were lost from the follow-up. One patient underwent a successful second re-construction because of primary graft failure.

A superficial SSI (surgical site infection) occurred in 4 patients (10.5 %), who were successfully treated with conservative wound management whereas a deep SSI including graft infection was reported in only two patients (5.3 %). One patient had primarily a venous bypass, which could be managed without graft explantation. In the other patient, the prosthetic aortoceliac bypass could not be removed because of severe inflammatory reaction intraoperatively. This patient underwent several lavages. Because of graft obstruction, a partial resection of the small intestine and another visceral reconstruction using a venous iliacomesenteric bypass were performed. The patient died in the early postoperative period.

Cardiovascular events occurred in only 3 patients (7.9 %); respiratory complications including pneumonia, pleural effusion, and respiratory decompensation occurred in 42.1 % of patients (*n*=16). There was an increase of the serum creatinine level in 6 patients (15.8 %); self-limited hepatobiliary complications including self-limiting pancreatitis and acalcular cholecystitis developed in 5 patients (13.2 %). Additional complications included cerebrovascular events which occurred in 8 patients (21.1 %). Postoperative surgical site bleeding occurred in 39.5 % of patients (*n*=15), of those ten patients required re-operation to stop the bleeding or to remove the intraabdominal hematoma (26.3 %). Peripheral vascular ischemia in the lower extremities developed in only two patients (5.3 %). Portal vein thrombosis occurred in one patient. Pulmonary embolism developed in one patient (2.6 %). Twenty-one percent of patients (*n*=8) developed urinary tract infection, which was treated successfully with a conservative approach. Upper gastrointestinal bleeding occurred in 10.5 % (*n*=4);

No patient sustained acute renal failure requiring permanent dialysis or pseudoaneurysm of the anastomosis. There was only one patient, who required hemodialysis preoperatively as a result of severe deterioration of renal function because of obstruction of the aorta including renal arteries and SMA. It could not be improved after combined reconstruction of mesenteric, renal and iliac arteries. Taken together, the specific complication rate relating to the surgery was 60.5 % whereas the general complication rate was 55.3 % resulting in an overall morbidity of 73.3 %. The overall mortality was 18.4 %.

4.6. Morbidity and preoperative characteristics

The preoperative comorbidities and anatomical factors were analyzed with univariate analysis using Chi-Square test to calculate the correlation with morbidity in the perioperative period, after one year and after five years, as shown in table 4.

Table 4: Morbidity (perioperatively, at 1 year and 5 years) with its correlation to preoperative risk factors.

Analyzed risk factor	Early postoperative morbidity	Morbidity at 1 year	Morbidity at 5 years
	p value		
Gender	0.358	0.594	0.280
Age	0.411	0.591	0.388
DM	0.652	0.930	0.829
Arterial hypertension	0.652	0.233	0.280
BMI	0.536	0.456	0.324
HLP	0.632	**0.018***	**0.040***
Preoperative TPN	0.215	0.809	0.308
History of smoking	0.173	0.583	0.197
PAD	**0.02***	0.2	**0.024***
Cerebrovascular disease	0.97	0.157	0.255
Renovascular disease	0.220	0.962	0.732
CHD	0.359	**0.025***	0.130
CHF	0.103	0.254	0.412
CRF	0.096	0.886	0.088
Previous malignancy	0.191	**0.025***	0.07
Previous abdominal surgery	0.874	0.901	0.952
Previous bowel surgery	0.163	0.870	0.914
Previous peripheral vascular surgery	0.489	0.318	0.070
Previous carotid surgery	0.946	0.294	0.412
Previous aortic surgery	0.087	0.739	0.308
Previous cardiac surgery	0.765	0.060	0.231
Previous mesenteric surgery	0.065	0.583	0.732

Bold with *: statistically significant
DM: diabetes mellitus, *BMI*: body mass index, *HLP*: hyperlipoproteinemia, *TPN*: total parenteral nutrition, *PAD*: peripheral arterial disease, *CHD*: coronary heart disease, *CHF*: congestive heart failure, *CRF*: chronic renal failure

HLP had significant impact onto one- and five-years morbidity (*p*=0.018 and 0.04). The presence of PAD was associated with more perioperative morbidity (*p*=0.02) and the morbidity at 5 years (*p*=0.024). There was also slightly more morbidity at 1 year but not statistically significant (*p*=0.2). Congestive heart disease was also associated with more morbidity at one year (*p*=0.025). Chronic renal failure had a trend of early postoperative morbidity and the morbidity at five years (*p*=0.096 and *p*=0.088), respectively. Previous malignancy was associated with significantly higher morbidity at one year and a trend of higher morbidity at five years (*p*=0.025 and *p*=0.07). Patients who had undergone previous aortic or mesenteric reconstruction had a trend of more perioperative morbidity (*p*=0.087 and *p*=0.07), respectively. Otherwise, patients with a history of previous cardiac surgery had a trend of more perioperative morbidity (*p*=0.06).

4.7. Mortality and preoperative characteristics

The preoperative comorbidities and anatomical factors were analyzed with univariate analysis using Chi-Square test to calculate the correlation with mortality in the perioperative period, after one year and after five years, as listed in tables 5.

Table 5: Mortality (early postoperatively, at 1 year and 5 years) with its correlation to the preoperative risk factors.

Analyzed risk factor	Early postoperative mortality	Mortality at 1 year	Mortality at 5 years
	p value		
Gender	0.132	0.164	0.714
Age	0.791	0.724	0.359
DM	0.196	0.139	0.438
Arterial hypertension	0.207	0.166	0.070
Body mass index	0.289	0.361	0.449
Hyperlipoproteinemia	0.10	0.054	0.245
Preoperative total parenteral nutrition	0.915	0.918	0.185
History of smoking	0.475	0.504	0.333
Peripheral arterial disease	0.314	0.220	0.398
Cerebrovascular disease	0.314	0.454	0.310
Renovascular disease	0.565	0.504	0.155
Coronary heart disease	0.074	**0.017***	**0.038***
Congestive heart failure	0.648	0.436	0.268
Chronic renal failure	0.416	0.353	0.464
Previous malignancy	0.925	0.812	0.919
Previous abdominal surgery	0.523	0.558	0.310
Previous bowel surgery	0.585	0.453	0.398
Previous peripheral vascular surgery	0.380	0.139	**0.038***
Previous carotid surgery	0.295	**0.026***	0.268
Previous aortic surgery	0.482	0.362	0.185
Previous cardiac surgery	**0.024***	**0.017***	0.104
Previous mesenteric surgery	0.477	0.436	0.919
bold with *: statistically significant			

Patients with arterial hypertension had a trend of more mortality at five years (*p*=0.07), whereas those with HLP had more mortality at one year postoperatively (*p*=0.054). Those with CHD had a trend of more early postoperative mortality and postoperatively at one and five years (*p*=0.017 and *p*=0.038, respectively). Patients who underwent previous peripheral vascular surgery had more early postoperative mortality and at 1 and 5 years postoperatively, but only at 5 years it was was statistically significant (*p*=0.038). Patients who underwent previous carotid surgery had more mortality but only statistically significant at one year (*p*=0.026). The same, patients who had undergone previous cardiac surgery had significantly more early postoperative mortality (*p*=0.024) and at one year postoperatively (*p*=0.017). The total morbidity was found to be 48 % of the patients (*n*=18) and total mortality 13.2 % (*n*=5).

4.8. Graft patency in relation to directionality and number of vessels reconstructed

Table 6 shows the primary, clinical and secondary patencies in correlation to both the directionality of reconstruction and number of reconstructed vessels in the early postoperative period.

Table 6: Patency (primary, clinical and secondary) with its correlation to both the directionality of reconstruction (antegrade or retrograde) and the number of reconstructed vessels (1-vessel or 2-vessel) in the early postoperative period.

Primary patency	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
Yes	90.5 %, *n*= 19	70.6 %, *n*= 12	85 %, *n*= 17	77.8 %, *n*= 14
No	9.2 %, *n*= 2	29.4 %, *n*= 5	15 %, *n*= 3	22.2 %, *n*= 4
In total	100 %, *n*= 21	100 %, *n*= 17	100 %, *n*= 20	100 %, *n*= 18
p-value	0.207		0.687	
Clinical patency	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
Yes	95.2 %, *n*= 20	82.4 %, *n*= 14	95 %, *n*= 19	83.3 %, *n*= 15
No	4.8 %, *n*= 1	17.6 %, *n*= 3	5%, *n*= 1	16.7 %, *n*= 3
In total	100 %, *n*= 21	100 %, *n*= 17	100 %, *n*= 20	100 %, *n*= 18
p-value	0.307		0.328	
Secondary patency	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
Yes	100 %, *n*= 2	75 %, *n*= 3	66.7 %, *n*=2	100 %, *n*= 3
No	0	25 %, n= 1	33.3 %, *n*=1	0
In total	100 %, *n*= 2	100 %, *n*= 4	100 %, *n*=3	100 %, *n*= 3
p-value	1.0		1.0	

Patients with “antegrade procedure” showed a trend of greater primary graft patency than retrograde one (*p*=0.207). There was no difference regarding the clinical patency of those patients and no difference comparing one- and two-vessel reconstructions regarding the primary and secondary patency (*p*= 0.687 and *p*= 1.0 respectively).

The primary, clinical and secondary patencies in correlation to both the directionality of reconstruction and number of reconstructed vessels at one year follow up are demonstrated in table 7.

Bypass obstruction occurred in 1 of 10 patients who have undergone reconstruction using ePTFE and in 2 of 16 patients (*p*= 0. 862).

Table 7: Patency (primary and clinical) with its correlation to the directionality of reconstruction (antegrade and retrograde) and the number of reconstructed vessels (1-vessel or 2-vessel) at 1 year.

Primary patency	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
Yes	92.3 %, *n*=12	100 %, *n*=9	92.9 %, *n*=13	0
No	7.7 %, *n*=1	0	7.1 %, *n*=1	100 %, *n*=8
In total	100 %, *n*=13	100 %, *n*=9	100 %, *n*=14	100 %, *n*=8
p -value	1.0		1.0	
Clinical patency	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
Yes	92.3 %, *n*=12	100 %, *n*=9	92.9 %, *n*=13	100 %, *n*=8
No	7.7 %, *n*=1	0	7.1 %, *n*=1	0
In total	100 %, *n*=13	100 %, *n*=9	100 %, *n*=14	100 %, *n*=8
p -value	1.0		1.0	

At one year follow up, there was no difference comparing the antegrade and retrograde reconstruction, and one-vessel *versus* two-vessels reconstruction regarding primary and clinical patency.

At 5 years follow up, primary and clinical patencies were reported in 4 patients (100%) underwent antegrade and 4 patients (100%) undergone retrograde reconstructions, all these patients had undergone 1-vessel reconstruction. There was no difference comparing the antegrade and retrograde reconstructions regarding primary and clinical patencies.

4.9. Postoperative complications in relation to directionality and number of vessels reconstructed

Patients who had undergone antegrade reconstruction had slightly more postoperative cardiac complications (p=0.239). On the other hand, patients undergone one-vessel reconstruction had slightly less cardiac complication (p=0.595). There was no statistical significance regarding the postoperative respiratory complications comparing antegrade and retrograde groups (p=0.743). In addition, the two-vessel group had slightly more respiratory complications than one-vessel group (p=0.188). The retrograde group had slightly more renal complications postoperatively (p=0.378). The two-vessel group had more renal complications, without statistical significance (p=0.395). The patients who had undergone retrograde reconstruction had slightly more postoperative hepatobiliary complications (p=0.64). Patients who had undergone two-vessel reconstruction had slightly more hepatobiliary complications (p=0.170). Cerebrovascular complications were slightly more common in the antegrade group and two-vessel group (p=0.257 and p=0.438, respectively). Frequency of major postoperative bleeding showed no difference comparing antegrade and retrograde groups (p=1.0). However, there was a trend to be higher in the two-vessel group (p=0.096). A trend of major postoperative surgical site bleeding requiring reoperation was noticed in patients who had undergone retrograde reconstruction (*p*=0.078) and also in the two-vessel group, however, here without statistical significance (*p*=0.468). Regarding the peripheral ischemic complications, there was no statistical difference comparing either one-vessel and two-vessel group (*p*=0.218) or comparing antegrade and retrograde groups (*p*=0.492). Postoperative UTI was slightly more in retrograde group (*p*=0.426). There was no difference between one-vessel versus two-vessels groups (*p*=1.0). Postoperative gastrointestinal bleeding was slightly more in the retrograde group (*p*=0.307). There was no difference comparing the one-vessel and the two-vessel groups (*p*=1.0). Regarding the postoperative lymphocele, there was no statistical difference comparing either one-vessel and two-vessel group (*p*=0.541) or comparing antegrade and retrograde groups (*p*=0.577). There was no statistical significance comparing antegrade and retrograde groups regarding postoperative SSI (*p*=0.672) and the two-vessel group had slightly more wound infection (*p*=0.383). The postoperative complications with their correlation to the directionality of reconstruction and the number of reconstructed vessels are listed in table 8.

Table 8: Postoperative complications with their correlation to the directionality of reconstruction (antegrade and retrograde) and the number of reconstructed vessels (1-vessel and 2-vessel).

Cardiac complications	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	85.7 %, n=18	100 %, n=17	95 %, *n*=19	88.9 %, *n*=16
Yes	14.3 %, *n*=3	0	5 %, *n*= 1	11.1 %, *n*=2
In total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.238		0.595	
Respiratory complications	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	61.9 %, *n*=13	52.9 %, *n*=9	70 %, *n*=14	44.4 %, *n*=8
Yes	38.1 %, *n*=8	47.1 %, *n*=8	30 %, *n*=6	55.6 %, *n*=10
In Total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.743		0.188	
Renal complications	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	90.5 %, *n*=19	76.5 %, *n*=13	90%, *n*=18	77.8%, *n*=14
Yes	9.5 %, *n*=2	23.5 %, *n*=4	10 %, *n*=2	22.2 %, n=4
In total	100 %, *n*=21	100 %, n=17	100 %, *n*=20	100 %, *n*=18
p-value	0.378		0.395	
Hepatobiliary complications	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	90.5 %, *n*=19	82.4 %, *n*=14	95 %, *n*=19	77.8 %, *n*=14
Yes	9.5 %, *n*=2	17.6 %, *n*=3	5 %, *n*=1	22.2 %, *n*=4
In total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.640		0.170	
Cerebrovascular complications	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessels**

No	71.4 %, *n*=15	88.2 %, *n*=15	85 %, *n*=17	72.2 %, *n*=13
Yes	28.6 %, *n*=6	11.8 %, *n*=2	15 %, *n*=2	27.8 %, *n*=5
Total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.257		0.438	
Postoperative bleeding	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	61.9 %, *n*=13	58.8 %, *n*=10	75 %, *n*=15	44.4 %, *n*=8
Yes	38.1 %, n=8	41.2 %, n=7	25 %, *n*=5	55.6 %, *n*=10
In total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	1.0		0.096	
Postoperative bleeding-reoperation	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	85.7 %, *n*=18	58.8 %, *n*=10	80 %, *n*=16	66.7 %, *n*=12
Yes	14.3 %, *n*=3	41.2 %, *n*=7	20 %, *n*=4	33.3 %, *n*=6
In total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.078		0.468	
Peripheral ischemia	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	90.5 %, *n*=19	100 %, *n*=17	100 %, *n*=20	88.9 %, *n*=16
Yes	9.5 %, *n*=2	0	0	11.1 %, *n*=2
In total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.492		0.218	
Urinary tract infection	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	85.7 %, *n*=18	70.6 %, *n*=12	80 %, *n*=16	77.8 %, *n*=14
Yes	14.3 %, *n*=3	29.4 %, *n*=5	20 %, *n*=4	22.2 %, *n*=4
In total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.426		1.0	
GI Bleeding	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	95.2 %, *n*=20	82.4 %, *n*=14	90 %, *n*=18	88.9 %, *n*=16
Yes	4.8 %, *n*=1	17.6 %, *n*=3	10 %, *n*=2	11.1 %, *n*=2
In total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.307		1.0	
Postoperative lymphocele	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	4.8 %, n=1	88.2 %, n=15	90 %, *n*=18	94.4 %, *n*=17
Yes	95.2 %, *n*=20	11.8 %, *n*=2	10 %, *n*=2	5.6 %, *n*=1
Total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100%, *n*=18
p-value	0.577		0.541	
Wound infection	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	81 %, *n*=17	88.2 %, *n*=15	90 %, *n*=18	77.7 %, *n*=14
Yes	19 %, *n*=4	11.8 %, *n*=2	10 %, *n*=2	22.2 %, *n*=4
In total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.672		0.383	

4.10. Survival in relation to directionality and number of vessels reconstructed

The overall survival of patients in the postoperative follow-up period was approximately 60 % at 60 months as shown in figure 7.

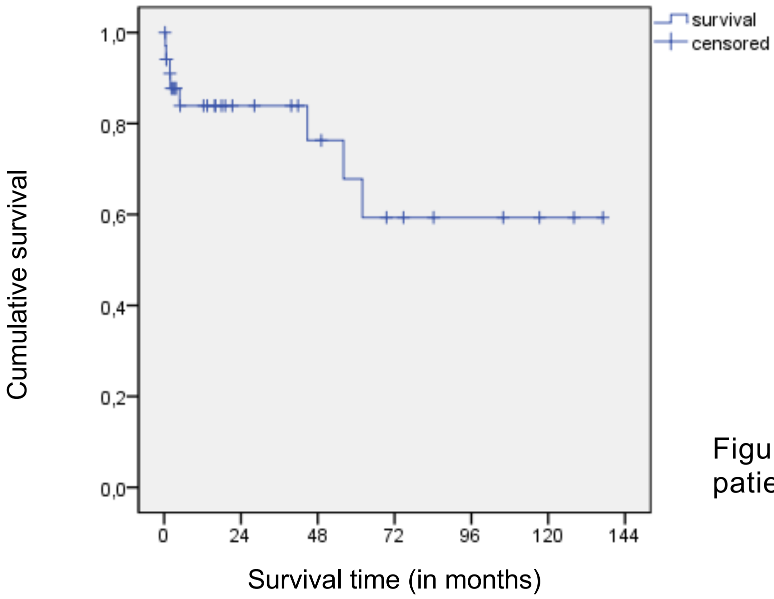

Figure 7: Overall survival of the whole patient group.

There was no statistical significance regarding the survival of patients who had undergone antegrade *versus* retrograde reconstruction (p=0.492), as shown in figure 8.

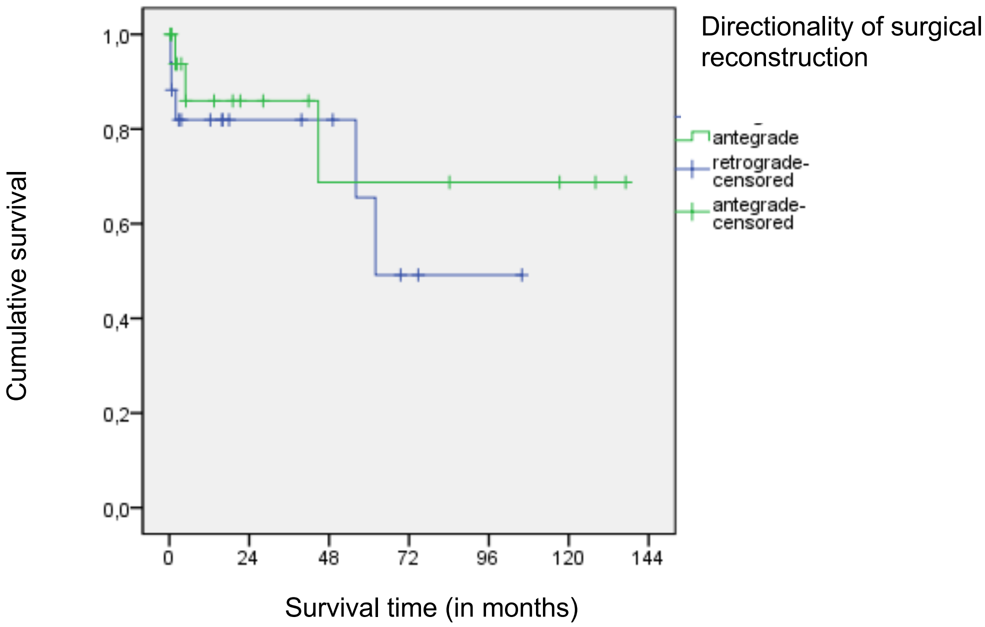

Figure 8: Cumulative survival in the comparison between antegrade and retrograde groups.

Regarding the directionality of reconstruction, there was a statistical significance in the cumulative survival comparing 1-vessel and 2-vessel groups, in favor of 1-vessel group (*p*=0.001), as shown in figure 9.

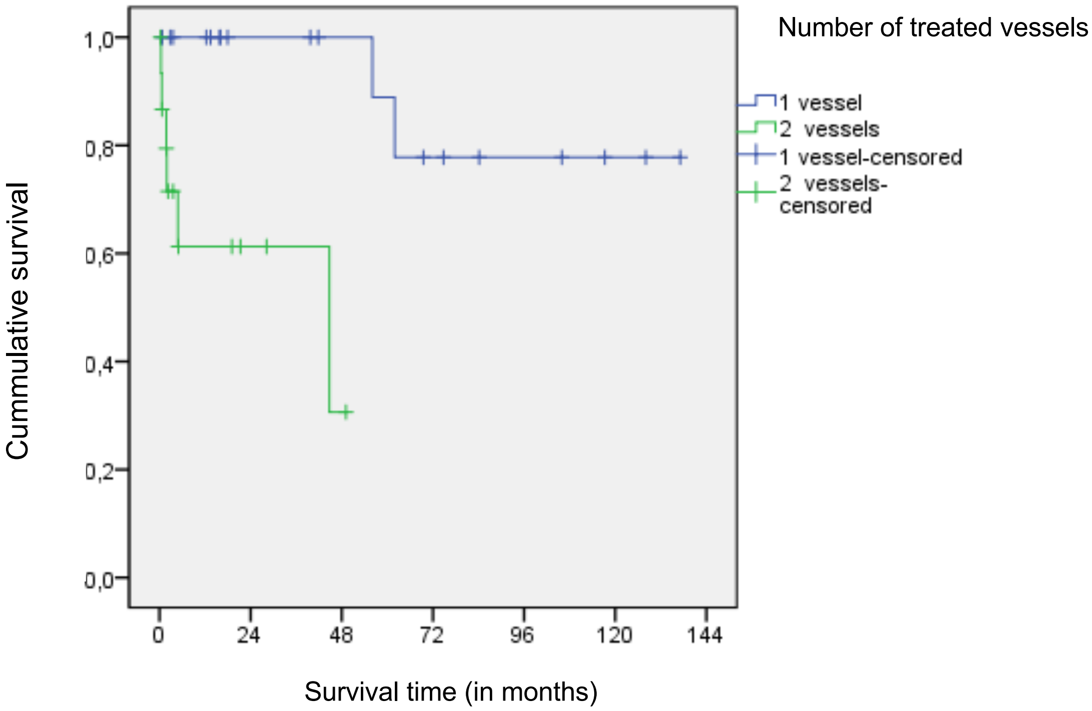

Figure 9: Cumulative survival comparing 1-vessel and 2-vessel groups.

Postoperative morbidity in the early postoperative period was slightly more in the retrograde group (*p*=0.161). The two-vessel group had a trend of higher mortality (*p*=0.086). At one year postoperatively, it was found that both patients who had undergone retrograde and two-vessel reconstruction had slightly higher morbidity (*p*=0.479). At five-years follow-up period, patients who had undergone retrograde reconstruction had slightly higher morbidity (*p*=0.367) whereas two-vessel group had a statistically significant higher morbidity (*p*=0.004), as listed in table 9.

Table 9: Any postoperative morbidity with its correlation to the directionality of reconstruction and the number of reconstructed vessels in the early postoperative period, at one year and at five years follow up.

Any morbidity (perioperative)	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	42.9 %, *n*=9	17.6 %, *n*=3	45 %, *n*=9	16.7 %, *n*=3
Yes	57.1 %, *n*=12	82.4 %, *n*=14	55 %, *n*=11	83.3 %, *n*=15
In total	100 %, *n*=21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.161		0.086	
Any morbidity (1 year)	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	58.8 %, *n*=10	42.9 %, *n*=6	58.8 %, *n*=10	42.9 %, *n*=6
Yes	41.2 %, *n*=7	57.1 %, *n*=8	41.2 %, *n*=7	57.1 %, *n*=8
In total	100 %, *n*=17	100 %, *n*=14	100 %, *n*=20	100 %, *n*=14
p-value	0.479		0.479	
Any morbidity (5 years)	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessels**
No	50 %, *n*=5	25 %, *n*=2	70 %, *n*=7	0
Yes	50 %, *n*=5	75 %, *n*=6	30 %, *n*=3	100 %, *n*=8
In total	100 %, *n*=10	100 %, *n*=8	100 %, *n*=20	100 %, *n*=18
p-value	0.367		0.004	
Statistically significant, regarding higher morbidity of the 2-vessel group at 5 years				

The postoperative mortality in the perioperative period was significantly higher in the 2-vessel group (*p*=0.017). The postoperative mortality at one year postoperatively was significantly greater in 2-vessel group with statistically significance (*p*=0.011). The postoperative mortality at five years postoperatively was significantly higher in the 2-vessel group (*p*=0.007), as shown in table 10.

Table 10: Postoperative mortality with its correlation to the directionality of reconstruction (antegrade and retrograde) and the number of reconstructed vessels (1-vessel and 2-vessel) in the perioperative period, at one year and five years follow up

Mortality (perioperative)	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	90.5 %, *n*=19	82.4 %, *n*=14	100 %, *n*=20	72.2 %, *n*=13
Yes	9.5 %, *n*=2	17.6 %, *n*= 3	0	27.8 %, *n*= 5
In total	100 %, *n*= 21	100 %, *n*=17	100 %, *n*=20	100 %, *n*=18
p-value	0.640		**0.017**	
Statistically significant, regarding higher mortality of the 2-vessel group perioperatively				
Mortality (1 year)	**Antegrade**	**Retrograde**	**1-vessel**	**2-vessel**
No	87.5 %, *n*= 14	76.9 %, *n*=10	100 %, *n*=16	61.5 %, *n*=8
Yes	12.5 %, *n*=2	23.1 %, *n*= 3	0	38.5 %, *n*=5
In total	100 %, *n*=16	100 %, *n*=13	100 %, *n*=16	100 %, *n*=13
p-value	0.632		**0.011**	
Statistically significant, regarding higher mortality of the 2-vessel group at 1 year.				

Mortality (5 years)	Antegrade	Retrograde	1-vessel	2-vessels
No	57.1 %, *n*=4	50 %, *n*=4	80 %, *n*=8	0
Yes	42.9 %, *n*=3	50 %, *n*=4	20 %, *n*=2	100 %, *n*=5
In total	100 %, *n*=7	100 %, *n*=8	100 %, *n*=10	100 %, *n*=5
p-value	1.0		**0.007**	
Statistically significant, regarding higher mortality of the 2-vessel group at five years.				

In total, 5 patients died in the early postoperative course. Three patients had bypass obstruction with intestinal ischemia, who needed to undergo operation and died postoperatively as a result of multiorgan failure. The remaining two patients hat bleeding at the surgical site requiring re-operation and died in the early postoperative period because of multiorgan failure.

Regarding the type of graft used for the reconstruction (ePTFE or Polyester). There was no statistical significance regarding general and specific morbidity related to surgery (p=0.958 and p= 0.514), subsequently.

5. Discussion

5.1. General concepts and risk factors

CMI most frequently occurs in senior women. The mean age of 64 years and the female predominance observed in this series was consistent with those of previously reported clinical experience. (84) For the rare conditions such as CMI, only pooled data of prospective controlled studies considering comparison of open *versus* endovascular repairs and considering several technical aspects for the open reconstructions in comparison can provide a large enough sample to obtain an accurate view on the practices and outcomes. Because of the rarity of the disease and the nature of this single-center study, the author listed here the data of the current study including previous reports; there are some similarities as well as differences, as shown in table 11.

Table 11: Patients' characteristics noted in previous reports and in the current study.

Author	Sex ratio (m/f)	Mean age	Weight loss	Smoking	PAD
Beebe (85)	7/10	54	10/10 (100 %)	Not reported	Not reported
Calderon (86)	17/20	59	13/20 (65 %)	6/20 (30 %)	3/20 (15 %)
Current study	**20/38 (53 %)**	**64**	**32/38 (84 %)**	**39/38 (78.9 %)**	**23/38 (60.5 %)**
Davenport (84)	119/156	65	54/156 (35 %)	77/156 (49 %)	37/156 (24 %)
Foley (87)	31/49	62	Not reported	48/49 (98 %)	28/49 (57 %)
Gentile (18)	16/26	59	Not reported	25/26 (96 %)	16/26 (62 %)
Geroulakos (88)	9/10	66	10/10 (100 %)	Not reported	Not reported
Hollier (89)	11/56	50	55/56 (98 %)	Not reported	Not reported
Jimenez (90)	33/47	62	39/47 (83 %)	43/47 (91 %)	23/47 (49 %)
Johnston (91)	11/21	58	1/21 (5 %)	19/21 (90 %)	17/21 (81 %)
Kihara (92)	30/42	60	Not reported	37/42 (88 %)	Not reported
Kruger (93)	22/39	65	37/39 (95 %)	36/39 (92 %)	16/39 (41 %)
Rheudasil (94)	21/41	59	23/41 (56 %)	36/41 (88 %)	18/41 (44 %)
Mateo (95)	60/85	62	74/85 (87 %)	75/85 (88 %)	Not reported
McMillan (80)	17/25	61	21/25 (84 %)	22/25 (88 %)	9/25 (36 %)
Moawad (74)	19/24	58	14/24 (58 %)	20/24 (83 %)	Not reported
Zelenock (96)	13/23	56	23/23 (100 %)	Not reported	Not reported

The collected experience is divided among many institutions, however, as only a few centers have reported more than 50 cases. (84) (95) (89) (97) (98) CMI was caused by atherosclerotic changes of the mesenteric vessels in about 92 % of this patients' cohort. It was consistent with other studies to be the main etiology for CMI as reported by van Bockel *et al*. It was estimated up to 95 % of cases, mainly affecting the ostium of mesenteric vessels. (38) There are several rare diseases which can affect the mesenteric vasculature, other than atherosclerotic changes. In the current study, one case of radiation induced CMI and two other cases of MALS were treated. The prevalence of such rare etiologies is difficult to estimate but certainly much lower than atherosclerosis as an etiology as reported by Rits *et al*. (99)

CMI as a result of radiation-induced vascular injury is a very rare entity. (100) It has two main extreme clinical manifestations. Either an acute arterial rupture, usually as a result of perivascular inflammation and infection, which occurs within weeks to months after exposure (101), or, on the other hand, a chronic occlusive fibrotic disease which may present anywhere from a few months to over 20 years after the first dose of therapeutic radiation. (102)

Guidelines for treatment are lacking, because of the rarity of this condition. Furthermore, there is no common consensus regarding the number of vessels to be revascularized, the technique of revascularization or the type of bypass conduit. Chun *et al*. reported a case study of radiation-induced CMI in a 65-years old male patient, who underwent cobalt-radiation therapy and chemotherapy about 35 years before presentation, because of metastatic testicular cancer, with successful endovascular therapy of CA and SMA. (103)

Surgical treatment is nearly always required in order to release the mechanical compression of the fibrous median arcuate band and resect the celiac ganglion (104) Although endovascular treatment of celiac compression has been reported, the risk of restenosis or stent compression is high. (105) It has been observed that patients with atypical pain, older than 60 years, having less than 20 pounds weight loss, and having a history of psychiatric disease or alcohol abuse were less likely to improve after MAL release. (104)

The revascularization of the CA through a retrograde bypass, which terminates at the hepatic artery, has been described by several authors in many instances. (17) Courbier *et al*. attributed importance to the hepatic artery. They performed an end-to-end anastomosis at it or re-implanted it, after transection, to the side of an aortomesenteric graft. (106)

In the current study, the common hepatic artery was revascularized in one case *via* the left common iliac artery using venous conduit bypass. This avoided the necessity of prolonged cross-clamping of the supraceliac aorta. An autologous reversed saphenous venous segment was used. In this situation, a synthetic graft could have increased risk of graft infection from the presence of intestinal necrosis and gangrene of the gallbladder. An extension of the bypass to SMA was not attempted during the first operation due to the high operative risk because of the septic condition of the patient as well as the extensive mesenteric collaterals through the arc of Riolan and Drummond. Afterwards, because of the extensive small intestine necrosis, it was essential to revascularize the SMA.

Of note, the differentiation of venous *versus* prosthetic graft could not be sufficiently considered due to the only limited number of patients, in particular, of the single groups.

5.2. Pathology

It is very rare that a pathological involvement of a single mesenteric vessel is responsible for symptoms of CMI. In the current study, only 2 patients (5.3 %) had involvement of the celiac trunk as pathological evidence of MALS. All other patients had involvement of two or even three mesenteric vessels (24 patients, 63.2 %, and 12 patients, 31.6 %, respectively). We did not report any case with pathological involvement of SMA alone. Although other authors have described patients with CMI in the presence of only one single mesenteric artery usually SMA (18) (74) (94) (86) (107) or rarely the CA (16). It is generally agreed that evidence of severe occlusive disease that involves at least two of the three mesenteric arteries is necessary to support the diagnosis of CMI. (77)

Moawad *et al*. (74) achieved overall patency rates of 92 % at 1 year. The experience in the current study as a large consecutive series of 55 visceral artery reconstructions performed in 38 patients is similar to an overall 1-year patency rate of 95 %. Table 12 summarizes the clinical outcome of the current study compared with previous reports.

Table 12: Postoperative outcome comparing the current study and previous reports

Author	**No. of patients / No. of vessels**	**Technical success (%)**	**Mortality (%)**	**Morbidity (%)**	**Recurrence (%)**	**1° patency (%)**
Cho (108)	25/41	100	0	60	Not reported	57
Current study	38/55	100	13.2	48.4	4.5	81.6
Foley (87)	28/28	100	3	Not reported	10	79
Illuminati (109)	11/12	100	0	27	10	90
Kihara (92)	42/52	100	10	35	10	65
Kruger (93)	39/67	100	2.5	12	5	92
Leke (110)	17/25	100	6	41	0	100
Mateo (95)	85/not reported	100	8	23	20	71
Park (111)	98/179	100	5	21	8	Not reported

5.3. Morbidity and mortality

The current analysis demonstrated that 30 % of patients experienced at least one major complication during their hospitalization (total morbidity, 48 %). Respiratory complications including respiratory failure requiring prolonged mechanical ventilation more than 7 days or pneumonia (*n*=16, 42 %), cardiac events (*n*=3.8 %), acute renal failure (*n*=6, 16 %), major bleeding requiring reoperation for hemorrhage or transfusion of at least four packed red blood cells (*n*=15, 39 %), peripheral ischemia (*n*=2, 5 %), hepatobiliary complications including hepatic failure or pancreatitis (*n*=5, 13 %), and cerebrovascular complications including postoperative psychosis or stroke (*n*=8, 21 %). Only one patient had a sustained stroke. Graft infection was observed in only two patients, whereas graft obstruction in seven patients.

In the present study, the total perioperative mortality was 13.2 %. In other studies, it was between 0-22% % within the perioperative period. (91)The author found that only the previous cardiac surgery as an independent variable was associated with an increased risk of peri-operative death (*p*=0.024) whereas at one year follow up, coronary heart disease (*p*=0.017), previous carotid surgery (*p*=0.026) and previous cardiac surgery (*p*=0.017) were associated with increased mortality, as well. Patients with hyperlipoproteinemia had a trend of a higher mortality rate (*p*=0.054). At five years, arterial hypertension (*p*=0.07), coronary heart disease (*p*=0.038) and peripheral vascular surgery (*p*=0.038) were associated with increased mortality as listed in table 6. In other studies, coronary artery disease ($p<0.01$) and chronic renal insufficiency ($p<0.01$) were the only independent variables associated with an increased risk of postoperative death. (92)

We reported more morbidity and mortality in comparison with other studies, because of the difference in the number of treated patients in our study, difference of techniques used for reconstruction and the more spectrum of postoperative complications involved in our study. Cho et al. considered only respiratory, cardiac, renal and colon ischemic complications. (108) Foley et. al. treated most of the patients using retrograde reconstruction. (87) Illuminati et. al. treated only one of 11 patients with supraceliac antegrade reconstruction. (109) Kihara et. al. treated 28 patients in his series using thoracoabdominal access for the reconstruction. Furthermore, they have considered only the major complications including respiratory failure more than 1 week, acute renal failure requiring dialysis, hepatic failure, colonic infarction and bleeding requiring reoperation. (92) Kruger et. al. considered only the following major complications including cardiac complications, bleeding requiring reoperation, bowel or ischemic infarction and Heparin-Induced-Thrombocytopenia (HIT). (93) Johnson et al. reported a perioperative mortality of 22%. (91) Table 11 summarizes the total morbidity rates in comparison to other studies in the literature.

5.4. Operative details

In the current study, the mesenteric vessels were reconstructed using antegrade bypass in 21 patients (55.3 %) and retrograde graft implantation in 17 patients (44.7 %). In a study from the Cleveland Clinic, 40 % of patients underwent retrograde bypass whereas only 29 % underwent antegrade bypass, the remaining underwent other reconstructions including local endarterectomy with local patch angioplasty. They performed one-vessel reconstruction in 75 % of patients, the residual 25 % underwent two-vessel reconstruction. (95)

5.4.1. Choice of procedure

The choice of procedure was usually affected by

- the pathological pattern of occlusive disease,
- a history of extensive abdominal surgery, and
- surgeon’s preference.

Saphenous vein was used in four patients, presumably to avoid synthetic graft material during the original procedure. Most often, in 29 of 38 bypass grafting procedures either using Dacron or ePTFE (76.3 %) was used.

5.4.2. Directionality

Many studies reported patients with CMI who had been treated with anterograde supraceliac aortomesenteric bypass grafting through upper abdominal exposure, and pancreatic displacement to expose the SMA. (90) (85) (112) (113) These authors saw advantages in this technique because there was:

- less turbulence in blood flow,
- less bypass compression by the mesenteric tissue,
- prolonged patency of the vessel reconstructions with better flow capabilities, and
- easier technical handling

compared to retrograde bypass grafting.

To avoid the complications of retropancreatic tunneling such as major bleeding from retropancreatic venous plexus or even pancreatic fistula, a modification in the tunneling of the antegrade bypass was used. A prepancreatic preparation was performed for the bypass graft. Although, it was not found any statistical significance regarding major postoperative bleeding between antegrade and retrograde groups (p=1).

Retrograde aortomesenteric bypass grafting was first described by Morris *et al*. (14). Many authors described the more accessible approach to the infrarenal aorta as favorable. (95) Furthermore, elderly patients and those with cachexia or severe cardiac, pulmonary, and renal dysfunction are frequently not good candidates for aortic-based procedures. One of the main problems in retrograde bypass grafting is bypass kinking because of the mobility of SMA especially if a short bypass is used. The French surgeon Leschi *et al*. combined the advantages of anterograde and retrograde bypass surgeries. (19) A retrograde reconstruction was done using retro-renal tunneling (French bypass) in four patients in the current study. The selection of this technique based on the preference of surgeon. Patients who had suitable iliac vessels without calcification have been considered for this technique. Here, the SMA was revascularized as one-vessel reconstruction in 3 patients, and one patient underwent two-vessel reconstruction of both CA and SMA. Although more perioperative morbidity was noted in the three patients who had undergone French bypass, only one patient died in the perioperative period. This patient had rheumatoid arthritis and had been treated with cortisone and other immunosuppressants. That patient proved to have ANCA-negative vasculitis, as well. The patient had major bleeding postoperatively, requiring reoperation and died later as a result of multiorgan failure. The primary perioperative patency was found in all patients who had undergone French bypass, whereas in the retrograde group only eight out of 13 patients had primary patency (p=0.140). It was not noticed any statistically significant better outcome for the French-bypass group because of the low patients' number.

Murolz *et al*. treated 16 patients using French bypass. Three patients (18.75 %) died intraoperatively, and seven patients had major perioperative complications. The primary early postoperative patency was 68.75 %. The obliterated French bypasses consisted of autologous vein material in 3 patients and ePTFE in one patient. (82)

Retrograde prosthetic bypass grafting to the SMA was performed alone or in conjunction with aortic reconstruction in 44.7 % of patients in this current study. Thus, the advantage of not necessitating dissection or cross-clamping of the supra-celiac aorta was found in the current study, which is a preference advocated by other authors. (17) (86) (114) (115)

Foley and associates showed the efficacy and durability of retrograde bypass with a 9-year assisted primary graft patency rate up to 79 %. (87) Several authors have also reported satisfactory results with this approach. (18) (89) The major disadvantage of this approach is that care must be taken to place the graft in a near-vertical orientation from its origin to its termination to minimize the tendency to kink when the viscera return to its normal anatomical location. (74) (112) Also, an isolated retrograde bypass graft to the mid-SMA, when thrombosed, may threaten the entry of mesenteric collaterals from the CA and SMA, leading to bowel necrosis. (108)

Although there are strong proponents for antegrade bypass reconstruction, there is no statistical superiority yet as has been shown in a randomized controlled trial because of the rarity of the disease. The antegrade orientation allows for a short segment bypass, which has no propensity to kink, provides direct inline flow with low turbulence, and avoids direct contact with bowel. (16) (74) (85) (91) (107) (116) (112)

Although, it was found in the current study that the antegrade group *versus* retrograde group shows a trend of a higher primary patency rate early postoperatively (90.5 % *vs*. 70.6 %, p=0.207), this difference was not found at longer follow-up periods of one year (92.3 % *vs.* 100 %, respectively, p=1.0) and five years (100 % primary patency in both groups). It was not found any significant difference in the complication and survival rates comparing the antegrade and retrograde groups except in the major postoperative bleeding. The retrograde group had only a trend of more major postoperative bleedings than antegrade group (41.2 % *vs*. 14.3 %; *p*=0.078).

Generally, the antegrade reconstruction is favored when the site of origin (usually supraceliac infra-diaphragmatic aorta) is disease-free at the time of implantation, which may affect the selection and, thus, might induce a bias.

5.4.3. Number of reconstructed vessels

The SMA is the most important artery that supplies the midgut. There is a little controversy that this vessel should be the main target for revascularization in patients with CMI. (18) (109)

The main advantages of SMA revascularization have been previously reported in the literature. The supporters to a single SMA revascularization refer to the marked improvement of symptoms. Furthermore, revascularization of a single mesenteric artery is simpler and potentially carries a lower risk of complications. (87) (18) Cunningham *et al.* found that a durable relief of symptoms does not correlate with the number of mesenteric arteries repaired. (107)

There is a controversy in the literature regarding the number of the involved mesenteric arteries, which requires a reconstruction. Although some authors prefer a single artery reconstruction, (107) conversely, others prefer two-vessel reconstruction. They consider that the addition of a celiac graft adds little time of dissection, the procedure can be performed safely in experienced hands, and two-vessel revascularization may reduce symptom recurrence. (89) (117) Hollier *et al*. found that there was a 29 % recurrence rate of symptoms after revascularization of two of three involved arteries. In contrast to a single artery reconstruction, the recurrence rate was about 50 %. Thus, they suggested that although single-artery revascularization may relieve symptoms, the optimal long-term result can be obtained by complete revascularization of all stenotic arteries. (89) A complete revascularization was also recommended by McAfee *et al.* (117)

In the current study, the benefits of complete revascularization (two-vessel group), however, were obtained at the expense of a higher trend of perioperative complications (83.3 % *vs*. 55 %, *p*=0.086). The mortality in the early postoperative period was higher in the two-vessel group (27.8 % *vs*. 0, *p*=0.017), which was statistically significant. Although the postoperative morbidity at one year was higher in the ‘two-vessel’ group (57.1 % *vs*. 41.2 %), it did not show any significant difference. Nevertheless, the morbidity of the two-vessel group at five years (100 % *vs*. 30 %) was significantly different to one-vessel group (*p*=0.004). The mortality was higher in the two-vessel group in the early postoperative period (only trend: 27.8 % *vs*. 0, p=0.17), at one year (38.5 % *vs*. 0, p=0.011) and at five years (100 % *vs*. 20 %, p=0.007).

Regarding overall survival, the one-vessel group showed a significant superiority above two-vessel group (p=0.001). Nevertheless, because of the small number of patients, a subgrouping of one- *vs*. two-vessel reconstruction in favor of directionality (antegrade *vs*. retrograde) could not be analyzed. Kieny *et al*. observed an 8.3 % recurrence rate during 8.5 years of follow-up of 60 isolated SMA reconstructions. (118) Similarly, Cormier *et al*. reported a recurrence rate of 4.8 % at a mean follow-up of about five years in 103 patients, of whom 63 % underwent single-vessel reconstruction. (119) Foley *et al*. reported a 5-year recurrence rate of 6 % after 49 retrograde SMA reconstructions and assumed that additional reconstruction to other mesenteric arteries was “unnecessary.” (87) Christensen *et al*. supported a single-vessel reconstruction of SMA in their review of 90 patients by its low operative mortality rate and technical simplicity. However, the patients in this series had a recurrence rate of 33 % during a median of 55 months of follow-up. (120) Adherents of multiple-vessel revascularization state that the incidence of recurrence with more than one-vessel reconstruction is lower if compared with single-vessel reconstruction if graft thrombosis occurs. Cho *et al*. observed that a graft thrombosis after multi-vessel revascularization usually does not present with clinical consequences. (108) Similarly, in a Mayo Clinic series, Hollier *et al*. adopted complete revascularization after they had observed a recurrence rate of nearly 50 % if only one of three arteries was reconstructed as compared with 11 % after repair of all diseased arteries. (89)

Rapp *et al*. suggested that the celiac trunk is the most important vessel to be revascularized. They reported that all known celiac axis re-stenosis has resulted in symptomatic recurrences, even with a patent SMA. (112) In contrast, Moneta *et al.* believed that the SMA is the critical vessel in the reconstruction of CMI by the fact that the SMA carries most of the increased blood flow during hyperemic postprandial state, an effect not observed in the celiac artery. (121) The same results were published by Cho *et al*. (108)

5.4.4. Type of conduit used for reconstruction

The question of the best optimal graft material is still controversial. (95) (91) Some authors use routinely a synthetic graft, [13] [48] [59] [63] (122) whereas others advocate the use of autogenous vein graft. (80) (89)

In the current study, most patients (79 %) underwent reconstruction using a vascular prosthetic graft either Dacron or ePTFE. Only four patients (11 %) underwent a mesenteric reconstruction using an autologous vein. All four cases underwent retrograde reconstruction (two cases with ‘two-vessel’ and two cases with ‘one-vessel’ reconstruction). Three of these patients had intestinal ischemia, which required resection and vascular revision, and the last one had a graft obstruction, without intestinal ischemia, who were managed at first conservatively, then, after one year, underwent new revascularization because of increasing post-prandial symptoms. These results are similar to those published by Kihara *et al*. Venous conduits were associated with more graft failure (p=0.02). (92) Similar results reported poor patency rates with venous grafts; This could be because of fibrous stenosis due to intimal hyperplasia as a result of a high flow in the graft and the large postprandial variations as reported by Cormie et. al. (119)

Again, the differentiation of venous *versus* prosthetic graft could not be sufficiently considered due to the only limited number of patients, in particular, of the single groups.

Regarding the type of graft used for the reconstruction (ePTFE or Polyester). There was no statistical significance regarding general and specific morbidity related to surgery (p=0.958 and p= 0.514), subsequently.
image-guided approach is beyond the scope of this study.

5.5. Drawbacks and pitfalls

There are several drawbacks in this study. This study has the usual limitations of any retrospective study, which are assumed to have more bias since the study operations, data collected, data entry, and data quality assurance, were not planned ahead of time. It also encompasses a relatively small number of patients. These shortcomings, however, highlight a common problem regarding the CMI: its rareness.

It is not likely that a single center can gather a large enough case/patient series during a relatively short period of time in order to provide substantial data from a prospective randomized study. Finally, this study represents a retrospective report, and surgeons' bias and patients' conditions that affected the choice of conduit could not be identified. So, these results can be subjected to selection bias, as the choice of type of conduit and directionality of reconstruction. Because autologous vein grafts using GSV were used in case of critically ill patients whose bowel viability is questionable or a SSI could be possible. Also, patients with a favorable supraceliac anatomy were selected for antegrade reconstruction. In addition, allocation bias regarding the choice of vascular procedure either open or endovascular could not be controlled. Patients who were fit for surgery underwent surgical treatment. So, the randomization that ensures that the subjects' characteristics do not affect which treatment they receive is absent.

Because of its retrospective nature and relatively small sample size, it is difficult to draw valid conclusions. Because this is a single-center study done by one vascular surgeon, our findings cannot be generalized and have to be compared with other studies to gain validity.

7. Conclusion

In conclusion, the current report represents outcomes in contemporary practice for operative treatment of CMI. Mesenteric reconstruction in case of CMI can be performed safely and effectively with a relatively low mortality rate in usually severily ill patients with a high risk of peri-/postoperative complications. Tertiary referral centers have reported excellent results with open reconstructions, including a recent series from the Mayo Clinic, with mortality of 0.9 % in low-risk patients. (123)

Although mortality was higher in patients with vein grafts compared with prosthetic conduit, it is believed that the patient condition at the time of operation was the primary determinate of outcome. Bowel resection was required in some patients, indicating that patients with CMI can progress to bowel infarction and subsequent gangrene. Therefore, it is critically important to revascularize patients expeditiously before the development of bowel infarction, a condition that increases the risk of operative mortality and increases the challenge of an appropriate individual perioperative case management.

The use of two-vessel reconstruction did not improve the patency of bypass and has resulted in higher complication rates. The survival rate has been reported being superior in one-vessel reconstruction group. Conceding the uncertainties for the number of vessels to be reconstructed and directionality of reconstruction, the vascular surgeon should currently attempt to reconstruct using the antegrade reconstruction of the most affected mesenteric artery if the anatomy is feasible.

7.1. The own theory

Mastering a variety of surgical techniques can provide durable relief of mesenteric ischemia and long-term symptom-free survival. The vascular surgeon should be prepared to use all the available techniques and to tailor the operative strategy to the specific needs of the individual patient.

7.2. Learning curve

A learning curve is important for the treating teams, especially that a good correlation was found between learning curve and clinical outcome in centers with high operative volume. (124) (125) (126)

7.3. Next audit cycle

It is still needed to answer the question about the results of mesenteric open vascular reconstruction on long-term more than five years with more confidence. Thus, larger prospective more risk-factor-oriented studies with multicenter design are required to produce individualized screening regimens based on screening history, and CMI-proved risk factors and to further emphasize the importance and generally valuable aspects of vascular surgical management of mesenteric ischemia. Because of the rarity of the disease, we recommend further multicenter prospective trials, with a standardized selection of the appropriate procedure to manage CMI. The drawbacks of this study can be seen but the own belief is that it can provide the function of auditing our current practice; optimizing the knowledge and experience of the treating team, including everybody involved in the diagnosis of this rare disease, will positively affect the results. The importance of an optimal understanding of the natural history and pathophysiology of mesenteric circulation and its compensatory mechanisms is stressed, this, in turn, guides the optimal patients' and operative procedure selection for an appropriate approach. The extent and frequency of hypogastric artery involvement are underestimated, because many of the records failed to describe the angiographic appearance of these vessels. The internal iliac artery and the collateral blood supply through the profound femoral artery is also essential for the pelvic collateral circulation in case of CMI, and their evaluation should be considered.

Vascular surgeons should probably be prepared to perform either antegrade or retrograde reconstruction or to alter the method of reconstruction as necessity dictates. Dense aortic calcification in the infrarenal or, more rarely, the supraceliac aorta may require a revision of the operative plan. If there is necrotic bowel or transudation of fluid, autogenous reconstructions or endarterectomy would be preferable *versus* prosthetic grafts. Both antegrade and retrograde reconstruction have their adherents, and both provide good results.

The distinction between symptomatic improvement and documented vessel patency is important because occult asymptomatic mesenteric bypass graft occlusion may occur in patients who have undergone multi-vessel reconstruction. Therefore, in order to evaluate the true efficacy of mesenteric revascularization procedures, both symptomatic and objective patency data need to be examined.

8. Summary

Introduction

Chronic mesenteric ischemia (CMI) is a rare chronic disease, which is characterized of insidious impairment of mesenteric blood flow. (27) The patients with CMI often complain of postprandial abdominal pain, usually referred to as abdominal angina, usually associated with weight loss. This disease usually affects elderly patients with a female predominance. (32) CA, SMA, and IMA are the main three arteries supplying the viscera. These vessels connect together and with other aortic and pelvic branches forming an extensive collateral vascular plexus. The most essential collaterals are the pancreaticoduodenal arcades, the arc of Buhler, the marginal artery of Drummond and the arc of Riolan. As a result of this extensive vascular network, it is usually necessary that at least two mesenteric vessels are affected, in order to manifest with symptoms of mesenteric ischemia. (77) The most common etiology for CMI is atherosclerosis. However, other unusual pathologies (such as vasculitis, arterial dissection, MALS, fibromuscular dysplasia, etc.) claimed to cause CMI. (38) About one third of patients have atherosclerotic manifestations of other systems such as coronary heart, cerebrovascular and peripheral arterial diseases. (45) Duplex ultrasonography can identify proximal stenosis of CA and SMA with relatively high sensitivity and specificity. (51) CTA and MRA are other reliable imaging tools to diagnose CMI. DSA has a high accuracy to diagnose CMI with the possibility to do interventions simultaneously. CMI should be treated interventionally, either by an open vascularsurgical or endovascular approach. Despite the documented advantages of percutaneous therapy, open surgical repair has shown to have up to date superior durability; therefore, the choice of therapy should be tailored to the patient's comorbidities and disease process. In general, endovascular therapy is associated with fewer complications but it does demonstrate lower primary patency rates and a greater need for earlier reintervention. (68) (127)

Aim of study

In the present study, more than ten years' experience and clinical outcome in the open vascular reconstruction of CMI were reviewed. The author aimed at evaluating short- and long-term results of patients who underwent surgical vascular reconstruction for CMI, regarding graft patency rate, and symptom-free and survival rates in relation to operative technique.

Patients and methods

In this systematic retrospective clinical observational study for quality assurance in vascular surgery in daily clinical practice as a contribution to research on clinical care, a total number of thirty-eight patients from 2005 to 2018, who underwent mesenteric reconstruction because of CMI, were identified. Patients presenting with acute mesenteric ischemia were excluded.

Results

Twenty-one patients (55.3 %) underwent antegrade revascularization, whereas the remaining 44.7 % of patients (*n*=17) underwent retrograde reconstructions that originated from the infrarenal aorta, a prosthetic graft or iliac axis. The most commonly used material for vascular reconstruction was prosthesis either Dacron or ePTFE in 29 patients (76 %). One-vessel reconstruction was used in 53 % of patients (*n*=20) whereas the two-vessel reconstruction was used in the remaining 47 % of procedures (*n*=18). HLP had a significant impact onto morbidity at one year and five years (*p*=0.018 and *p*=0.04, respectively). The presence of PAD was associated with more perioperative morbidity (*p*=0.02) and morbidity at 5 years (*p*=0.024). Congestive heart disease was also associated with more morbidity at one year (*p*=0.025). Patients who underwent previous peripheral vascular surgery had more morbidity postoperatively and at 1 and 5 years postoperatively, but only at 5 years, it was significantly different (*p*=0.038). The morbidity was 48 % (*n*=18) and mortality 13.2 % (*n*=5). Patients with antegrade procedures showed the slight trend of a higher primary graft patency than retrograde one (*p*=0.207). There was no difference regarding the clinical patency of those patients as well as no difference comparing one- and two-vessel reconstruction regarding the primary and secondary patency. A trend of more major postoperative surgical site bleedings requiring reoperation was observed in patients who had undergone retrograde reconstruction (*p*=0.078) and slightly more in the two-vessel group (*p*=0.468). In addition, there was no significant difference regarding the cumulative survival of patients who had undergone ante- *versus* retrograde reconstruction (*p*=0.492). Regarding the number of reconstructed vessels, there was a significant difference comparing 1-vessel and 2-vessel groups, in favor of the 1-vessel group (*p*=0.001). Postoperative morbidity in the early postoperative period was slightly higher in the retrograde group (*p*=0.161). The two-vessel group showed a trend of higher mortality (*p*=0.086). At five-years follow-up period, patients who had undergone retrograde reconstruction had slightly “more” morbidity (*p*=0.367), whereas two-vessel group had a significantly higher morbidity (*p*=0.004). The mortality was significantly higher in the 2-vessel group in the perioperative period (*p*=0.017), at one year postoperatively (*p*=0.011), and at five years postoperatively (*p*=0.007).

Conclusion

Although, the antegrade *versus* retrograde group offers more primary patency rates perioperatively (90.5 % *vs*. 70.6 %), this difference was not found at longer follow-up, such as at one year and five years. The benefits of complete revascularization, however, were obtained at the expense of a tendency of more early postoperative complications (83.3 % *vs*. 55 %). The mortality in the perioperative period was significantly higher in the 2-vessel group (27.8 % *vs*. 0 %, *p*=0.017). The presented results, however, are comparable with the literature and, thus, provide evidence for a favoring quality of vascularsurgical results as it had been originally intended to do according to the aim of the study. They represent a retrospective review with surgeons' bias and patients' conditions that affected the choice of conduit. Vascular surgeons should be prepared to perform several kinds of mesenteric reconstruction (antegrade and retrograde; single- or multiple-vessel) in order to cope with the intraoperative unsuspected changes and to adapt various patients' anatomy and pathology conditions.

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11. Ethical statement

I declare that I submitted the doctoral thesis to the Otto-von-Guericke University Medical School of Magdeburg, entitled

‘Open Surgical Treatment for Chronic Mesenteric Ischemia - Revascularization Techniques, Operative and Clinical Outcomes’

with the support of Prof. Dr. med. Z. Halloul without any other help and did not use any aids other than those listed there when writing the dissertation and the support of Mrs. Lux from the Institute of Biometry and Medical Informatics regarding recommendations for statistical analysis.

Third party rights were not violated when writing the dissertation.

12. Curriculum vitae

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13. Addendum

13.1. List of Figures

13.2. List of Tables