Chronic mesenteric ischemia: Clinical practice guidelines from the Society for Vascular Surgery

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ABSTRACT

Background: Chronic mesenteric ischemia (CMI) results from the inability to achieve adequate postprandial intestinal blood flow, usually from atherosclerotic occlusive disease at the origins of the mesenteric vessels. Patients typically present with postprandial pain, food fear, and weight loss, although they can present with acute mesenteric ischemia and bowel infarction. The diagnosis requires a combination of the appropriate clinical symptoms and significant mesenteric artery occlusive disease, although it is often delayed given the spectrum of gastrointestinal disorders associated with abdominal pain and weight loss. The treatment goals include relieving the presenting symptoms, preventing progression to acute mesenteric ischemia, and improving overall quality of life. These practice guidelines were developed to provide the best possible evidence for the diagnosis and treatment of patients with CMI from atherosclerosis.

Methods: The Society for Vascular Surgery established a committee composed of vascular surgeons and individuals experienced with evidence-based reviews. The committee focused on six specific areas, including the diagnostic evaluation, indications for treatment, choice of treatment, perioperative evaluation, endovascular/open revascularization, and surveillance/remediation. A formal systematic review was performed by the evidence team to identify the optimal technique for revascularization. Specific practice recommendations were developed using the Grading of Recommendations Assessment, Development, and Evaluation system based on review of literature, the strength of the data, and consensus.

Results: Patients with symptoms consistent with CMI should undergo an expedited workup, including a computed tomography arteriogram, to exclude other potential causes. The diagnosis is supported by significant arterial occlusive disease in the mesenteric vessels, particularly the superior mesenteric artery. Treatment requires revascularization with the primary target being the superior mesenteric artery. Endovascular revascularization with a balloon-expandable covered intraluminal stent is the recommended initial treatment with open repair reserved for select younger patients and those who are not endovascular candidates. Long-term follow-up and surveillance are recommended after revascularization and for asymptomatic patients with severe mesenteric occlusive disease. Patient with recurrent symptoms after revascularization owing to recurrent stenoses should be treated with an endovascular-first approach, similar to the de novo lesion.

Conclusions: These practice guidelines were developed based on the best available evidence. They should help to optimize the care of patients with CMI. Multiple areas for future research were identified. (J Vasc Surg 2021;73:87S-115S.)

TABLE OF CONTENTS

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SUMMARY OF THE GUIDELINES

Diagnostic evaluation

Recommendations.

1. In patients with abdominal pain, weight loss, and food fear, we recommend an expedited workup to exclude gastrointestinal malignancies and other potential causes. The expedited workup may include an esophagogastroduodenoscopy, a colonoscopy, an abdominal computed tomography (CT) scan and an abdominal ultrasound. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)
2. We recommend making a diagnosis of chronic mesenteric ischemia (CMI) in patients with the appropriate clinical scenario and the presence of significant stenoses (>70%) within the celiac axis and superior mesenteric artery (SMA). The diagnosis maybe also made in patients with the appropriate clinical scenario and a significant stenosis (>70%) in either the celiac axis or SMA alone. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)
3. We recommend using the mesenteric duplex ultrasound (DUS) examination as the preferred screening test for mesenteric artery occlusive disease (MAOD). Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)
4. We recommend using CT arteriography (CTA) as the preferred definitive imaging test for MAOD unless unusual anatomic features obscure the anatomy such that a catheter-based arteriogram may be required. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)

Indications for treatment

Recommendations.

1. We recommend revascularization in patients with CMI to reverse their presenting symptoms (ie, weight loss, food fear, diarrhea, postprandial pain) and improve their overall quality of life. Level of recommendation: Grade 1 (Strong), Quality of Evidence: A (High)
2. We recommend that total parenteral nutrition is not an acceptable alternative to revascularization for patients with CMI owing to the risk of clinical deterioration, bowel infarction, and catheter-related complications. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)
3. We suggest that the SMA is the primary target for revascularization. Level of recommendation: Grade 2 (Weak), Quality of Evidence: B (Moderate)
4. We suggest that the celiac axis and inferior mesenteric artery are secondary targets for revascularization and that revascularization may aid in symptom relief if the SMA is not suitable for intervention or the technical result is not acceptable. Level of recommendation: Grade 2 (Weak), Quality of Evidence: B (Moderate)
5. In patients with symptoms consistent with CMI and occlusive disease isolated to a single mesenteric vessel, particularly the SMA, we suggest a shared decision-making approach between the patient and provider to discuss revascularization as a treatment option. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)
6. In select asymptomatic patients with severe MAOD, we suggest a shared decision-making approach between the patient and provider to discuss revascularization as a treatment option. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)
7. We recommend that asymptomatic patients with severe MAOD be closely followed for symptoms consistent with CMI. A possible follow-up schedule includes an annual evaluation with a mesenteric DUS examination. Level of recommendation: Grade 1 (Strong), Quality of Evidence: C (Low)
8. In patients with severe MAOD involving the SMA undergoing aortic reconstruction, both open and endovascular, we suggest a shared decision-making approach between the patient and provider to discuss

revascularization as a treatment option. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)

9. In patients with combined MAOD and mesenteric artery aneurysms, we recommend revascularization at the time of treatment for their mesenteric artery aneurysms if the repair alone would disrupt the collateral network. Level of recommendation: Grade 1 (Strong), Quality of Evidence: C (Low)

Choice of treatment

Recommendations.

1. The choice of treatment for patients with CMI should be a shared decision-making process between the patient and provider considering the risks/benefits of the various options and the patient's goals of care. (*Ungraded Good Practice Statement*)
2. We recommend endovascular revascularization as the initial treatment for patients with CMI and suitable lesions. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)
3. We recommend reserving open surgical revascularization for patients with CMI who have lesions that are not amenable to endovascular therapy, endovascular failures, and a select group of younger, healthier patients for whom the long-term benefits may offset the increased perioperative risks. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)

Preoperative evaluation

Recommendations.

1. Patients undergoing revascularization for CMI should be optimized from a medical standpoint before intervention, although their preoperative evaluation should be expedited. (*Ungraded Good Practice Statement*)
2. We recommend obtaining a CTA to delineate the vascular anatomy before any revascularization. A catheter-based arteriogram may be an alternative if the anatomy is not clear on the CTA. Level of recommendation: Grade 1 (Strong), Quality of Evidence: A (High)

Endovascular revascularization

Recommendation.

1. We suggest using balloon-expandable covered intraluminal stents for the treatment of the MAOD in patients with CMI. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)

Open surgical revascularization

Recommendation.

1. The choice of open surgical revascularization for CMI should be determined by anatomy, comorbidities, prior interventions, and provider preference. (*Ungraded Good Practice Statement*)

Surveillance and remediation

Recommendations.

1. Patients undergoing revascularization for CMI should be educated and counseled about recurrent symptoms owing to the high rate of recurrence. (*Ungraded Good Practice Statement*)
2. Patients should be followed in the outpatient setting after revascularization for CMI. A possible follow-up schedule includes within 1 month of the procedure and then biannually for the first 2 years, and then annually thereafter. (*Ungraded Good Practice Statement*)
3. We suggest surveillance with mesenteric DUS examination to identify recurrent stenoses after revascularization for CMI. A possible ultrasound surveillance schedule includes within 1 month of the procedure and then biannually for the first 2 years, and then annually. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)
4. We recommend performing a CTA or catheter-based arteriograms to confirm any restenoses detected by DUS examination in patients with symptoms consistent with CMI. Level of recommendation: Grade 1 (Strong), Quality of Evidence: C (Low) (*1C*)
5. In patients with recurrent symptoms of CMI, we recommend remedial treatment as recommended for the de novo lesions. Level of recommendation: Grade 1 (Strong), Quality of Evidence: C (Low)
6. In select patients with asymptomatic recurrent stenosis, we suggest a shared decision-making approach between the patient and provider to discuss revascularization as recommended for the de novo lesions. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)
7. We suggest that the choice of revascularization for recurrent stenoses should be similar to the de novo lesions with the endovascular approach recommended as the initial option and open revascularization reserved for lesions not amenable to the endovascular approach. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)

INTRODUCTION

Chronic mesenteric ischemia (CMI) is caused by the failure to achieve postprandial intestinal blood flow resulting in an imbalance between the supply and demand for oxygen and other metabolites. This adverse hemodynamic event is typically caused by atherosclerotic occlusive disease at the orifices of the mesenteric vessels (ie, celiac artery [CA], superior mesenteric artery [SMA], inferior mesenteric artery [IMA]), although a variety of other etiologies have been incriminated. The presence of mesenteric artery occlusive disease (MAOD) is a relatively common finding in the elderly population, particularly in those with evidence of occlusive disease in other vascular beds. In a prospective study of more than 500 patients, Wilson et al[1] reported that 17% of elderly adults had evidence of significant occlusive disease in the CA or SMA. Furthermore, more than 25% of patients undergoing a catheter-based arteriogram for lower extremity occlusive disease were found to have a greater than 50% stenosis in either artery.[2,3] Despite the high prevalence of MAOD, CMI is significantly less common given the extensive collateral network and redundancy in the mesenteric circulation. It is generally accepted that symptoms do not occur unless at least two of the mesenteric vessels are involved although symptoms can develop in patients with single-vessel disease, particularly the SMA.[4-7] The diagnosis of CMI requires the appropriate clinical symptoms, the presence of MAOD, and the exclusion of other potential causes of postprandial abdominal pain. Definitive treatment with mesenteric revascularization is required with the treatment goals of reversing the symptoms, facilitating weight gain, improving the overall quality of life, and preventing bowel infarction.

Both the diagnostic imaging and definitive treatment for CMI have evolved over the past 2 decades, paralleling the larger discipline of vascular surgery, with an increased emphasis on triphasic multidetector CT arteriography (CTA) and percutaneous endovascular treatment. CTA is currently recommended as the first-line imaging study for mesenteric ischemia (both acute and chronic) by the American College of Radiology Appropriateness criteria and has largely replaced catheter-based arteriography as the gold standard for diagnosis.[8] It affords the ability to assess the bowel and other intra-abdominal abdominal organs as a potential cause of the abdominal pain, in addition to providing a more comprehensive view of the extent and distribution of the MAOD and collateral networks. Endovascular treatment with angioplasty and intraluminal stents has largely replaced open surgical bypass as the first treatment option for mesenteric revascularization. Notably, the number of endovascular procedures for mesenteric ischemia has increased 10-fold over the past decade and now accounts for more than 70% of the initial revascularization procedures.[6,9,10] This evolution from open to endovascular revascularization has been justified by the consistent themes for all endovascular procedures, including excellent technical success and decreased perioperative complication rates, despite concerns about decreased patency rates and an increased rate of recurrent symptoms.

The evidence supporting the diagnosis and treatment for CMI has been somewhat limited, despite the dramatic evolution in the care paradigms over the past decades. The supporting evidence is largely retrospective, single-center reports with heterogeneous patient populations in terms of comorbidities, distribution of occlusive disease, acuity of symptoms, and type of revascularization. The limitation of the evidence is compounded by the lack of widely accepted reporting standards and the relative low prevalence of the disease process.

These clinical practice guidelines were developed by the committee under the guidance of the Society for Vascular Surgery to facilitate evidence-based clinical decision making for patients with CMI. They were limited to patients with CMI related to atherosclerotic occlusive disease. CMI was defined as ischemic symptoms caused by insufficient intestinal blood flow to the gastrointestinal tract for a duration of 3 months as defined by the European Society of Vascular Surgery Guidelines.[11] The current guidelines do not address the management of acute mesenteric ischemia (AMI) or nonatherosclerotic causes (eg, median arcuate ligament syndrome, SMA dissection) potentially contributing to the development of CMI. Although the goal of the guidelines was to provide the best possible evidence, there are multiple gaps in our overall understanding and it is anticipated that future studies will likely impact the specific recommendations. Furthermore, the guidelines provide a generic approach to patients with CMI and may not be appropriate for every clinical scenario, thereby emphasizing the importance of a patient-specific approach.

METHODS

The Society for Vascular Surgery selected a committee consisting of vascular surgeons with an expertise in CMI. A guideline methodologist, a librarian, and a team of investigators with expertise in conducting systematic reviews and meta-analyses assisted the committee. The committee communicated in person and remotely. Specific questions were grouped into six areas of focus (diagnostic evaluation, indications for treatment, choice of treatment, perioperative evaluation, endovascular/open revascularization, and surveillance/remediation) and subgroups of the committee were assigned to the focus areas. A formal systematic review and meta-analysis comparing open and endovascular revascularization for CMI was performed by the Evidence-Based Practice Center at the Mayo Clinic.[12] The evidence in the other areas was summarized and recommendations determined by a consensus of the committee members.

The committee used the GRADE approach (Grades of Recommendation Assessment, Development and Evaluation) to rate the quality of evidence (confidence in the estimates) and grade the strength of recommendations.[13,14] This system categorizes recommendations as *strong* GRADE 1 or *conditional* GRADE 2, based on the certainty of evidence, the balance between desirable/undesirable effects, patient values/preferences, and resource use. GRADE 1 recommendations are meant to identify practices where benefit clearly outweighs risk. These recommendations can be made by clinicians and accepted by patients with a high degree of confidence. GRADE 2 recommendations are provided when the benefits and risks are more closely matched and are more dependent on specific clinical scenarios. In general, physician and patient preferences play a more important role in the decision-making process in these latter circumstances. The committee denoted strong and conditional recommendations by stating "recommend" and "suggest," respectively. The certainty of evidence to support the recommendation in either GRADE is divided into three categories: A (high certainty), B (moderate certainty), and C (low or very low certainty). Conclusions based on high-certainty evidence are unlikely to change with further investigation, whereas those based on moderate-certainty evidence are more likely to be affected by further scrutiny. Those based on low-certainty evidence are the least supported by current data and the most likely to be subject to change in the future. The committee also made some statements that were labeled as *ungraded good practice statements*.[15] These statements did not have direct supporting evidence, but had ample indirect evidence and would be considered by many surgeons as surgical principles.

Diagnostic evaluation

Recommendations.

1. In patients with abdominal pain, weight loss, and food fear, we recommend an expedited workup to exclude gastrointestinal malignancies and other potential causes. The expedited workup may include an esophagogastroduodenoscopy, a colonoscopy, an abdominal CT scan, and an abdominal ultrasound examination. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)
2. We recommend making a diagnosis of CMI in patients with the appropriate clinical scenario and the presence of significant stenoses (>70%) within the celiac axis and SMA. The diagnosis maybe also made in patients with the appropriate clinical scenario and a significant stenosis (>70%) in either the celiac axis or SMA alone. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)
3. We recommend using the mesenteric duplex ultrasound (DUS) examination as the preferred screening test for MAOD. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)
4. We recommend using CTA as the preferred definitive imaging test for MAOD unless unusual anatomic features obscure the anatomy such that a catheter-based arteriogram may be required. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate) (*1B*)

Rationale and background

CMI is caused by the failure to achieve adequate postprandial intestinal blood flow. This condition usually results from the presence of atherosclerotic occlusive disease at the origin of the mesenteric arteries and is associated with the typical atherosclerotic risk factors. There is a tremendous amount of redundancy in the mesenteric circulation, and, accordingly, the symptoms of CMI do not typically develop unless both the CA and SMA have hemodynamically significant lesions (>70%). However, it is possible to have symptoms consistent with CMI and disease isolated to a single mesenteric vessel, typically the SMA. MAOD, in contradistinction to CMI, is relatively common and affects a large percentage of patients with peripheral vascular and aneurysmal disease. Patients with CMI typically present with postprandial abdominal pain, weight loss, and food fear. The differential diagnosis for this clinical presentation is quite extensive and includes gastrointestinal malignancies first and foremost. Accordingly, the diagnostic workup should exclude other gastrointestinal causes and potentially include an esophagogastroduodenoscopy, colonoscopy, abdominal ultrasound examination, and abdominal CT scan. The diagnosis of CMI requires the appropriate clinical presentation and the presence of significant MAOD. Neither physical examination nor routine laboratory studies are particularly helpful and, unfortunately, there is no well-accepted functional test that is sufficiently sensitive or specific. Mesenteric DUS examination is an excellent screening test for MAOD, and CTA is the definitive imaging test and has largely replaced catheter-based arteriography.

Detailed justification

The blood flow to the gastrointestinal tract is provided via the CA, SMA, and IMA with collateral contributions via the internal iliac artery, most notably the hemorrhoidal arteries. The gastroduodenal and pancreaticoduodenal arteries provide connections between the CA and SMA. The marginal artery of Drummond and the arc of Riolan (meandering or central anastomotic artery lying in the mesentery close to the inferior mesenteric vein) connect the inferior mesenteric (via the left colic artery) to the superior mesenteric (via the middle colic artery).[16] The disruption of these collateral networks, for whatever reason (eg, IMA ligation during exposure of the infrarenal aorta), can lead to AMI and CMI in patients with MAOD. Because of this well-developed network of collaterals, most patients usually do not develop symptoms of CMI or AMI unless there is a significant stenosis or occlusion in at least two of the mesenteric vessels (ie, CA, SMA, and/or IMA). Notably, Oderich et al[6] described the arteriographic findings of more than 200 patients with CMI and reported that 98% had significant occlusive disease in two of the three mesenteric vessels and 92% had an occlusion or critical stenosis in the SMA. In a longitudinal study of asymptomatic patients with mesenteric ischemia, only patients with significant occlusive disease in all three mesenteric vessels eventually developed symptoms.[17] However, significant occlusive disease in a single mesenteric vessel, usually the SMA, can lead to CMI if the collateral network is inadequate.[4-6] Unfortunately, there is not a direct association between the number of mesenteric vessels involved and the presence of symptoms, thereby confounding the diagnosis and underscoring the difference between MAOD and CMI.

During the fasting state, 20% of the cardiac output courses through the mesenteric arteries.[18] The gastrointestinal blood flow increases after a meal, achieving levels that exceed the fasting values by 100% to 150% over the ensuing 3 to 6 hours.[19] This hyperemic response starts with the anticipation of the meal, but the major hemodynamic effects become most evident after ingestion and movement of the food bolus into the small bowel. The vasodilation of the mesenteric vessels begins 3 to 5 minutes after ingestion and persists for 4 to 6 hours depending on the meal composition with the maximal

Table I. Characteristics of patients included in meta-analysis (comparative and noncomparative studies)

	Endovascular group	Open surgery group	Overall
No.	10,679	8047	18,726
Age, mean (range), years	69.91 (18-97)	67.83 (9-99)	68.70 (9-99)
Male (%)	27.95	36.73	28.22
Risk factors			
Smoking	57.65	77.27	65.95
Diabetes	19.41	17.34	18.70
Hypertension	63.81	63.62	63.67
Coronary artery disease	38.91	34.21	37.58
Peripheral artery disease	56.11	49.79	54.40
Chronic renal insufficiency	5.16	9.03	6.66
Hyperlipidemia	48.62	31.96	41
Presenting symptoms			
Abdominal pain	89.49	87.05	88.17
Weight loss	70.65	78.55	74.48
Diarrhea	30.97	40.77	35.89

Data are presented as percentage unless otherwise indicated.

response occurring within 30 to 90 minutes.[20] The majority of the increased blood flow is via the SMA as reflected by the marked increased end-diastolic velocity (EDV) noted on DUS imaging during a meal challenge.[21] Within the bowel wall itself, the quantity of blood flow is greater in the mucosa than the submucosa or muscularis, thereby making the mucosa layer more susceptible to an ischemic insult.[22] In patients with CMI, the postprandial hyperemic response is blunted or decreased owing to the occluded or stenotic mesenteric vessels. This can result in a mismatch between the supply and demand for oxygen and other metabolites, leading to pain (visceral nerves), malabsorption (intestinal mucosa), and bowel emptying (peristalsis), the cardinal symptoms of CMI.[23-25]

The overwhelming majority of patients with CMI have atherosclerotic occlusive disease as the underlying etiology. The occlusive disease usually affects the orifice and first few centimeters of the mesenteric vessels with relative sparing of the distal segment, and this orifical process is usually associated with plaque within the aorta.[4] The MAOD is a manifestation of a systemic process and patients typically present with the standard atherosclerotic risk factors and involvement in the other vascular beds. The breakdown of the cardiovascular risk factors and comorbidities among patients undergoing revascularization identified in the accompanying meta-analysis is shown in Table I.[12] Notably, the mean patient age among all patients was 68.7 years and the majority were smokers, hypertensive, and had evidence of peripheral artery disease. Unlike most other cardiovascular disorders associated with atherosclerotic occlusive disease, the majority of patients with CMI are women. There is a small percentage of patients that present in the third to fourth decades of life and may have a different female to male sex ratio (eg, 1:1 for coarctation and 5:1 for vasculitis). Furthermore, they do not have the usual atherosclerotic risk factors and associated systemic vascular disease.[26-29] However, these guidelines are restricted to patients with CMI from atherosclerotic occlusive disease, as noted elsewhere in these guidelines.

The presence of MAOD, in contradistinction to CMI, is quite common. As noted, Wilson et al[1] reported that 17% of independent, elderly adults (n = 553) had evidence of significant occlusive disease in the CA or SMA on routine mesenteric DUS screening. However, there were no deaths attributable to mesenteric infarction at follow-up (mean, 6.5 years) in this population and none of the surveyed survivors (71%) reported symptoms consistent with CMI. Unselected autopsy studies have reported the presence of a stenosis of 50% or more in at least one of the mesenteric vessels in up to 10% of patients and almost 30% of patients undergoing catheter-based arteriography before peripheral artery revascularization had evidence of a comparable degree of stenosis in either the CA or SMA.[2,3] A recent report from Zettervall et al[30] examining the national trends in mortality for both CMI and AMI from the Nationwide Inpatient Sample and Centers for Disease Control and Prevention database reported that there has been a dramatic increase in the number of endovascular procedures for both conditions. This finding was associated with a decrease in the population mortality for AMI but no change for CMI, suggesting that the widespread adoption of the endovascular approach was responsible for the improved mortality trend for AMI. Notably, they identified only 14,810 revascularizations for CMI over a 13-year period (2000-2012) and this corresponded to roughly 800 endovascular and 400 open revascularizations per year.

The diagnosis of CMI requires the appropriate clinical presentation along with the presence of hemodynamically significant MAOD. The classic symptoms of CMI include postprandial abdominal pain, weight loss, and food fear. However, it is important to note that this triad is not always present, even at the time of revascularization, and patients can present with nonspecific intestinal complaints, including abdominal discomfort, nausea/vomiting, diarrhea, and constipation.[6,31-34] The abdominal pain is described as mid-abdominal, crampy, or dull. It usually occurs within 30 minutes after eating and can persist for up to 6 hours as suggested by the time course of postprandial hemodynamic changes outlined elsewhere in this article. Certain foods may exacerbate the symptoms, and, accordingly, patients tend to avoid these foods by altering their eating habits.

The postprandial pain can lead to a decrease in oral intake and food fear with the end results that patients lose weight and can even become cachectic in the more extreme scenarios. In one series of patients undergoing mesenteric revascularization, abdominal pain was present in 96%, occurring after eating in only 74%, whereas weight loss occurred in 84% and food fear in 45%.[6] Notably, there was a delay of 15 months from the onset of symptoms to the definitive diagnosis in this series. In another series from Europe, the typical postprandial abdominal pain was present in 85%, weight loss in 77%, and food fear in 63%, whereas diarrhea, nausea, or vomiting were noted in 56%.[35] Allain et al[36] examined the impact of malnutrition on outcome after revascularization for CMI (n = 54) using body mass index, percentage of weight loss and serum albumin. They found that 70% of the patients undergoing revascularization were malnourished and that it was associated with increased perioperative mortality and decreased longer term survival. Interestingly, not all patients are cachectic or malnourished at the time of presentation. Mansukhani et al[37] reported that 35% of the patients in their recent series undergoing revascularization for CMI were overweight or obese with a body mass index of greater than 25, a trend that they attributed to the obesity epidemic across the country. The common delays in diagnosis can often be explained by inconsistencies in the patient's symptoms, the extensive differential for chronic abdominal pain with weight loss, and the low prevalence of CMI in the population. These delays are usually attributed to the extensive diagnostic workups performed by the responsible primary care physician or gastroenterologist, before referral to the vascular specialist. In practice, many of the patients have completed their extensive evaluation and are referred to the specialist with a tentative diagnosis of CMI. Regardless of the explanations for the diagnostic delay, an expeditious diagnosis can lead to timely treatment and avoid the sequelae of CMI, as well as the nutritional deficiencies that may affect the perioperative course.

Although patients with CMI present with abdominal pain and weight loss, the differential diagnosis for this presentation is quite extensive, with gastrointestinal malignancy being foremost among the potential causes. Unfortunately, there are no specific physical examination findings or laboratory studies to aid in the diagnosis. Endoscopy is an integral part of the diagnostic algorithm for abdominal pain and weight loss and, therefore, is often completed before considering CMI in the differential. Both esophagogastroduodenoscopy and a colonoscopy should likely be performed as a part of the diagnostic workup to exclude a malignancy, unless the diagnosis of CMI is clear. Although the findings of ischemic gastritis, duodenitis, and colitis are somewhat nonspecific, they can be suggestive of CMI.[38,39] Notably, the presence of a gastric ulcer in the absence of a malignancy is highly suggestive of CMI.[40-42] A variety of adjunct functional studies have been described to aid in the diagnosis of CMI, including oxygen light spectroscopy[43,44] and intestinal tonometry,[45] although their collective experience is limited and they have not achieved clinical usefulness. It is conceivable that the widespread availability of CT imaging may help to identify the culprit mesenteric stenoses sooner and expedite the diagnosis of CMI when compared with historic series when catheter-based arteriography was the primary diagnostic imaging modality.

Because there is no reliable functional test for the diagnosis of CMI, the diagnosis must rely on the appropriate clinical scenario and the presence of MAOD. Harki et al[46] have attempted to develop a predictive model based on the clinical presentation and anatomic findings to increase the diagnostic accuracy. They identified female sex, weight loss, presence of cardiovascular disease, duration of symptoms, and the presence of SMA/CA stenosis as diagnostic predictors. Van Dijk et al[47] have recently prospectively validated the predictive model (n = 666) and found that it discriminated well with the addition of a predictor for the cause of the CA stenosis. Notably, 94% of the high-risk patients had CMI based on durable symptom relief after revascularization, although the diagnosis was confirmed in only 8% of the low-risk patients.

Mesenteric DUS examination is an excellent screening tool for patients suspected of having CMI.[48] Although the test is technically demanding and requires an advanced skill set, it can yield consistent, reproducible results in experienced hands. Patients are routinely fasted for 6 to 8 hours to minimize the amount of bowel gas. Nevertheless, obesity can complicate the examination owing to the depth of the vessels. Comparison of mesenteric DUS findings with catheter-based arteriography demonstrated that the CA and SMA were visualized 83% and 93%, respectively, with ultrasound examination and virtually 100% of the time with arteriography.[49] The common DUS criteria for a SMA stenosis of 70% or greater is a peak systolic velocity (PSV) of 275 cm/s or more, whereas 200 cm/s or more indicates a similar stenosis of the CA with no flow in either vessel consistent with an occlusion. These criteria for the SMA were associated with a sensitivity of 92%, specificity of 96%, positive predictive value (PPV) of 80%, and negative predictive value (NPV) of 99% with an overall accuracy of 96%.[49,50] Importantly, a negative study essentially rules out a significant stenosis of the SMA. These peak systolic criteria for the CA are associated with a sensitivity of 87%, specificity of 80%, NPV of 63%, PPV of 94%, and an overall accuracy of 82%. Alternatively, an EDV of 45 cm/s or more corresponded with a 50% or greater stenosis of the SMA with a 90% sensitivity, 91% specificity, 90% PPV, 91% NPV, and 91% accuracy.[51] An EDV of greater than 55 cm/s in the CA corresponded with a 50% or greater stenosis with an accuracy of 95%, sensitivity of 93%, and specificity of 94%; reversal of flow in the hepatic arteries was predictive of a proximal CA stenosis or occlusion.[51] The use of postprandial DUS imaging has not been shown to improve the overall accuracy for the evaluation of either SMA or CA stenoses.[21,52]

The reported DUS criteria used to determine the degree of stenosis in the SMA and CA may vary by vascular laboratory and the specific imaging equipment, underscoring the importance of local validation. In a more recent study by AbuRahma and colleagues,[53] the most accurate determination of a 50% or greater SMA stenosis was a fasting PSV of 295 or higher (accuracy 88%, NPV 84%, PPV 91%) and for a 70% or greater stenosis, it was 400 cm/s or more (accuracy 85%, NPV 85%, PPV 84%). For the CA, a 50% or greater stenosis correlated with a PSV of 240 cm/s or higher (accuracy 86%) and a 70% or greater stenosis with a PSV of 320 cm/s or more (accuracy 85%). The DUS velocities used to determine the degree of stenosis can also be affected by the presence of collaterals and by respiration.[54,55] An extensive collateral network, as often seen in the presence of an SMA or CA occlusion, can lead to increased flow velocities in the other, unaffected mesenteric vessels, suggesting a significant stenosis when one is not actually present.[54] Similarly, significantly high peak systolic and diastolic velocities were found during expiration (vs inspiration), thus, potentially impacting the accurate assessment of the degree of stenosis.[55]

The IMA can serve as an important collateral when the other mesenteric vessels have significant occlusive disease. Unfortunately, the published experience with DUS for the IMA is fairly limited. One study comparing DUS imaging with angiography demonstrated that a greater than 50% stenosis of the IMA was associated with a greater than 250 cm/s PSV with an accuracy of 95%, whereas an IMA to aortic PSV ratio of greater than 4.0 had an accuracy of 93%.[56] A second study used greater than 200 cm/s as the criteria for a greater than 50% stenosis, but the sample size in the study was small and there were only nine vessels that were adequately imaged.[57] Unfortunately, there are no prospective studies examining the DUS criteria for as significant IMA stenosis.

Although mesenteric artery DUS is a rapid, noninvasive screening study that can often confirm or refute the presence of arterial occlusive disease, additional imaging is required to confirm the presence of MAOD and to define the precise location and extent of disease for operative planning. CTA provides anatomic clarity and can exclude other potential causes of chronic abdominal pain.[6,9,58,59] The technique employs three-dimensional multiplane reformatting along with centerline measurements. The diagnostic accuracy for patients with CMI has been reported to range from 95% to 100%[59] and it is recommended as the first-line study by the American College of Radiologists Appropriateness Criteria as well as the European Society of Vascular Surgery Mesenteric Guidelines.[8,11] A recent prospective study compared DUS, CTA, and mesenteric resonance arteriography (MRA) to catheter-based arteriography as the gold standard reported that CTA provided the best image quality, the highest level of correlation for grading the degree of stenosis, and was the most accurate.[60] Triphasic CTA provides excellent spatial resolution and image detail and is considered the best study to define the anatomic characteristics of the mesenteric lesions (eg, lesion length, diameter, presence of thrombus, or calcification) and the potential inflow sites for open revascularization (eg, calcification of the supraceliac aorta) that are required for intervention planning. Furthermore, the delayed phase can be helpful to identify other vascular pathologies, including mesenteric venous thrombosis. The obvious limitations of CTA include image artifact from severe calcification or metallic devices, the need for iodine-based contrast, expense, and radiation exposure. CTA is also very helpful to identify other intra-abdominal pathology and is particularly helpful in the setting of acute or subacute mesenteric ischemia to assess the appearance of the bowel wall with the hallmarks of ischemia being bowel wall thickening, edema, hemorrhage, and/or hyperemia. CTA has been shown to be both sensitive (93%) and specific (96%) for detecting bowel infarction and perforation.[61-64] Unfortunately, Karkkainen et al[65] reported that only one-third of the patients who presented with AMI and an antecedent history of CMI (ie, acute on CMI) had evidence of ischemic-specific findings in their bowel on CT scan, and they suggested that any bowel-related findings in patients with an SMA obstruction should be attributed to ischemia.

CTA has also been shown to be superior to MRA after endovascular intervention owing to better visualization of the lumen, higher spatial resolution, and faster acquisition times.[58,66-68]

MRA affords many of the same advantages as CTA for the diagnosis of CMI and should be considered an alternative modality.[66,69] Gadolinium-enhanced MRA was shown to have an overall sensitivity and specificity of greater than 95 % when compared with catheter-based arteriography for the detection of significant mesenteric artery stenoses.[70] The interobserver variability was excellent, but the degree of stenosis was consistently overestimated owing to the lack of submillimeter resolution.[70,71] The limitations of MRA include the inability to scan patients with pacemakers, inability of patients with claustrophobia to tolerate the closed space, lengthy examination times, and the inability to assess patients with mesenteric stents.[66] Furthermore, MRA is not as helpful to characterize the degree of calcification in the target vessels or inflow arteries for planning revascularization, although it can be supplemented with a noncontrast CT scan. Caution must be used when administering gadolinium to patients with chronic kidney disease and/or on dialysis owing to the risk of nephrogenic systemic fibrosis.[72] Furthermore, MR scanners are not as readily available or widespread as CT scanners and most vascular specialists feel more comfortable with CTAs.

Catheter-based arteriography has historically been considered the gold standard for the diagnosis of MAOD.[48] However, owing to the evolution of the other less invasive imaging modalities outlined elsewhere in this article and the known complications associated with the catheter-based procedures (eg, vessel perforation, bleeding, and peripheral emboli),[73-75] the use of catheter-based arteriography as a diagnostic test has decreased significantly.[76] However, it can be useful when the other less invasive imaging modalities are nondiagnostic (eg, extensive vessel calcification, prior stent, other metallic artifact) or when percutaneous intervention is planned. Optimal biplane imaging includes anterior-posterior (renal and aortoiliac), lateral (SMA and celiac arteries), and right anterior oblique views (IMA) for optimal visualization of specific vessels. The anterior-posterior projections are helpful to visualize the branches of the SMA and its collaterals, including the gastroduodenal and marginal arteries, whereas the lateral projection is optimal to view the origins of the CA and SMA given their posterior-anterior orientation. Selective cannulation can provide additional visualization of the mesenteric vessels, including their more distal segments and any collateral channels. Intraluminal pressure measurements can be made across a stenosis at the time of arteriography if there is a question regarding the hemodynamic significance of the lesion.[77] It is worth emphasizing that the other less invasive imaging studies (ie, DUS examination, CTA, MRA) cannot provide any functional or hemodynamic data in terms of pressure gradients. Concerns have been raised about the impact of the catheter itself and its contribution to the gradient. These concerns can be overcome by the use of an intraluminal pressure wire, although it is associated with additional expense. Alternatively, intravascular ultrasound examinations can be used at the time of the catheter-based arteriography to calculate the degree of stenosis in the lesion.[78,79] Carbon dioxide has been used as an alternative contrast agent for patients with chronic renal insufficiency, but it may be contraindicated for evaluation of the mesenteric vessels in patients with CMI owing to its potential to cause bowel infarction, particularly in the case of selective injections.[80]

Implementation considerations

The diagnosis, treatment, and overall management of patients with CMI is well-known to most vascular care providers. Indeed, the diagnostic workup has usually been completed by the primary care provider and/or gastroenterologist at the time of referral. The excessive diagnostic delays from onset of symptoms to definitive diagnosis and referral for revascularization are due to the low prevalence of the disease, the unfamiliarity of most primary care providers, and the extensive differential diagnosis. Accordingly, it is incumbent upon vascular care providers to help educate primary care providers to reduce the diagnostic delay and expedite treatment. CT scans are universally available and provide the best chance for early diagnosis in the patient with abdominal pain and weight loss. Appreciation of the presence of MAOD in this setting and the potential for CMI may expedite definitive care.

Future research

- Development of reporting standards for patients with CMI
- Development of a standard diagnostic algorithm for CMI
- Development of a functional test for CMI

Indications for treatment

Recommendations.

1. We recommend revascularization in patients with CMI to reverse their presenting symptoms (ie, weight loss, food fear, diarrhea, postprandial pain) and improve their overall quality of life. Level of recommendation: Grade 1 (Strong), Quality of Evidence: A (High)
2. We recommend that total parenteral nutrition is not an acceptable alternative to revascularization for patients with CMI owing to the risk of clinical deterioration, bowel infarction and catheter-related complications. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)

3. We suggest that the SMA is the primary target for revascularization. Level of recommendation: Grade 2 (Weak), Quality of Evidence: B (Moderate)
4. We suggest that the celiac axis and IMA are secondary targets for revascularization and that revascularization may aid in symptom relief if the SMA is not suitable for intervention or the technical result is not acceptable. Level of recommendation: Grade 2 (Weak), Quality of Evidence: B (Moderate)
5. In patients with symptoms consistent with CMI and occlusive disease isolated to a single mesenteric vessel, particularly the SMA, we suggest a shared decision-making approach between the patient and provider to discuss revascularization as a treatment option. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)
6. In select asymptomatic patients with severe MAOD, we suggest a shared decision-making approach between the patient and provider to discuss revascularization as a treatment option. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)
7. We recommend that asymptomatic patients with severe MAOD be closely followed for symptoms consistent with CMI. A possible follow-up schedule includes an annual evaluation with a mesenteric DUS. Level of recommendation: Grade 1 (Strong), Quality of Evidence: C (Low)
8. In patients with severe MAOD involving the SMA undergoing aortic reconstruction, both open and endovascular, we suggest a shared decision-making approach between the patient and provider to discuss revascularization as a treatment option. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)
9. In patients with combined MAOD and mesenteric artery aneurysms, we recommend revascularization at the time of treatment for their mesenteric artery aneurysms if the repair alone would disrupt the collateral network. Level of recommendation: Grade 1 (Strong), Quality of Evidence: C (Low)

Rationale and background

Treatment goals for patients with CMI are to reverse the symptoms, facilitate weight gain, prevent the development of AMI, and improve the patient's overall quality of life. The optimal treatment represents a balance between the natural history of the underlying disease process and the risks associated with the specific treatment. Unfortunately, the natural history of both CMI and MAOD remain poorly defined, although the potential adverse sequelae are well-known. Accordingly, patients with CMI require revascularization to optimize mesenteric perfusion. There is essentially no role for prolonged total parenteral nutrition given the associated risks and prolonged attempts to optimize the nutritional status before revascularization may be harmful. The SMA is the optimal target for revascularization and revascularization of the SMA alone is usually sufficient given the extensive mesenteric collateral network. Revascularization of the CA or IMA alone should likely be reserved for scenarios when revascularization of the SMA is inadequate or not feasible. It is possible for patients to develop symptoms consistent with CMI with occlusive disease isolated to the SMA despite the traditional teaching that it requires involvement of at least two mesenteric vessels. Revascularization is indicated in this scenario given the potential adverse sequelae and the resolution of symptoms can actually serve as a diagnostic tool for CMI in patients with equivocal symptoms. Similarly, even though the natural history of MAOD can be benign, there is a subset of patients that may benefit from revascularization given the potential for adverse sequelae, including those undergoing aortic reconstruction (both open and endovascular), those with involvement of all three of the mesenteric vessels, and those undergoing treatment for mesenteric artery aneurysms in which treatment would disrupt the collateral vessels.

Detailed justification

Treatment goals for patients with CMI are to reverse the symptoms, facilitate weight gain, prevent the development of AMI, and improve the patient's overall quality of life. Similar to most medical and surgical therapies, the treatment algorithm represents a balance between the natural history of the disease process and the risks/benefits associated with treatment. Unfortunately, the natural history of CMI is not well-defined, given the lack of randomized, controlled trials and the presence of a true noninterventional control group in the observational studies. Furthermore, it would seem unethical to propose a clinical trial with a noninterventional group given the sequelae of AMI, including death. The natural history of CMI has largely been defined by the clinical course of patients before intervention as reflected by the duration of symptoms or the development of AMI. Admittedly, there is a tremendous amount of selection bias in these studies. Untreated patients with CMI can clearly waste away from inanition and/or progress to AMI, and it has been reported that the 5-year mortality rate for untreated patients approaches 100%.[81] Furthermore, up to 50% of patients with AMI present with thrombosis of an existing lesion and antecedent symptoms consistent with CMI.[82] In contrast, revascularization, either open or endovascular, has been associated with excellent results in terms of both symptomatic relief and long-term graft or mesenteric vessel patency.[31,35,83,84] Notably, Blauw et al[85] surveyed patients before and after revascularization for CMI using the Euroqol-5D survey tool and reported that revascularization was associated with an overall improvement in quality of life with improvement within the activities and pain/discomfort domains.

There may be a role for noninterventional treatment for patients with CMI, although this role may be more theoretical or simply a short-term bridge before revascularization. Small, more frequent meals or complete cessation of enteral feeding can decrease the metabolic demand of the gut and alleviate symptoms, and parenteral nutrition can fulfill the nutritional requirements. However, the role for prolonged total parenteral nutrition is limited given the catheter-related risks and the potential for clinical deterioration with bowel infarction.[17,86] Interestingly, Baxter et al[87] examined the quality of life for patients on home parenteral nutrition and found that it was worse in patients with mesenteric ischemia than in those with Crohn's disease. The published experience using parenteral nutrition as short-term bridge to revascularization for patients with CMI is fairly limited, although data extrapolated for the use of total parenteral nutrition for severely malnourished patients before nonvascular surgical procedures suggests that it decreases major morbidity without reducing the infectious complications.[88-90] Furthermore, it cannot replace revascularization as noted by Rheudasil et al,[86] who reported two patients who developed fatal bowel necrosis while on parenteral nutrition awaiting open revascularization. Palliative care and hospice are both reasonable alternatives for patients with CMI who are not candidates for revascularization owing to their advanced comorbidities and/or personal preference.

The SMA is the most important of the three mesenteric vessels given the extent of its distribution to the bowel and is the primary target for revascularization. The crucial role of the SMA is indirectly supported by the overall better symptomatic relief noted when the SMA is revascularized, regardless of what other combination of vessels are treated or whether performed by an open or endovascular approach. Notably, Goldman et al[91] compared the outcomes associated with the endovascular treatment of CA alone vs SMA alone or the latter in combination with the CA. They found that the treatment of the CA alone was associated with the highest rate of symptomatic recurrence and concluded that the SMA was the key determinant of successful revascularization.

Isolated revascularization of the CA or IMA may be justified in select patients when the SMA is not suitable for revascularization. The characteristics of the SMA that affect treatment selection include vessel diameter, extent of stenosis or occlusion, presence of tandem lesions, degree of calcification, and the extent of collateralization. Admittedly, most of these concerns are more relevant for endovascular revascularization, because it is usually possible to identify a suitable distal target in either the SMA or CA for open revascularization. Several recent studies have reported that endovascular revascularization of the SMA is possible for long segment occlusions and/or severe calcifications.[33,92,93] Endovascular revascularization of the CA with an intraluminal stent is associated with a high risk of restenosis[94] and is relatively contraindicated if there is significant compression by the median arcuate ligament, although it is feasible to release the median arcuate ligament with either a laparoscopic or open surgical approach. The reported experience with isolated IMA revascularization for the treatment for CMI is limited to relatively small case series and the outcomes have been somewhat equivocal.[95,96] The isolated endovascular revascularization of the CA or IMA in the setting of a severely disease SMA may be considered as a bridge to open bypass or retrograde SMA stenting.[97]

There has been a long-standing debate about the number of mesenteric vessels that should be revascularized in patients with CMI that has persisted since the era when only open surgical revascularization was an option. There are some theoretical advantages to revascularizing both the SMA and CA, but most reports indicate that treatment of the SMA alone is sufficient.[33,94,98] Two recent retrospective studies from the Massachusetts General Hospital group and by Silva et al[31] have shown a nonsignificant trend towards a lower recurrence rate with treatment of both vessels.[98] However, Malgor et al[94] from the Mayo Clinic reported similar recurrence rates at 2 years in patients treated with intraluminal stents in the SMA compared with those treated with stents in both the SMA and CA. It is conceivable that the lack of significant difference in these studies was due to the small sample size and a type 2 error. Furthermore, there may have been a selection bias with stent placement in both the SMA and CA reserved for patients with a suboptimal results of SMA treatment alone. Revascularization of both the CA and SMA may have a role in select patients with severe gastric ischemia and those without adequate collaterals. However, there is no proven benefit that revascularizing both vessels provides more durable relief, and the second (or additional) intervention adds cost and potential risk.

There is likely a role for revascularization in patients with symptoms consistent with CMI and occlusive disease isolated to single mesenteric vessel, particularly the SMA. Patients with CMI typically have MAOD affecting both the CA and the SMA or all three of the mesenteric vessels as noted, and there has been a classic teaching that stressed the concept that patients cannot develop CMI unless at least two of the three mesenteric vessels are involved given the collateral network and redundancy in the mesenteric circulation. However, this teaching point is likely incorrect; it is possible to develop CMI from isolated mesenteric involvement, usually in the setting of a poor collateral network between the mesenteric vessels. The common clinical scenario is a patient with vague abdominal complaints, not necessarily consistent with CMI, who is found to have significant occlusive disease isolated to the SMA or CA. The treatment decision represents a balance between the natural history of untreated CMI and the risks/costs associated with the open or endovascular treatment. Unfortunately, there is no functional study to truly confirm or refute the diagnosis. This small cohort of patients should undergo the extensive diagnostic evaluation outlined elsewhere in this article for patients with the more classic symptoms of CMI. Revascularization can serve as both a diagnostic and therapeutic tool in this setting, with the resolution of symptoms confirming the diagnosis. Notably, van Dijk et al[99,100] published their series (n = 59) of patients with symptoms consistent with CMI and isolated MAOD (CA, 81%; SMA, 19%). They reported that 73% of the patients had sustained relief of their symptoms and that the favorable results were not related to the location of the lesion (ie, CA vs SMA).

Because the natural history of patients with asymptomatic MAOD remains poorly defined, it is no surprise that the indications for prophylactic revascularization remain unresolved. Justification for revascularization in this setting is provided by the fact that a significant percentage of patients with MAOD present with symptoms of AMI from thrombosis of a preexisting lesion rather than the more typical, protracted symptoms associated CMI.[101,102] Furthermore, patients with MAOD can develop CMI. Thomas et al[17] attempted to retrospectively define the natural history of asymptomatic MAOD among a cohort of 980 consecutive patients undergoing mesenteric arteriography. They reported that significant MAOD (>50% stenosis) was present in 8.3% of the patients (n = 82) with 1.5% of the patients (n = 15) demonstrating stenosis of all three mesenteric vessels. There were four deaths owing to mesenteric ischemia during the follow-up period that ranged from 1 to 6 years,with all of the deaths occurring in patients with significant involvement of all three mesenteric vessels. More impressively, 86% of the patients with involvement of all three mesenteric vessels developed symptoms consistent with mesenteric ischemia.

Revascularization may be justified in a small subset of asymptomatic patients with severe MAOD involving all three mesenteric vessels. These patients should be monitored closely and counseled regarding the presence of symptoms and the importance of seeking medical care. Accordingly, revascularization may be justified for noncompliant patients or those with limited access to medical care. Revascularization is also likely indicated in the presence of vague or nonspecific abdominal pain given the potential adverse sequelae, including progression to AMI.

The perioperative perturbations associated with any major surgical procedure, particularly open and endovascular aortic aneurysm repair, can lead to mesenteric ischemia in patients with significant MAOD. This is relevant for open aortic procedures given the physiologic and hemodynamic changes and the potential disruption of any collateral networks, particularly the marginal artery that runs at the base of the mesentery adjacent to the inferior mesenteric vein. Similarly, it is relevant for endovascular aneurysm repair owing to the obligatory exclusion of the IMA by the endovascular device and the frequent need to coil embolize the vessel to prevent a significant type II endoleak. Review of the preoperative CTA to examine the status of the CA, SMA, IMA, and internal iliac artery should be obligatory before any aortic reconstruction. This review should include an evaluation of any collateral vessels between the named mesenteric vessels, suggesting a hemodynamically significant stenosis. Preoperative or concomitant revascularization of the SMA and/or CA is likely justified in this setting, although revascularization represents a balance between the additional morbidity and mortality associated with repair vs the risk associated with progression to CMI or AMI after aortic reconstruction. Unfortunately, the role for prophylactic revascularization in this setting remains unresolved. The Society for Vascular Surgery clinical practice guidelines for abdominal aortic aneurysms have recommended (2C) “prophylactic treatment of asymptomatic, high-grade stenosis of the SMA in the presence of a meandering mesenteric artery based off a large IMA, which will be sacrificed during the course of treatment”.[103] The choice of revascularization included both endovascular and open approaches, with the former approach generally favored provided that the lesions are amenable. A study from the National Inpatient Sample reported that simultaneous renal revascularization at the time of open infrarenal aneurysm repair was associated with an increased mortality rate and the findings are likely applicable to combined mesenteric revascularization.[104,105] Single institution series have reported somewhat equivocal findings in terms of the increased morbidity and mortality associated with simultaneous mesenteric revascularization.[7,106,107] Unfortunately, it is unclear from the nationwide and single institution series whether the simultaneous mesenteric revascularization increased or decreased the overall mortality rate for the underlying condition given the lack of appropriate controls. Patients with CMI who require aortic reconstruction for either occlusive or aneurysmal disease require mesenteric revascularization as outlined for patients with CMI alone. The mesenteric revascularization should be performed before or simultaneous with the aortic reconstruction for patients with CMI, as recommended by the Society for Vascular Surgery’s guidelines for abdominal aortic aneurysms.[103] Notably, they state that patients with symptomatic disease of the SMA (ie, CMI) should undergo angioplasty and stenting before open or endovascular repair (1A), whereas those who are not amenable to an endovascular approach should undergo concomitant revascularization at the time of open aneurysm repair (1A).

Aneurysms can develop within the major mesenteric vessels and their collateral networks. One of the presumed mechanisms is the hemodynamic forces that result from the increased flow through the collateral vessel as a result of a stenosis or occlusion in the major vessels (eg, aneurysm in inferior pancreaticoduodenal artery with concomitant CA occlusion).[108] Many of these flow-related aneurysms can be treated with ligation or coil embolization. However, it is important to detail the full extent of the mesenteric circulation and the extent of the contribution of the collateral network before treatment. Revascularization of the CA or SMA may be justified to preserve the mesenteric perfusion concomitant with treatment of the aneurysm.[109]

Implementation considerations

The indications, targets, and goals of treatment for CMI are relatively well-known to vascular surgeons. However, vascular care, including endovascular treatment of for CMI, is provided by a variety of physicians, including primary care providers, gastroenterologists, cardiologists, and radiologists. It is incumbent upon the vascular surgery community to help educate the other providers involved in the care of vascular patients regarding the importance of timely referral, appropriate treatment indications, and targets for revascularization.

Future research

- Natural history of CMI
- Natural history of MAOD
- Management of MAOD and open aortic reconstruction
- Management of MAOD and mesenteric artery aneurysms

Choice of treatment

Recommendations.

1. The choice of treatment for patients with CMI should be a shared decision-making process between the patient and provider considering the risks/benefits of the various options and the patient's goals of care. (*Ungraded Good Practice Statement*)
2. We recommend endovascular revascularization as the initial treatment for patients with CMI and suitable lesions. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)
3. We recommend reserving open surgical revascularization for patients with CMI who have lesions that are not amenable to endovascular therapy, endovascular failures, and a select group of younger, healthier patients in which the long-term benefits may offset the increased perioperative risks. Level of recommendation: Grade 1 (Strong), Quality of Evidence: B (Moderate)

Rationale and background

The choice of treatment for patients with CMI should represent a shared decision-making process between the patient and vascular care provider that involves a thorough understanding of the associated risks/benefits of any intervention and incorporates the individual patient's goals of care, including quality of life. The important outcome measures include both perioperative and longer term morbidity and mortality, along with the rates of recurrent symptoms and the need for remedial interventions. Endovascular revascularization is the recommended initial treatment for the overwhelming majority of patients, provided that the lesion is amenable. The endovascular approach is associated with a lower perioperative complication rate and shorter inpatient hospital length of stay, although the rate of recurrent symptoms and need for reintervention are both higher. There does not seem to be a difference in the perioperative or longer term mortality rate between the endovascular and open approaches. The evidence supporting the initial endovascular approach has been consistent across the literature and includes individual case series, meta-analyses, national series from administrative databases, decision analyses, and other clinical practice guidelines. Open surgical revascularization should be reserved for patients who are not endovascular candidates and those who have failed prior endovascular interventions. Open revascularization may also be appropriate as the initial procedure for select younger, healthier patients with longer life expectancies, assuming that the improved long-term patency offsets the increased perioperative risks.

Detailed justification

A systematic review and meta-analysis of the literature was performed as a component of these guidelines to determine the optimal revascularization strategy (ie, open vs endovascular) for patients with CMI.[12] A total of 100 observational studies (22 comparative, 78 noncomparative) were identified that encompassed almost 19,000 patients. The perioperative complication rate was found to be increased in the open group (relative risk [RR], 2.19; 95% confidence interval [CI], 1.84-2.60; Fig 1), although there was no significant increase in the 30-day mortality rate (5.5% vs 1.4%; RR, 1.57; 95% CI, 0.84-2.93; Fig 2). Open revascularization was associated with a lower risk of 3-year recurrence (RR, 0.47; 95% CI, 0.34-0.66; Fig 3), but there was no significant difference in the 3-year survival rate between the groups (RR, 0.96; 95% CI, 0.86-1.07; Fig 4). Based on these observational studies, it was concluded that the endovascular approach may offer better early outcomes, although the effect may not be as durable even though the long-term survival rates seem to be similar with appropriate reintervention when needed. Unfortunately, the overall quality of the evidence was deemed to be low.

The findings from our meta-analysis are largely consistent with several other comparable reviews examining the optimal revascularization strategy for patients with CMI (Table II). Saedon et al[110] (12 studies and 7365 patients) reported no differences in perioperative morbidity, perioperative mortality or survival, but a marked increase in patency (odds ratio [OR], 3.57; 95% CI, 1.83-6.97; $P = .0002$) in the open group. Cai et al[111]

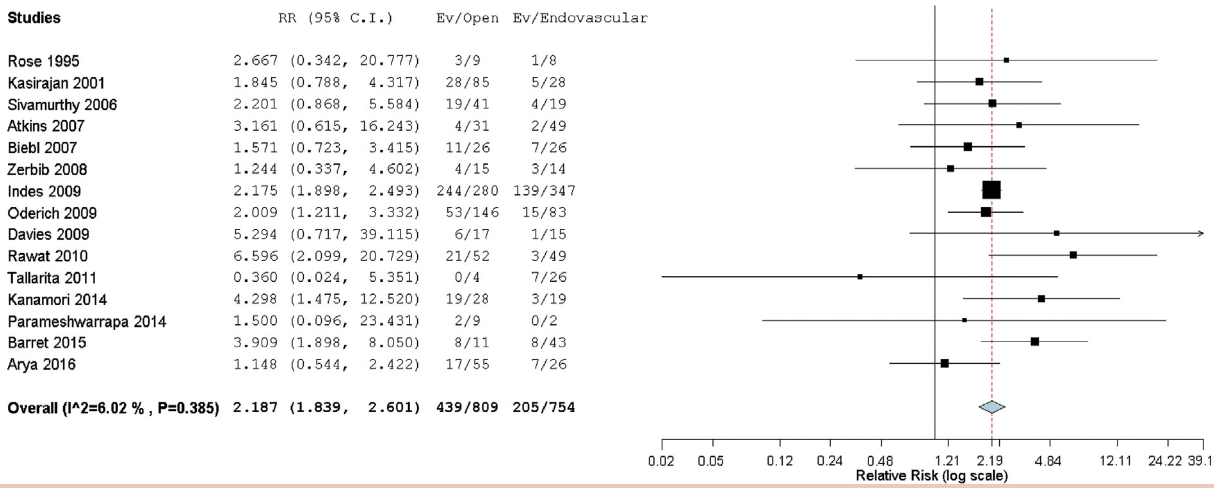

Fig 1. In-hospital complications among patients with chronic mesenteric ischemia (CMI) who had undergone endovascular (*Ev*) revascularization vs those who had undergone open surgery. *CI*, Confidence interval; *RR*, relative risk.

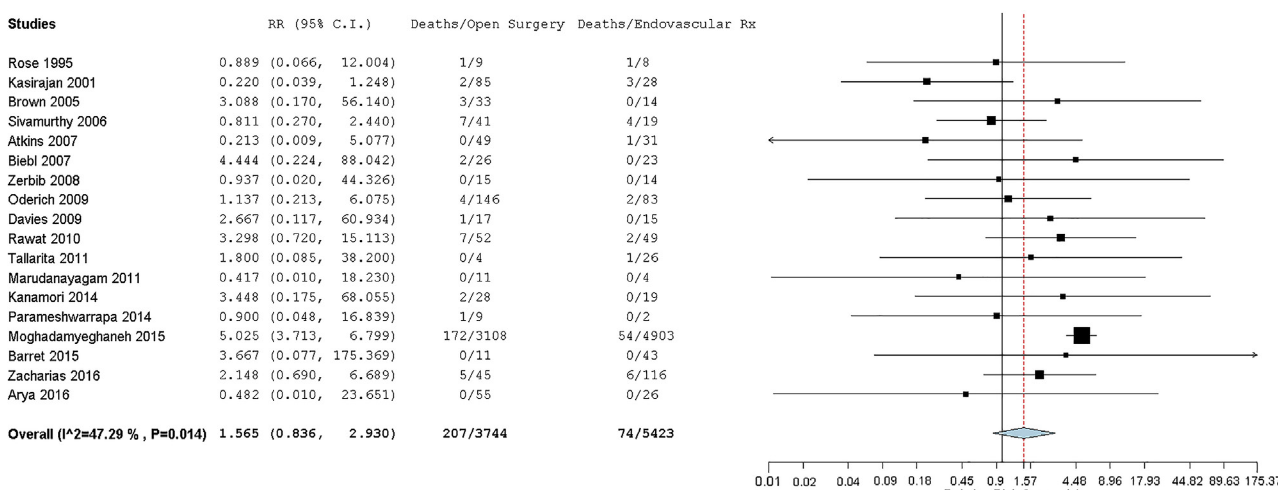

Fig 2. The 30-day mortality among patients with chronic mesenteric ischemia (CMI) who had undergone endovascular revascularization vs those who had undergone open surgery. *CI*, Confidence interval; *RR*, relative risk.

(8 studies and 569 patients) reported no difference in perioperative mortality or survival between the groups, but a lower perioperative complication and higher recurrence rate in the endovascular group. Gupta et al[113] (1939 patients) reported that the open repair was associated with a higher perioperative complication rate, higher 5-year primary patency (OR, 3.8; 95% CI, 2.4-5.8; $P < .001$) and higher 5-year freedom from recurrent symptoms (OR, 4.4; 95% CI, 2.8-7.0; $P < .001$) despite no difference in perioperative mortality or survival. Last, Pecoraro et al[112] (43 studies and 1795 patients) reported lower perioperative morbidity and mortality in the endovascular group despite lower patency rates and no difference in survival. The similarity between the findings among the various meta-analyses is not particularly surprising given the significant overlap among the studies that comprised the reviews. However, it is worth emphasizing that the meta-analysis that accompanied the guidelines represents the most comprehensive and extensive review in the literature and any discrepancy with the other reviews is likely due to their small sample size and the earlier dates of publication, before the widespread adoption of the endovascular approach.

The results of several recent clinical series comparing the outcome of patients with CMI underscore the findings of the meta-analyses, but provide more granular information. Lejay et al[35] reported their outcomes for open revascularization during the endovascular era with a

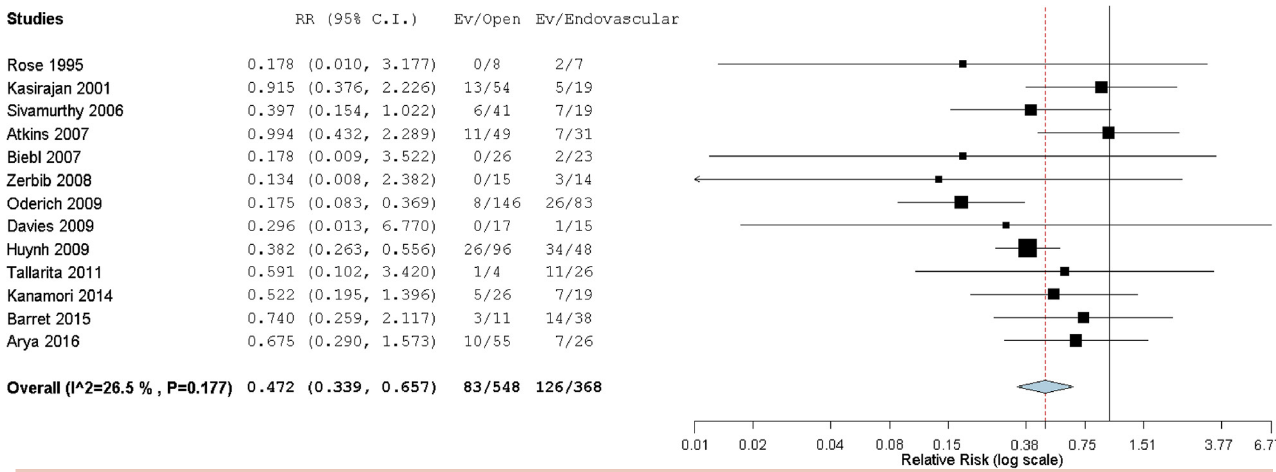

Fig 3. The 3-year recurrence rates of symptoms among patients with chronic mesenteric ischemia (CMI) who had undergone endovascular (*Ev*) revascularization vs those who had undergone open surgery. *CI*, Confidence interval; *RR*, relative risk.

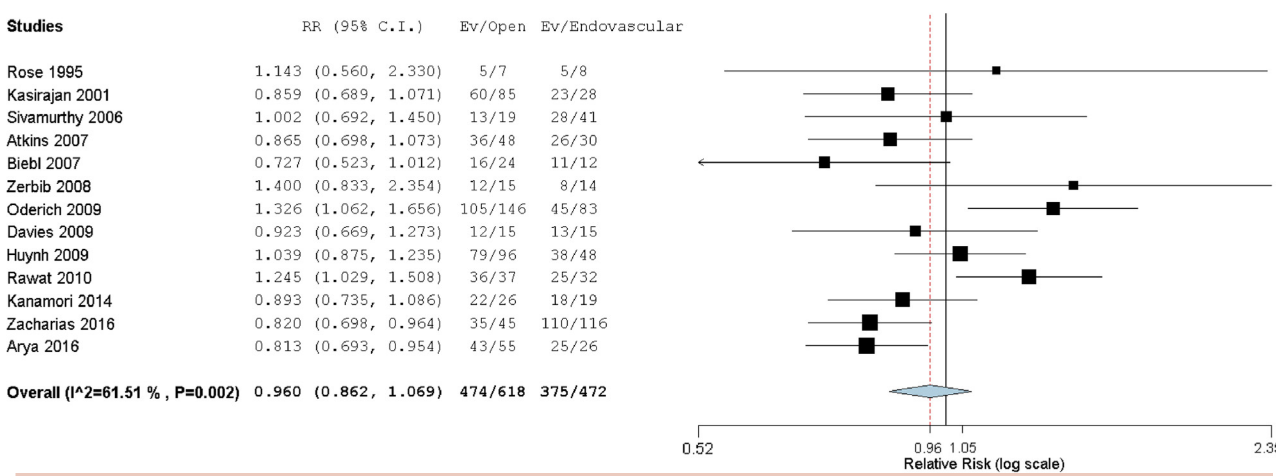

Fig 4. The 3-year survival among patients with chronic mesenteric ischemia (CMI) who had undergone endovascular (*Ev*) revascularization vs those who had undergone open surgery. *CI*, Confidence interval; *RR*, relative risk.

perioperative morbidity and mortality rate of 13.9% and 3.5%, respectively, and a 10-year survival and primary patency rate of 88% and 84%, respectively. Oderich et al[6] compared the outcomes of 229 consecutive patients undergoing revascularization for CMI (open, 146; endovascular, 83) and reported that the perioperative morbidity (36% vs 18%; $P = .001$) and hospital length of stay (12 ± 8 days vs 3 ± 5 days; $P = .001$) were higher for the open group, although there was no difference in perioperative mortality (open, 2.7% vs endovascular, 2.4%). The 5-year survival (72 ± 5% vs 55 ± 9%; $P < .0001$), freedom from recurrent symptoms (89 ± 4% vs 51 ± 9%), and primary patency rates (88 ± 2% vs 41 ± 9%) were all higher in the open group. Similarly, Zacharias et al[114] compared their outcomes after open (n = 45) and endovascular (n = 116) repair and reported that the hospital length of stay (5 ± 8 days vs 23 ± 20 days; $P < .001$) was lower in the endovascular group, but there was no difference in the perioperative mortality rate (endovascular, 5.2% vs open, 11%). The 3-year primary patency rates were higher in the open group (91% vs 74%; $P = .18$), although the survival was lower (78% vs 95%; $P = .003$). These findings are underscored by the fact that there has been a shift in the patient cohort undergoing open revascularization since the introduction of the endovascular therapies, reflected by the presence of more extensive MAOD and more advanced comorbidities.[76]

The results of the meta-analyses are largely consistent with the statewide and national observations. Indes et al[115] examined the outcome of patients undergoing revascularization for CMI (n = 666; open, 280; endovascular, 347) in the state of New York from 2000

Table II. Systematic reviews for endovascular vs open revascularization for chronic mesenteric ischemia (CMI)

Study	Sample	Findings
Alahdab, 2018[12]	100 studies, 18,726 patients	Endovascular with lower perioperative complications, higher recurrence, comparable perioperative and 3-year survival
Saedon, 2015[110]	12 studies, 7365 patients	No difference in morbidity and mortality, patency rates lower with endovascular
Cai, 2015[111]	8 studies, 569 patients	Endovascular with lower perioperative complications but higher recurrence, no difference in perioperative or longer term survival
Pecoraro, 2013[112]	43 studies, 1795 patients	Endovascular with lower perioperative morbidity and mortality, but lower patency and higher recurrence, no difference in long-term survival
Gupta, 2010[113]	1939 patients	Endovascular with lower perioperative complications but lower patency and higher recurrence, no difference in mortality

to 2006. They reported that there was a steady increase in the number of endovascular procedures (vs open) from 28% (2000) to 75% (2006) and that the endovascular interventions were associated with a lower perioperative mortality (11.0% vs 20.4%; $P = .001$), mesenteric complications (6.9% vs 17.1%; $P < .0001$), and individual organ system complications (ie, cardiac, pulmonary, and infections), although a higher percentage were discharged home (55% vs 37%; $P < .0001$). Erben et al[116] examined the outcomes across the country for patients (n = 15,475) undergoing intervention for CMI using the National Inpatient Sample from 2000 to 2014. They reported a similar trend in the breakdown of procedures with 70.6% of the patients undergoing endovascular treatment. Despite the fact that a higher percentage (43.3% vs 33.1%; $P < .0001$) of the patients in the endovascular group had a Charlson Comorbidity Index score of 2 or higher, they had a lower mortality rate (2.4% vs 8.7%; $P < .0001$), mean length of stay (6.3 days vs 14.0 days; $P < .0001$), and lower cost of hospitalization ($21,686 vs $42,974; $P < .0001$) and these differences persisted after adjustment for clinical and hospital factors. Based on these findings, the authors concluded that endovascular revascularization should be the first line of therapy for patients with CMI. Lima et al[117] performed a similar analysis using the same database from the years 2007 to 2014 to examine the impact of the choice of revascularization on major cardiac and cerebrovascular events. In their propensity-matched cohort, they reported that the major cardiac and cerebrovascular events and composite in-hospital complications occurred less often after endovascular revascularization (8.6% vs 15.9% [$P < .001$] and 15.3% vs 20.3% [$P < .0006$], respectively) and that the endovascular approach was associated with a shorter hospital length of stay and lower hospital costs.

The aggregate evidence from the meta-analyses, case series, and nationwide experience seems to support an endovascular-first approach for patients with CMI. The consistent themes suggest that the endovascular approach is associated with fewer perioperative complications, shorter length of hospital stay, and lower hospital costs, although the rates of recurrent symptoms and reinterventions are higher. The longer term survival rates are comparable between the open and endovascular approaches, although there seems to be trend toward a higher perioperative mortality in the open cohort. The comparable longer term survival seems to suggest that endovascular failures and higher rates of recurrent symptoms are not leading an increased rate of death from AMI. Fortunately, the endovascular-first approach does not seem to preclude subsequent open revascularization. In addition, the endovascular-first recommendation is consistent with other practice guidelines from the European Society of Vascular Surgery,[11] the American College of Radiology,[118] and the Society of Interventional Radiologists.[119]

The recommendation for an endovascular-first approach must be tempered by the quality of the underlying evidence. Although the systematic reviews and meta-analyses have attempted to identify the best possible evidence, the trials that comprised the review were largely retrospective, single-center studies and the overall quality of the evidence in our review was defined as low. Furthermore, the individual case series likely included a heterogeneous group of patients, clinical presentations, treatments (both open and endovascular), surveillance protocols and remedial interventions.

The optimal treatment approach to patients with CMI should likely encompass the patient's anatomy, comorbidities, life expectancy, and individual goals of care and may not be as simple as an endovascular-first or open-first issue. Tallarita et al[120] examined the long-term survival and cause of death after open and endovascular treatment for CMI. They found that the independent predictors of death were age greater than 80 years, diabetes, chronic kidney disease, and home oxygen with the leading causes of death being cardiac > cancer > pulmonary > mesenteric. The 5-year survival was identical for the open and endovascular cohorts in their propensity-matched analysis, suggesting that survival is dictated more by patient comorbidities than by the choice of revascularization. Similarly, Lima et al[121] examined the indications for readmission after revascularization for CMI in the National Inpatient Sample from 2007 to 2014. They reported that the 30-day readmission rate was 19.5% with one-quarter of the readmissions related to cardiovascular or cerebrovascular conditions. The independent predictors of readmission included nonelective index admission, chronic kidney disease, and discharge to home health care or a skilled nursing facility; the revascularization modality did not predict the readmission rate. Interestingly, Hogendoorn et al[122] developed a decision analysis model to compare open and endovascular revascularization for CMI that incorporated perioperative and longer term mortality, complications, patency, reinterventions, and their associated costs. They reported that the endovascular therapy cost more for patients less than 60 years of age, but the incremental cost effectiveness ratio was less than $60,000 per quality-adjusted life-year. For patients 60 years of age and older, the endovascular approach was preferred because the effectiveness was greater and the costs were lower. They concluded that the endovascular approach was favored for all age groups because it seems to be cost effective despite the higher rate of reinterventions.

Despite the advances in the endovascular therapies over the past few decades, there remains a role for open revascularization for patients with CMI. The potential indications include endovascular failures, lesions not amenable to endovascular treatment, and younger/healthier patients who may do better in the long term with open revascularization. The specific anatomic findings that would potentially preclude endovascular treatment include flush aortic occlusions, long segment occlusions, severe calcification, tandem lesions, distal lesions, and small diameter vessels. A variety of creative endovascular solutions have been described to overcome these relative contraindications. Notably, Sharafuddin et al[92] described their experience with endovascular recanalization of total mesenteric vessel occlusions and reported that neither the presence of a stump, ostial plaque, extensive calcification, recanalization route (ie, intraluminal vs subintimal), occlusion length, nor vessel diameter impacted the procedure success. Their technical success rate was 85%, but the 1- and 3-year primary patency rates were only 58% and 33%, respectively, and two patients died from abdominal catastrophes and sepsis at 2 and 23 months. Similarly, Haben et al[123] reported that the total chronic occlusions of the SMA were associated with decreased patency after endovascular treatment when compared with stenoses. Longer term data are required to establish the role of endovascular treatment for these higher risk anatomic lesions, although it is conceivable that the optimal treatment may be dictated by the individual provider skill set and patient compliance with longer term follow-up.

Special discussions

The various treatment recommendations outlined above may not be relevant for all patient populations, specifically the elderly. It is certainly conceivable that elderly patients (and potentially other groups) respond differently to the various interventions, similar to carotid artery stenting. Cardin et al[124] did a systematic review to identify relevant articles for the treatment of CMI in the elderly (≥65 years of age). They were able to identify only 13 relevant articles and concluded that the management of CMI in the geriatric population is poorly documented.

Implementation considerations

The recommended endovascular-first approach to revascularization for patients with CMI largely reflects the current national practice although open revascularization should still play a significant role and should be considered within the treatment algorithm. The evolution of the endovascular therapies for CMI (and other vascular surgical problems) has decreased the overall number of open procedures, and, unfortunately, this has impacted the number of open aortic procedures performed in many training programs. This change in the training paradigms has the potential to diminish the open operative skill set of the graduating trainees and, ultimately, the care of patients with CMI.

Future research

- Level 1 evidence to define the role of endovascular vs open revascularization for patients with CMI
- Further define the indications for endovascular revascularization for CMI
- Further define the indications for open revascularization for CMI
- Develop patient-specific treatment algorithms

Preoperative evaluation

Recommendations.

1. Patients undergoing revascularization for CMI should be optimized from a medical standpoint before intervention although their preoperative evaluation should be expedited. (*Ungraded Good Practice Statement*)
2. We recommend obtaining a CTA to delineate the vascular anatomy before any revascularization. A catheter-based arteriogram may be an alternative if the anatomy is not clear on the CTA. Level of recommendation: Grade 1 (Strong), Quality of Evidence: A (High)

Rationale and background

Patients with CMI typically have systemic vascular disease and associated comorbidities. Accordingly, patients undergoing treatment for CMI should undergo an expedited preoperative evaluation designed to optimize their underlying medical conditions and management of their atherosclerotic risk factors. Patients may benefit from enteral or parenteral nutritional supplements, although this should not delay or prolong the preoperative evaluation before definitive revascularization. A CTA should be obtained before revascularization to further define the anatomy and extent of occlusive disease.

Detailed justification

The atherosclerotic MAOD that leads to the development of CMI is a local manifestation of a systemic disease. Accordingly, patients undergoing treatment for CMI have the typical cardiovascular risk factors and associated comorbidities (Table I). The associated comorbidities and risk factors should be managed optimally before any revascularization for CMI, similar to patients undergoing any major vascular surgical procedures. There are well-accepted, published guidelines from most of the medical subspecialties to guide the preoperative evaluation, including those from the American Heart Association and the American College of Cardiology for the optimal preoperative cardiac evaluation for patients undergoing major noncardiac surgery.[125] Patients with active cardiac conditions, including unstable angina, recent myocardial infarction, significant arrhythmias, poorly compensated congestive heart failure, and/or significant valvular disease should be seen in consultation with a cardiologist and may benefit from preoperative cardiac intervention. Patients should be counseled about the importance of smoking cessation and should be treated with an antiplatelet agent and a cholesterol-lowering agent, preferentially a statin, unless there are specific contraindications.

The preoperative evaluation and workup should be expedited in patients with CMI to avoid any untoward events and progression to AMI. There is a spectrum of symptoms for patients with CMI that range from intermittent, mild postprandial pain to persistent pain, unrelated to any oral intake. The latter is clearly more worrisome for the progression to AMI with bowel infarction. Accordingly, patients with these more severe symptoms should likely be admitted and revascularized urgently. They may benefit from systemic anticoagulation, although the supporting evidence is limited. Parenteral or enteral (if appropriate) nutritional supplements can help to replete the nutritional status of patients with CMI, although revascularization should not be delayed.

The preoperative preparation before revascularization for CMI is similar to most aortic surgical procedures. Patients should be well-hydrated and administered prophylactic antibiotics, typically against skin and enteric organisms. Bowel preparations should likely be avoided owing to the theoretical risk to develop AMI. All patients should have a CTA to facilitate revascularization, if not already performed as part of the diagnosis workup, to assess the location and extent of the MAOD, the presence of any anatomic variants (eg, origin of the right hepatic artery from the SMA), the quality of the inflow sources for open revascularization, and the status of the access vessels for the endovascular approach.[8,11]

Endovascular revascularization

Recommendation.

1. We suggest using balloon-expandable covered intraluminal stents for the treatment of the MAOD in patients with CMI. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)

Rationale and background

The generic endovascular approach to patients with CMI is consistent with the broader principles of endovascular therapy with many of the more specific choices based on provider skill and personal preference. The SMA is the primary target vessels for revascularization, whereas the CA and IMA are secondary targets if it is not possible to revascularize the SMA or the clinical result is inadequate. Several anatomic findings can complicate the endovascular revascularization of the mesenteric vessels, as mentioned, including flush aortic occlusion, small caliber vessels, extensive calcification, the presence of tandem lesions, and the extent of involvement (ie, lesion length). Multiple reports have documented successful endovascular revascularization for these scenarios, although the long-term patency rates for these higher risk lesions remains unclear and the requisite skill set may not be universal. The use of balloon-expandable intraluminal stents has replaced balloon angioplasty alone for the treatment of de novo lesion. Balloon-expandable covered stents seem to have better longer term patency, presumably owing to the prevention of tissue ingrowth through the interstices of the stent by the fabric. A completion imaging study is an integral part of any endovascular intervention and should be performed routinely. Intravascular ultrasound examination and/or intraluminal pressure measurements can be helpful to further interrogate any residual stenoses or lesions. The postoperative management after endovascular revascularization for CMI is comparable with other catheter-based procedures, although it is possible for patients to develop multiple organ problems from the ischemia/reperfusion injury similar to that seen after open revascularization. All patients should be maintained on antiplatelet agents and a cholesterol-lowering agent, preferentially a statin, unless there is a contraindication.

Detailed justification

The endovascular revascularization for patients with CMI is similar to the approach for the other vascular beds in terms of access, imaging, choice of systems, device delivery, device deployment, management of complications, and medical therapy, with the majority of the clinical decisions based on provider preference and skill set. Both the femoral and brachial arteries are appropriate access sites, although an open brachial approach may be favored based on the orientation of the mesenteric vessels (ie, posterior to anterior, cephalad to caudal), the favorable vector forces associated with the antegrade introduction of the various endovascular catheters and devices, and the diminutive size of the brachial artery with the inherent risk of injury or thrombosis associated with the percutaneous approach. Likewise, the choice of wires (eg, 0.018 vs 0.035) should be dictated by the specific characteristics of the lesion and provider preference. A completion imaging study should be performed at the time of the procedure. Intraluminal pressure measurements may be helpful to document the pressure gradient across the stent if there is any concern about its appearance.

Balloon-expandable covered intraluminal stents seem to be the optimal stent choice and likely afford the same advantages as reported in other anatomic locations.[126,127] The characteristics of the balloon-expandable stents (eg, high radial force, functionality at short lengths, limited shortening with expansion) make them well-suited for the common atherosclerotic, calcified lesion at the orifice of the mesenteric vessels. Furthermore, the fabric of the covered stent seems to inhibit the ingrowth of tissue seen with bare metal stents that leads to the development of intimal hyperplasia and recurrent stenoses. Generically, the balloon-expandable and self-expanding stents should be viewed as complementary with the later potentially having a role in the SMA for longer lesions (ie, beyond the orifice), intraluminal dissections related to the initial endovascular technique, and for preserving any significant collateral vessels (eg, high take-off of a right hepatic artery). Interestingly, there has been an evolution from angioplasty alone to balloon-expandable bare metal stents to balloon-expandable covered stents.[32,128,129] Oderich et al[32] compared the outcomes of patients with primary or secondary endovascular interventions for CMI between those undergoing treatment with bare metal (n = 164 patients and 197 vessels) or balloon-expandable covered stents (n = 61 patients and 67 vessels). They reported that the freedom from restenosis (92% ± 6% vs 52% ± 4%; $P = .003$), freedom from symptom recurrence (92 ± 4% vs 50 ± 4%; $P = .003$), freedom from reintervention (91 ± 6% vs 56 ± 5%; $P = .005$), and primary patency at 3 years (92 ± 6% vs 52 ± 5%; $P < .003$) were all better for covered stents for the treatment of the primary lesions. Similarly, they reported that the freedom from restenosis (89 ± 10% vs 49 ± 14%; $P < .04$), freedom from symptom recurrence (100% vs 64 ± 9%; $P = .001$), and freedom from reintervention (100% vs 72 ± 9%; $P = .03$) were all better for the covered stents in the reintervention group. Notably, van Dijk et al[130] have published the study protocol for a randomized trial (CoBaGI) comparing balloon-expandable covered vs balloon-expandable bare-metal stents for CMI.

There may be a role for the use of embolic protection devices for select patients undergoing endovascular revascularization for CMI, similar to the scenario for carotid artery stenting or infrainguinal revascularization, although the supporting evidence is limited. Mendes et al[131] reported their experience with the selective use (36%) of embolic protection devices among 170 patients undergoing revascularization for mesenteric ischemia (both CMI and AMI). The indications for the devices included severe calcification, acute thrombus, and total occlusions. Macroscopic debris was detected in 66% of the filter patients although distal emboli were detected in only 6%. There were no technical complications associated with the filter deployment or retrieval.

Endovascular revascularization for CMI can be associated with both local and systemic complications from the intervention and underlying disease process.[132,133] The perioperative complications were lower after the endovascular approach and these lower rates partly justify the endovascular-first approach as detailed elsewhere in this article. Not surprisingly, access complications, contrast-induced renal insufficiency, target vessel dissection, device failure, and arterial embolization have all been reported after interventions for CMI.[131,134-138]

Patients should be maintained on antiplatelet agents and a statin after intervention, both open and endovascular.[139] The optimal antiplatelet agent regimen and endovascular interventions for CMI remains unresolved. Peeters Weem et al[140] performed a meta-analysis to examine the optimal antiplatelet regimen after endovascular arterial procedures. They did not support the use of dual antiplatelet therapy (vs monotherapy) and actually advised against it owing to an increased bleeding risk. A meta-analysis examining the impact of more intense low-density lipoprotein cholesterol-lowering strategies reported that all-cause mortality was decreased by 10%, largely from deaths owing to coronary heart disease, for each 1 mmol/L reduction in low-density lipoprotein cholesterol (RR, 0.90; 95% CI, 0.87-0.93; $P < .0001$).[141] The COMPASS Trial reported that the combination of rivaroxaban (2.5 mg twice daily) and aspirin (100 mg daily) was associated with a lower incidence of major adverse cardiac and limb events than aspirin alone for patients with stable peripheral and cerebral arterial disease.[142] However, the role for rivaroxaban and ticagrelor for patients with CMI undergoing revascularization remains to be determined.[143,144] Enteral feedings can usually be reintroduced shortly after revascularization. A completion imaging study, typically a mesenteric DUS examination, should be performed in the early postoperative period to confirm the technical adequacy of the procedure and serve as a baseline for follow-up and surveillance imaging.

Future research

- Define the optimal endovascular approach for patients with CMI.
- Define the optimal postoperative care paradigm after endovascular revascularization for CMI

Open surgical revascularization

Recommendation.

1. The choice of open surgical revascularization for CMI should be determined by anatomy, comorbidities, prior interventions and provider preference. (*Ungraded Good Practice Statement*)

Rationale and background

The choice of open revascularization for CMI should be determined by anatomy, patient comorbidities, prior interventions, and provider preference. There are a variety of open and hybrid approaches, including antegrade bypass from the supraceliac aorta, retrograde bypass from the common iliac artery (or infrarenal aorta), aortic endarterectomy, and open retrograde mesenteric stenting. The antegrade and retrograde bypasses are the most commonly performed, but all of the approaches can be viewed as complementary because they may play a role in specific situations. Revascularization of both the SMA and CA, as typically performed with the antegrade bypass, affords some theoretical advantages, although the outcomes have not been consistently better than those reported for the SMA alone as typically performed with the retrograde bypass. The perioperative care for patients undergoing open revascularization is comparable with the endovascular approach although the incidence of complications and hospital length of stay are both increased as detailed previously. Medical treatment should include antiplatelets and a statin, and all patients should obtain a completion or surveillance imaging study.

Detailed justification

Similar to most bypass procedures, revascularization for CMI requires a suitable inflow source, a suitable outflow target, a lesion to bypass, and an acceptable conduit. The common inflow sources include the supraceliac aorta (antegrade bypass) and the infrarenal aorta/common iliac arteries (retrograde bypass). The ultimate determinant of the inflow choice (and the bypass configuration) is contingent upon the distribution of the arterial occlusive disease and the provider familiarity with various exposures. The supraceliac aorta tends to be relatively spared from atherosclerotic disease, although the exposure is a bit more complicated and mandates mobilizing the left lobe of the liver and incising the crus of the diaphragm. It is possible to place a partial occluding clamp on the supraceliac aorta (eg, Satinsky) and maintain visceral perfusion while avoiding some of the hemodynamic changes associated with a complete supravisceral aortic clamp, although this maneuver is not always possible. The infrarenal aorta and iliac vessels can be suitable donor sites, although they are more prone to atherosclerotic occlusive disease that preclude their use, as seen in the case of a circumferentially calcified infrarenal aorta commonly referred to as the porcelain aorta. The potential options in this setting included replacing the involved aortoiliac segment or simply choosing another inflow site. A variety of alternative inflow sources have been describe, including the ascending aorta,[145] the descending aorta,[145] and the axillary artery,[146] although the published experience is small.

The retrograde open mesenteric stenting is a reasonable hybrid (ie, open and endovascular) alternative for patients with extensive aortoiliac occlusive disease, particularly for those involving both the infrarenal and suprarenal aorta, because it does not require the placement of an aortic (or iliac clamp).[147] Oderich et al[148] recently reported the collective experience (n = 54) with open retrograde stenting for both CMI (19%) and AMI (81%) from the Low Frequency Vascular Disease Research Consortium. The technical success rate was excellent (98%) and the patency rates at 2 years (primary, 76% ± 8%; secondary 90% ± 8%) were comparable with those achieved with percutaneous stenting. The procedure can be facilitated by snaring the wire introduced retrograde through the SMA from the brachial artery at the antecubital fossa, thereby increasing the functional working length and allowing the endovascular devices to be introduced in the more familiar antegrade fashion.

The atherosclerotic occlusive disease that leads to MAOD typically affects the origin of the vessels. Accordingly, the more distal extent of the mesenteric vessel tends to be spared and, thus, is a suitable bypass target. This choice of distal target can be complicated by the presence of an occluded stent, prior mesenteric bypasses, or more extensive occlusive disease (ie, extending beyond the origin). The option in this setting includes selecting a target that is further distal on the involved vessel. This can require a limited endarterectomy and a vein patch to help create a more patulous vessel and better bypass target.

Prosthetic grafts are suitable conduits and, historically, the longer term patency rates have been equivocal when compared with autogenous conduits.[149,150] They are contraindicated in the setting of AMI and bowel infarction with contamination. Notably, Davenport et al[151] reviewed the patients (n = 156) undergoing aortomesenteric bypass for CMI in the American College of Surgeon's National Surgical Quality Improvement Program Participant Use File during 2005 to 2009. They reported that patients undergoing bypass with vein were more likely to require a bowel resection and that there was a higher mortality rate (16% vs 5%; $P = .039$), although there were no other differences in the other perioperative complications. These findings likely reflect the fact that the vein conduits were used for patients with AMI rather than specific concerns about the quality of the conduit itself.

The retrograde bypass may be a little more straightforward and less time consuming than the antegrade bypass and, thus, potentially more suitable for patients with advanced comorbidities. Interestingly, Scali et al[152] compared the outcomes after antegrade and retrograde bypass for AMI and reported that there was no difference in the perioperative outcomes, although the antegrade bypass was associated with a lower reintervention rate. Furthermore, the exposure of the infrarenal aorta and iliac vessels is more familiar than the supraceliac aorta for most vascular surgeons.

The retrograde iliosuperior mesenteric bypass originating from the proximal common iliac artery has been criticized because of the potential for the bypass to kink. Indeed, the bypass passes from a caudal to cephalad and posterior to anterior course. The potential for kinking may be decreased by the use of a ringed bypass graft and by performing the distal anastomosis to the SMA in an end-to-end fashion. The retrograde bypass can also be tunneled deep (or around) the left renal artery to optimize the course of the graft with a technique referred to as the French Bypass.[153,154] Alternatively, Huerta et al[155] have described a technique (direct open retrograde revascularization) in which the bypass is tunneled directly through the small bowel mesentery. A pedicle of omentum can be mobilized and used to cover the retrograde bypass graft to avoid contact with the bowel.

Aortic endarterectomy may play a role in patients with a hostile operative field from multiple prior procedures, complex abdominal wall defects, radiation injury, and/or the presence of bacterial contamination. Mell et al[156] reported their experience with 80 patients (endarterectomy, 37; bypass, 29; combined, 14) undergoing treatment for CMI. They reported excellent results in terms of survival (1 year, 92.2%; 5 years, 64.5%) and symptom-free survival (1 year, 89.7%; 5 years, 82.1%) with endarterectomy for revascularization identified as predictor of freedom from recurrent symptoms on their multivariate analysis (5.2% vs 27.6%; HR, 0.2; 95% CI, 004-0.92; $P = .02$).

There has been a debate about the number of vessels to be revascularized at the time of open mesenteric bypass, similar to the scenario with the endovascular revascularization. Multiple vessel revascularization affords the theoretical advantage that a greater extent of the bowel is perfused directly and provides some redundancy if one of the grafts were to fail. However, the long-term outcomes comparing the SMA alone and SMA/celiac bypasses have been equivocal, further underscoring the importance of the SMA as the definitive target.[7,157]

There are reports of patients undergoing revascularization of the IMA[96] and branches of the SMA[158] for CMI, although these options should be reserved for select patients who are not candidates for the more standard options.

Although the guidelines are directed at the management of patients with CMI, a moderate percentage of patients will present with progression of their symptoms (ie, acute-on-chronic disease), with an even smaller percentage having bowel infarction with perforation. The management principles include resection of the frankly necrotic bowel, reassessment of the marginal bowel after revascularization, autogenous vascular reconstruction, the avoidance of primary bowel anastomoses in the setting of ischemia, and liberal use of a second-look laparotomy.

The perioperative management of patients undergoing open revascularization for CMI is comparable with that for patients undergoing other open aortic procedures. The obligatory ischemia/reperfusion injury can lead to multiple organ dysfunction with respiratory, renal, hepatic, and hematologic insufficiency.[157,159] The optimal treatment regimen includes simply supportive care until the end-organ failure resolves. The clinical sequelae of the ischemia/reperfusion injury can mimic graft thrombosis and AMI, underscoring the importance of confirming that the bypass grafts are patent with the appropriate imaging when in question. The return of bowel function is commonly delayed and may necessitate the temporary use of parenteral nutrition. A small percentage of patients will develop prolonged diarrhea requiring home parenteral nutrition.[157]

Similar to the patients undergoing endovascular revascularization, patients should be maintained on antiplatelet agents and a statin.[139] A completion imaging study should be performed intraoperatively at the time of the procedure and/or before discharge to confirm the technical adequacy of the procedure and to serve as a baseline. Technical defects have been identified in up to 15% of the procedures with a low rate of graft failure among normal studies.[160] Identification and correction of major defects using intraoperative ultrasound has been reported to significantly decrease graft-related complications and death after open mesenteric revascularization.[160]

The higher rate of perioperative complications associated with the open approach has been used to justify the endovascular-first approach. The open approach has been associated with a higher perioperative complication rate, hospital length of stay, and cost, although the perioperative mortality rates seem to be equivocal. These increased perioperative complications are offset by a lower rate of recurrent symptoms and reinterventions, despite no difference in long-term mortality. Interestingly, Wagenhäuser et al[161] reported that patients undergoing open revascularization had a lower health related quality of life compared with normative data, suggesting that the benefit from open repair may be modest.

Special discussions

A select group of patients with MAOD involving the SMA may require revascularization at the time of an open aortic procedure, as summarized elsewhere in this article. A retrograde SMA bypass for the aortic graft (or the iliac limb) is feasible for transperitoneal open repairs. This is also feasible for retroperitoneal aortic repairs although it usually involves entering the peritoneal cavity and dissecting the proximal SMA after mobilizing the duodenum.

Future research

- Define the optimal, open technique for revascularization for CMI
- Define the optimal perioperative care for patients undergoing open revascularization for CMI

Surveillance and remediation

Recommendations.

1. We suggest patient education and counseling about recurrent symptoms in all patients undergoing revascularization for CMI owing to the high rate of recurrence. (*Ungraded Good Practice Statement*)
2. Patients should be followed in the outpatient setting after revascularization for CMI. A possible follow-up schedule includes within 1 month of the procedure and then biannually for the first 2 years, and then annually thereafter. (*Ungraded Good Practice Statement*)
3. We suggest surveillance with mesenteric DUS to identify recurrent stenoses after revascularization for CMI. A possible ultrasound surveillance schedule includes within 1 month of the procedure and then biannually for the first 2 years, and then annually. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)
4. We recommend performing a CTA or catheter-based arteriograms to confirm any restenoses detected by DUS imaging in patients with symptoms consistent with CMI. Level of recommendation: Grade 1 (Strong), Quality of Evidence: C (Low)
5. In patients with recurrent symptoms of CMI, we recommend remedial treatment as recommended for the de novo lesions. Level of recommendation: Grade 1 (Strong), Quality of Evidence: C (Low)
6. In select patients with asymptomatic recurrent stenosis, we suggest a shared decision-making approach between the patient and provider to discuss revascularization as recommended for the de novo lesions. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)
7. We suggest that the choice of revascularization for recurrent stenoses should be similar to the de novo lesions with the endovascular approach recommended as the initial option and open revascularization reserved for lesions not amenable to the endovascular approach. Level of recommendation: Grade 2 (Weak), Quality of Evidence: C (Low)

Rationale and background

Patients may develop recurrent stenoses and/or recurrent symptoms after both endovascular and open revascularization for CMI. Indeed, it is well-accepted that endovascular revascularization is associated with a higher rate of recurrent stenoses and symptoms. The clinical presentation can range from high-grade asymptomatic stenoses to AMI with bowel infarction. Unfortunately, the natural history of these recurrent stenoses and recurrent symptoms remains poorly defined. Patients should be educated about the potential to develop recurrent symptoms and counseled to seek medical care at the onset of their symptoms. An image-based surveillance protocol can help to identify recurrent stenoses. However, it is not clear that the identification of these recurrent lesions and remediation with either an endovascular or open approach results in improved outcomes in terms of symptoms, survival, and/or quality of life. DUS examination is the optimal surveillance imaging study after revascularization although the criteria for the native arteries tend to overestimate the degree of stenosis (ie, 70% stenosis in treated arteries associated with higher PSV and EDV). CTA can help to confirm or refute the DUS findings. The management of significant recurrent stenoses, both asymptomatic and symptomatic, should be the same as outlined for de novo lesions. Specifically, patients with recurrent CMI should undergo revascularization with an endovascular-first approach, regardless of the initial approach, whereas open revascularization should be reserved for patients who are not amenable to the endovascular approach. A select group of patients with asymptomatic recurrent stenosis may also benefit from reintervention, but the exact indications for such reintervention remain undefined.

Detailed justification

Patients who undergo revascularization for MAOD and CMI are at risk for recurrent stenoses and recurrent symptoms. The incidence of these adverse events is greater after endovascular revascularization, as noted elsewhere in this discussion. The presentation can range from asymptomatic stenoses to AMI and bowel infarction. Fortunately, the latter condition seems to be less common and it is encouraging that the higher rate of recurrence seen in the endovascular group is not associated with a higher longer term mortality rate. Fortunately, the incidence of recurrent symptoms is less common than the incidence of recurrent stenoses, but highlights the fact that the presence of recurrent symptoms is not a surrogate for vessel or graft patency. The natural history of these recurrent stenoses, both asymptomatic and symptomatic, remains poorly defined. It is conceivable that the asymptomatic, recurrent stenosis has a worse prognosis than a comparable, untreated asymptomatic lesion, given that the index lesion was initially treated for CMI, although this remains to be documented.

Patients should be counseled about the risk of recurrent stenosis and recurrent symptoms. They should be engaged in their health care and counseled to seek urgent medical attention if they develop recurrent symptoms. Ideally, they should be engaged in a longer term follow-up protocol, although the frequency of visits beyond the immediate perioperative period remains undefined. There is likely some usefulness in an image-based surveillance protocol based on the contention that the identification of a significant lesion may lead to a remedial intervention that will translate into a better outcome in terms of vessel/graft patency and a lower incidence of recurrent symptoms and death. The purported benefits of surveillance in this setting are similar to those after lower extremity bypass, but it is noteworthy that surveillance after lower extremity bypass has not been shown to be effective in a well-performed randomized trial[162] nor supported in the Trans-Atlantic Inter-Society Consensus II recommendations.[163] Schoch et al[164] reported that 83% of the patients undergoing endovascular treatment for CMI (n = 107) developed elevated velocities of the target lesion on DUS imaging, although 53% did not require any remedial intervention. Liem et al[165] reported the results of their surveillance protocol after open mesenteric bypass. Although they were able to identify an association with smaller graft diameter and increased PSVs, they were unable to identify any predictors of graft thrombosis. A practical longer term follow-up protocol may include clinic evaluation and image-based surveillance within 1 month of the initial procedure (either open or endovascular revascularization) and then every 6 months for the first 2 years and yearly thereafter. However, the frequency of visits may well be influenced by the presence or severity of recurrent stenosis or symptoms. The value of the early postoperative imaging study to confirm the technical adequacy of the revascularization and to serve as a baseline for future studies has been emphasized in the preceding sections. Notably, the suggested follow-up and surveillance protocol is consistent with the Society for Vascular Surgery practice guidelines for follow-up after arterial procedures.[166]

DUS examination is the ideal initial imaging study for the detection of recurrent stenoses and the recommended surveillance imaging study for the de novo lesions. However, the velocity criteria for the native mesenteric vessel tend to overestimate the degree of stenosis in the treated vessels after both endovascular and open revascularization. Several studies have documented the velocity criteria for recurrent stenoses after revascularization and there seems to be relatively broad range of criteria that corresponded to with a more than 70% stenosis.[167-169] Ideally, these criteria should be validated in each individual vascular laboratory although this is likely impractical. Simplistically, a PSV of more than 300 cm/s with an EDV of more than 50 cm/s at an angioplasty site or bypass anastomosis or a dampened velocity spectra and a PSV of less than 40 cm/s within a bypass graft are all suggestive of a greater than 70% stenosis.[167,168]

CTA is the definitive imaging study for recurrent stenosis and can be helpful to confirm/refute the DUS findings and to help plan any further intervention.[170] Furthermore, it can be helpful as a surveillance imaging study for the few patients who cannot be adequately imaged with DUS imaging. The presence of an intraluminal stent can confound the determination of the degree of stenosis on CT scans, similar to the scenario with DUS imaging. Noncontrast images can be helpful to interrogate the stent architecture. A catheter-based arteriogram with the measurement of intraluminal pressures may occasionally be helpful in equivocal cases to determine the hemodynamic significance of a recurrent stenosis.[77]

The management of patients with a recurrent stenosis and recurrent symptoms consistent with CMI is similar to the management of a symptomatic de novo lesion. Patients should undergo a CTA to facilitate the intervention, if not already performed. An endovascular-first approach is recommended for both failing endovascular and open revascularization with the specifics of the procedure contingent upon the extent of the lesion, the presence of thrombus, and the details of the initial procedure. It is interesting that endovascular revascularization has evolved from a "bridge to open revascularization" to actually a "bridge to further percutaneous procedures."[171] The endovascular options include thrombomechanical lysis for acute thrombus, balloon angioplasty alone for in-stent restenosis, and/or the placement of a balloon-expandable covered stent within a bare metal stent. Tallarita et al[172] reported their outcomes for patients undergoing reintervention after mesenteric artery and stenting. Among the 157 patients treated initially, 57 (36%) developed recurrent stenosis at a mean follow-up of 29 months with 24 patients (42%) with recurrent stenoses developing recurrent symptoms (CMI, 21; AMI, 3). Repeat endovascular treatment was possible in 26 (87%) and was associate with low mortality (3%) and excellent symptom improvement (92%), despite a moderate complication rate (27% access site, embolization/bowel ischemia, congestive heart failure, stent thrombosis). Importantly, 43% of the areas of restenosis corresponded with technical defects identified at the index procedure. Admittedly, this is only a single series, but it suggests that many of the recurrent stenoses are really inadequately treated index lesions, underscoring the importance of completion imaging and an adequate initial technical result.

The remedial strategies for a failing or thrombosed bypass graft are similar to those outlined for the endovascular approach. Although somewhat counterintuitive, endovascular options should be thoroughly explored given the complexity of a reoperative mesenteric bypass. Kanamori et al[173] identified 47 patients with failing or thrombosed mesenteric bypasses presenting with CMI (81%) and AMI (91%). Remedial endovascular therapy was possible in 40% and was associated with a lower periprocedural complication rate, although the periprocedural mortality and longer term recurrence and reinterventions rates were similar to the patients undergoing remedial open procedures. Notably, the outcomes after the remedial open revascularization procedures were comparable with the first-time procedures in their case-matched controls, although the patency rates were inferior. The remedial open revascularizations can be facilitated by using an alternative inflow source to avoid some of the challenges associated with a reoperative field (ie, convert failed retrograde bypass to antegrade bypass or vice versa). Notably, Zacharias et al[114] reported that the perioperative mortality was higher among patients undergoing open revascularization after a failed endovascular revascularization when compared with the primary endovascular or open groups (15% vs 2%; $P = .005$). Giswold et al[174] have reported reasonable outcomes after redo mesenteric bypass ($n = 22$) with a perioperative mortality and morbidity rate of 6% and 33%, respectively, and a 1-year primary patency and survival rate of 74% and 76%, respectively. Furthermore, alternative outflow sources should be considered. Schneider et al[96] reported a small series of isolated IMA revascularizations for CMI. They stated that the revascularization was sufficient to relieve the symptoms and prevent bowel infarction, although it required a well-developed collateral pathway.

The optimal management of asymptomatic recurrent stenoses after both endovascular and open revascularization for CMI remains unresolved. Indeed, the natural history is even less defined than for de novo mesenteric artery lesions. The basic management principles for the de novo asymptomatic lesions are likely appropriate, although a lower threshold for remedial intervention may be justified given the prior symptomatology and the potential rate of recurrent symptoms, particularly since the remedial endovascular interventions are relatively safe.

FUTURE RESEARCH

- Define the natural history of symptomatic recurrent stenosis after both endovascular and open revascularization for CMI
- Define the natural history of asymptomatic recurrent stenosis after both endovascular and open revascularization for CMI
- Define the optimal surveillance protocol after both endovascular and open revascularization for CMI
- Define the optimal remedial strategies after failed endovascular and open revascularization for CMI
- Define the optimal medical treatment after revascularization for CMI

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