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Chronic splanchnic ischaemia

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Chronic splanchnic ischaemia is a relatively unusual clinical entity consisting of pain and/or weight loss and caused by chronic splanchnic disease (i.e. stenosis and/or occlusion of the coeliac and superior mesenteric artery). The occlusive disease is usually caused by atherosclerosis and is in itself not rare in older individuals. Extensive collateral circulation can develop between the three splanchnic arteries and may compensate for the decreased splanchnic perfusion over time. The pathophysiology of chronic splanchnic ischaemia has still not been completely elucidated.

A reliable diagnosis of chronic splanchnic ischaemia, based on a proven causal relationship between the occlusive disease and the symptoms, can be very difficult. Traditionally, tests for evaluating the haemodynamic consequences of the vascular stenoses were not available. Important improvements in establishing a more reliable diagnosis have been achieved with duplex ultrasound and magnetic resonance evaluation of the splanchnic circulation. Tonometry is another promising functional test that may prove useful not only for gaining greater insight into the pathophysiology of chronic splanchnic ischaemia but also for the clinical evaluation of this syndrome.

The natural history of chronic splanchnic disease suggests that progressive disease may result in acute mesenteric ischaemia. Surgical reconstruction of the coeliac and/or the superior mesenteric artery is the therapeutic standard with excellent short and long-term results. Satisfactory early results using angioplasty with or without stent suggest that this type of intervention may relieve symptoms in selected patients with a higher surgical risk.

Key words: splanchnic; mesenteric arteries; coeliac artery; superior mesenteric artery; mesenteric vascular occlusion; angiography; tonometry; vascular patency; angioplasty.

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INTRODUCTION

The mesenteric circulation consists of the arterial, venous and lymphatic circulation of the intraperitoneal and secondary retroperitoneal organs. There is much confusion regarding the wording used. Synonyms of the terms 'mesenteric', 'visceral', 'intestinal' and 'splanchnic' are used confusingly. *Mesenteric* is derived from the New Latin word mesenterium and indicates 'any peritoneal membrane that enfolds an internal vertebrate organ and attaches it to the body wall'. *Visceral* is derived from Mediaeval Latin and means 'pertaining to, or affecting the organs in the cavities of the body'. *Intestinal* is of New Latin origin and means 'pertaining to, being in, or affecting the lower part of the alimentary canal, extending from the pylorus to the anus'. We prefer the synonym '*splanchnic*', which is derived from the New Latin word splanchnicus and indicates 'pertaining to, or supplying the organs in the cavities of the body'.

Splanchnic vascular diseases encompass a spectrum of acute and chronic occlusive and aneurysmal disorders affecting the vessels of the abdominal entrails. Of these relatively uncommon disorders, splanchnic ischaemia occurs most frequently. Chronic splanchnic disease is characterized by symptomless but significant stenosis in the coeliac artery (CA), the superior mesenteric artery (SMA) and/or the inferior mesenteric artery (IMA).[1] It is important to distinguish chronic splanchnic disease from chronic splanchnic ischaemia or syndrome, which is the combination of splanchnic disease with the symptoms of ischaemia. In this respect, there is a close analogy between chronic splanchnic disease and renovascular disease. Vascular stenosis may be incidental in both conditions and be present without symptoms in most patients (chronic splanchnic disease and renovascular disease) and/or with symptoms (chronic splanchnic ischaemia and renovascular hypertension, diagnoses that can only be made retrospectively, i.e. relief of symptoms after successful intervention). Splanchnic artery stenoses may have important clinical implications since their appearance in more than one splanchnic artery can be considered a risk factor for developing acute splanchnic ischaemia, which has a poor prognosis. Consequently, prophylactic splanchnic artery reconstructive surgery has been proposed if both the CA and the SMA are occluded.[2] Chronic splanchnic ischaemia results from stenotic and occlusive disease of splanchnic arteries, which prevents the increased blood flow necessary for satisfying the metabolic demands of the bowel that arise from increased motility, secretion and absorption after meals. The early symptomatology of gradually developing splanchnic artery stenosis is non-specific. Until recently, invasive biplane selective angiography was the only reliable method of assessing the splanchnic circulation in vivo. With the introduction of duplex ultrasound, gastrointestinal tonometry, three-dimensional spiral computed tomographic angiography and magnetic resonance flowmetry, non-invasive or minimally invasive examination of the anatomy and function of the splanchnic circulation is now possible.

Chronic splanchnic ischaemia is rare and experiences in diagnosis and therapy have been limited. If chronic splanchnic ischaemia is diagnosed, a variety of surgical and endovascular techniques have been advocated for repairing the splanchnic vessels. The conclusions of many reports are flawed by variety in patient selection, a relatively short follow up and insufficient documentation of the patency of the reconstructions. Consequently, the evidence for the various methods and techniques used in the diagnosis and treatment of chronic splanchnic ischaemia is usually based on the preference and experience of the authors rather than being evidence-based.

Prospective randomized studies on the diagnosis and treatment of splanchnic disease and ischaemia are not available.

In this review the current methods of assessing the splanchnic circulation are discussed. The discussion is restricted to chronic arterial occlusive disease. The latest opinions, most of them only 'authority based', on the diagnosis and treatment of chronic splanchnic ischaemia are then summarized.

ANATOMY OF THE SPLANCHNIC CIRCULATION

Three main arteries that arise from the abdominal aorta supply the mesenteric vascular bed: the CA, the SMA and IMA. Initially, these vessels develop as paired vessels. Thereafter they merge, which provides the potential for abundant persistent collateral vascular connections. Each of these vessels, alone or in combination, can be affected by occlusive disease resulting in decreased splanchnic perfusion. In relation to ischaemia, two aspects of the anatomy are relevant for the potential consequences of mesenteric occlusive disease: (i) there is a wide range of anatomical variation in the CA and SMA, in particular, and (ii) abundant compensatory collateral circulation between the vascular beds of the CA, the SMA and the IMA and their branches may develop during chronic occlusion. The CA, which supplies the foregut, arises from the aorta at the level of the median arcuate ligament of the diaphragm. For full surgical exposure the muscular fibres of the diaphragm must be divided. The vessel is a short, wide vessel that is 1–1.5 cms long and divides into three branches: the splenic artery, the common hepatic artery and the left gastric artery. The SMA, which is the arterial supply of the midgut, arises from the aorta about 1 cm caudally from the CA. The origin is located behind the pancreas and the splenic vein. Because of the complex upper abdominal anatomy and because both the CA and the SMA origins are surrounded by dense autonomic nerve tissue, the coeliac plexus, the surgical access to the origin of both the coeliac and superior mesenteric artery is usually not easy. An excellent surgical approach has been described by Reilly et al.[3] The IMA arises from the aorta 3–5 cm above the aortic bifurcation and divides into an ascending and descending branch.

Because of the development from paired vessels numerous anatomical variations may exist. In fact, in a study of 400 dissections of the abdominal vasculature, no two specimens were the same. The most common variations relevant for this review are the origin of the common hepatic artery (8%) and right hepatic artery (16%) from the SMA.[4] For an in depth review of anatomical variations the reader is referred to the excellent monograph of VanDamme and Bonte.[5]

In addition to the anatomical variations, abundant collateral circulation is present and easily developed if chronic occlusion of one or more of the three main arteries occurs. In fact, by 1869 the efficiency of the collateral network in chronic splanchnic occlusion had been described.[6] Collateral pathways between the CA and the SMA include the pancreaticoduodenal arcades and, occasionally, the arc of Bühler, which provides a direct connection between the CA and SMA. During chronic occlusion of the CA and SMA, these arcades may play a role in the pathophysiology and symptomatology of chronic intestinal ischaemia when, during gastric feeding, an increase in gastric flow may occur only at the expense of stealing blood from the bed of the SMA.[7] The collateral bed between the SMA and the IMA consists of the inconsistent arc of Riolan and the marginal artery of Drummond, which can be very prominent on an angiogram as an indicator of a chronic occlusion of the SMA.[8]

EPIDEMIOLOGY, AETIOLOGY AND RISK FACTORS

Epidemiology

The prevalence of splanchnic disease, especially in the elderly population, is not insignificant. In a 30 year old angiographic study of 713 patients, 5% of the splanchnic arteries were occluded and in 70% of these occlusions the IMA was involved.[9] Another more recent angiographic study revealed a 40, 29 and 25% incidence of asymptomatic stenosis of one splanchnic artery in patient population with abdominal aortic aneurysms, aorta–iliac obstructive disease and lower extremity ischaemic disease, respectively. In 3.4% of these patients more than one splanchnic artery appeared to be involved.[10] In a recent angiographic study of 980 patients, 82 (8%) were found to have 50% stenosis of at least one splanchnic artery and in 3.9% of the patients one splanchnic artery was occluded. In this study 10 patients were lost to follow up. In the remaining 72 patients, the CA was involved in 65 (90%), the SMA in 31 (43%) and the IMA in 40 (56%), while 15 patients had significant three-vessel disease.[11]

Summarizing the available data we conclude that in populations with manifestations of atherosclerotic diseases, the incidence of chronic splanchnic disease ranges between 8% and 70%.[9–16] Of these patients, 0.5–15% had a greater than 50% narrowing of more than one splanchnic artery. In spite of the relatively high prevalence of splanchnic disease, the incidence of chronic splanchnic ischaemia appears to be low.[17] Probably the most important factor that contributes to this low incidence is a low index of suspicion since most patients present atypically with only vague abdominal symptoms. Recognizing splanchnic ischaemia can be improved by organizing a multidisciplinary approach for the evaluation of insufficiently explained abdominal pain. In the Medisch Spectrum Twente Centre, the recognition of chronic splanchnic ischaemia increased from seven to 23 persons per million per year after the introduction of a multidisciplinary splanchnic diseases workgroup.[18]

Aetiology

Stenosis or occlusion of the splanchnic arteries can be caused by a variety of diseases such as atherosclerosis, fibrodysplasia and compression at the diaphragm, as well as rare causes such as vasculitis, Takayashu's disease, etc. Atherosclerosis is probably responsible for occlusions in more than 95% of cases. These lesions, like those of other visceral vessels affected by atherosclerosis (e.g. the renal arteries), are mostly located in the origin (ostial lesions) and are caused by progressive atherosclerosis of the anterior wall of the aorta. This also explains why isolated stenosis of occlusion of the ostium of one of the visceral vessels by atherosclerosis is relatively rare.

Isolated occlusive disease of the coeliac trunk may be caused by the compression of this vessel by the arcuate ligament of the diaphragm, the so-called 'coeliac axis compression syndrome' or 'median arcuate ligament syndrome'.[19] The existence of this syndrome is still controversial since it is commonly accepted that at least two of the three major splanchnic vessels must be involved before symptoms will occur.[14] There is no reliable diagnostic test for CA syndrome and the diagnosis can only be made retrospectively after the success or failure of surgery in relieving the symptoms. The suspicion of CA compression syndrome ultimately depends on the careful elimination of other possible causes for abdominal pain.[20] In the future, evaluation by gastric and jejunal tonometry for measuring the degree of mucosal ischaemia and the relief of ischaemia by CA decompression may help to elucidate this syndrome.[21]

Finally, chronic splanchnic disease may rarely be caused by other disease such as fibrodysplasia[22,23], vasculitis and radiation and autoimmune arteritis. A review of systemic disease affecting the mesenteric circulation has been published by Harris et al.[24]

Risk factors

The well-known risk factors for atherosclerotic disease are also applicable for chronic splanchnic ischaemia.[25] However, in contrast to atherosclerosis in other conditions such as myocardial ischaemia, stroke and lower extremity ischaemia, mesenteric vascular disease seems to be more frequent in women than in men. In a review of published studies it appeared that 26% were male and 74% were female.[26] The reasons for this significant gender difference remain unknown. A possible explanation lies in the more frequent occurrence in women of CA stenosis caused by diaphragmatic compression, a condition that may make affected females more susceptible to atherosclerotic narrowing of intestinal arteries. This may cause less effective collateral compensation for obstruction of the SMA. At present, this explanation should be regarded as an unproven speculation.

PATHOPHYSIOLOGY AND SYMPTOMS

Chronic splanchnic ischaemia results from blood supply that is not sufficient to satisfy the metabolic demands of the bowel arising from increased motility, secretion and absorption after meals. The intestine received 10–20% of testing and up to 35% of post-prandial cardiac output and 70% of this volume supplies the mucosa.[27] The blood supply to the intestine is significantly decreased in hypovolaemic shock or during heavy exercise.[28] In healthy volunteers splanchnic ischaemia has been reported after extreme physical exercise.[29,30]

The classical syndrome of chronic splanchnic ischaemia is characterized by upper abdominal pain that is usually provoked by eating, an epigastric bruit, loss of weight and haemodynamically significant stenosis of two or more of the splanchnic arteries.[31] This classical triad does not always appear in patients with chronic splanchnic ischaemia.[32] Only half of our patients exhibited all three classical symptoms, but after arterial repair, relief of abdominal pain was achieved in all cases. This corroborates the observations of others that weight loss and epigastric bruit do not occur in all patients with chronic splanchnic ischaemia.[1,33–39]

The typical post-prandial pain occurs within the first hour after eating and diminishes 1–2 h later (Table I). An ischaemic basis for the pain is widely accepted. However, the pathophysiological mechanism that is responsible for the pain has not been elucidated. Severe pain that occurs exclusively with the intake of food suggests a

Table I. Clinical presentation of chronic splanchnic ischaemia.

- Post-prandial pain usually with a dull aching, sometimes of a cramping character
- The pain starts within the first hour after eating and lasts for 1–4 h
- Loss of weight, often more than 10% of the body weight, due to 'food fear'
- Occasional changes in bowel habit (constipation or diarrhoea due to malabsorption)
- Non-specific abdominal pain

lack of oxygen in the small bowel. However, most patients experience their symptoms within 20–30 minutes after eating, well before the food has reached the small bowel. Also, some patients are aware of occasional abdominal pain during and after mild physical exercise.

It has been proposed that a vascular steal phenomenon is involved in chronic ischaemia. Poole et al[40] used a dog model. By using tonometric assessment of the splanchnic blood flow, the haemodynamic changes produced by a meal in dogs with a fixed decreased splanchnic blood flow (50% stenosis of both the CA and the SMA) was evaluated. It appeared that the intestinal intramural pH decreased significantly when blood flow was decreased to 50% after food intake. The haemodynamic explanation of the decrease was explained as a steal from the intestinal to the gastric circulation stimulated by food placed in the stomach. Such a steal could explain the pain resulting from gastric ischaemia that is experienced by patients with chronic mesenteric ischaemia.[40]

Although chronic splanchnic ischaemia may develop without weight loss, this symptom appears to be an important characteristic and is assumed to be caused by a decrease in the size of the patient's meal owing to post-prandial pain rather than malabsorption or its content.[41,42] Patients may unconsciously modify their diet to minimize the pain. Therefore, an increase in body weight has been proposed as an objective parameter of the beneficial effects of increasing splanchnic inflow by intervention in patients with chronic splanchnic ischaemia. This is supported by our findings, although an increase in body weight is not uncommon during ageing, the mean relatively rapid increase of more than 10 kg after surgery strongly suggests a beneficial effect of successful reconstructive surgery.[32]

An arterial bruit, per se, may not be associated with a haemodynamically significant stenosis. A midsystolic murmur indicates that flow and pressure gradients are essentially unchanged, but a loud diastolic murmur strongly suggests a stenosis severe enough to reduce flow and increase the pressure gradient.[43,44]

The existence of chronic splanchnic ischaemia with haemodynamically significant stenosis in only one splanchnic artery is controversial. Bron and Redman[9] demonstrated that almost half of the patients with only a significant CA stenosis suffered abdominal symptoms. Szilagyi et al[45] reviewed the entire literature on the CA compression syndrome and found that no patient had ever been proven, on scientific grounds, to have had an abnormality of intestinal structure or function that was caused by extraluminal compression of the CA or that supposed relief from the operation could be anything other than a placebo effect. Nevertheless in the three decades since that review, good results for CA decompression operations have been reported.[46,47] Short follow up and small numbers of cases are flaws in these studies. There are a few case reports concerning ischaemia of the coeliac region that show ischaemic gastroparesis with diffuse superficial micro-ulceration in the stomach.[48–50] Two studies, with carefully selected patients and long-term follow up, have supported the existence of CA compression.[51,52] In these studies, which reported beneficial results in both the short and long term, the patients had a reconstruction of the CA. This could be important because CA reconstruction might diminish the propensity for re-stenosis in the long term. Stanley and Fry[53] suggested that a steal phenomenon from the superior mesenteric to the coeliac bed, the so-called intra-mesenteric steal might be the explanation for the non-specific symptoms of CA compression syndrome. This is supported by our observation that an intra-mesenteric steal could be the pathogenesis of repeated colonic ischaemia.[54] However, there is voluminous clinical and experimental evidence that long-standing isolated obstruction of one of

the intestinal arteries is compensated for by collateral circulation from both other arteries without symptoms.

Chronic splanchnic ischaemia should be considered in the absence of a bruit, or even in the absence of weight loss, in patients with chronic abdominal pain and severe stenosis of the splanchnic arteries, where the more common causes of post-prandial pain have been excluded.[25] The existence of CA compression syndrome is still controversial and this will remain so until a long term follow up study has been completed that includes appropriate post-operative visualization of the splanchnic flow with a gastric tonometry exercise test.

EVALUATION OF SPLANCHNIC VASCULAR DISEASE AND ISCHAEMIA

The diagnosis of chronic splanchnic ischaemia is clinically difficult. Usually the classical triad of upper abdominal pain provoked by eating, weight loss and an epigastric bruit is incomplete or absent.[49] Currently there is still no single test or combination of tests that can confirm or reject the diagnosis of chronic splanchnic ischaemia. The diagnosis can only be made retrospectively if symptoms are relieved after a successful repair of the occlusive disease. Meanwhile, a probable diagnosis is made pre-operatively on the basis of a clinical suspicion after the exclusion of the more common causes of abdominal pain, combined with positive test results on duplex ultrasound, angiography, magnetic resonance or tonometry, either alone or in combination (Table 2).

Duplex ultrasound

The role of duplex ultrasound in the evaluation of patients with suspected chronic splanchnic ischaemia has still not been completely defined.[55] This is in spite of the fact that the first publications addressing duplex ultrasound as a non-invasive tool for the assessment of the splanchnic vascular tree had already been published by the mid-1980s. Physiological differences between patients and the technical difficulties inherent in duplex ultrasound make splanchnic duplex ultrasound results difficult to interpret. The influence of respiration, meal, exercise, anatomical variations and collateral circulation on the commonly used duplex ultrasound parameters have not been fully clarified. Although post-prandial scanning has been suggested as a means of increasing the sensitivity of the test for identifying obstructive disease of the splanchnic arteries, it has been demonstrated that this adjunct only marginally improves on results obtained after fasting.[56] We systematically reviewed the accuracy of duplex ultrasound recently, A total of nine studies from five institutions have compared splanchnic duplex ultrasound results with multiplane angiography.[55] Only two of these were performed in a prospective, blind setting[57,58], and only two other studies dealt exclusively with patients suspected of having chronic splanchnic ischaemia.[59,60] Commonly accepted criteria for diagnosing a haemodynamically significant stenosis in the CA are a peak systolic velocity (PSV) of more than 200 cm/s and an end diastolic velocity of more than 55 cm/s. For the SMA, these thresholds are a peak systolic velocity of more than 275–300 cm/s and an end diastolic velocity of 45 cm/s.

In experienced hands a successful duplex visualization of the CA and SMA can be obtained in 80–95% of patients, and in these cases ultrasound is a reliable screening test for chronic splanchnic disease. However, the diagnosis of a chronic splanchnic

Table 2. Diagnostic tests for the evaluation of chronic splanchnic ischaemia (CSI).

Diagnostic test	Advantages	Disadvantages
Laboratory tests	• Helps to exclude other, more common, causes of abdominal pain	• Non-specific for CSI
Gastric tonometry	• Functional test with potential to evaluate insufficient intestinal perfusion	• Still investigational • Not easily performed
Duplex ultrasound	• Reliable assessment of patency of the coeliac and superior mesenteric arteries • Non-invasive • Widely validated	• Observer dependent • Not possible in approximately 10% because of bowel gas etc
Contrast enhanced magnetic resonance angiography	• Non-invasive • No use of iodine contrast agents • Evaluation of vessels by multiple projections resulting in high sensitivity and specificity • Potential for functional evaluation of insufficient arterial and portal flow	• Contraindication for MR • Threatening for claustrophobic patients • Limited resolution • Potential for over-estimating of stenosis
Angiography	• Still the 'gold standard' of the evaluation of patency of the coeliac, superior mesenteric artery and the inferior mesenteric artery • Imaging of collateral circulation • High resolution allowing for optimal planning of intervention	• Invasive catheterization • Contrast allergy • Small but inherent risk of complications of angiography

ischaemia remains a challenge, since the symptoms are not specific and there is a poor correlation between anatomical information and abdominal symptoms. Consequently, if duplex ultrasound clearly demonstrates haemodynamically significant stenosis in the origins of the CA and the SMA this may provide support, but not be conclusive evidence, for the existence of chronic splanchnic ischaemia.

Angiography

Biplanar selective angiography of the mesenteric arteries remains the investigation against which all others must be compared when diagnosing occlusive disease. Until recently, it was stated that mesenteric angiography was always indicated when chronic mesenteric ischaemia was suspected.[61] Although this dogma is still valid, both duplex ultrasound[62] and magnetic resonance angiography (MRA) have a role to play. As with renal artery disease and renovascular hypertension, stenosis or occlusions in the mesenteric vessels that have been demonstrated on angiography are a prerequisite for conforming the diagnosis of splanchnic vascular disease, but do not prove the diagnosis of chronic splanchnic ischaemia.[63] Again, from epidemiological data it is well known that atherosclerotic narrowing of the splanchnic vessels in elderly individuals is common but that chronic ischaemia is rare.[15]

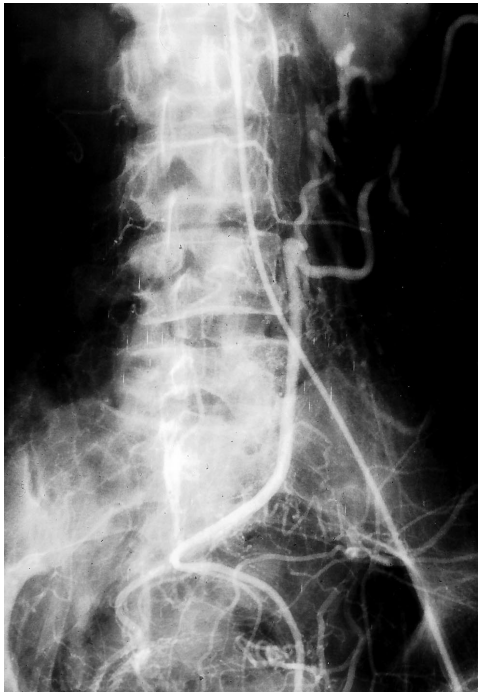

Figure 1. Angiography in a patient with occlusion of the coeliac and superior and inferior mesenteric arteries. The angiography catheter is located in the aorta. Extensive collateral circulation is provided via the internal iliac arteries, the inferior mesenteric artery and the marginal artery along the ascending colon to the superior mesenteric artery.

Angiography is typically performed after the more common disorders that cause pain after a meal, such as ulcer disease, gallbladder stone, pancreatitis etc, have been excluded. A positive duplex ultrasound is nowadays a prerequisite for performing angiography. MRA, including physiological evaluation of flow, should preferably be performed before angiography. The advantage for performing MRA first is that multiple projections can easily be made that may help to select the optimal projection angle during angiography.

Since the mesenteric vessels originate anterior from the aorta, ostial lesions can be easily missed if just an AP (anterior–posterior) film is taken. Angiography in at least two projections (AP and lateral) is required. Rapid filming is necessary for visualizing the origins of the CA and the SMA. Late filming is required to evaluate the retrograde flow, delayed proximal visualization and collateral pathways between the CA, the SMA and the IMA. An injection in the distal aorta may be required to identify collaterals between the branches of the internal iliac artery and the IMA (Figure 1). Finally, potential inflow sites such as the suprarenal or lower thoracic aorta, infrarenal aorta and iliac arteries should be visualized. In addition, the potential use of angioplasty can be deduced from the angiogram.[61]

Additional films during deep inspiration and expiration may be required to evaluate compression of the CA if CA compression syndrome is anticipated.[64] CA compression can easily be demonstrated on the lateral film as a smooth and symmetrical narrowing of the upper portion of the vessel just beyond its origin, while a post-stenotic

dilatation is often present. As a result of the compression, the artery is pushed posteriorly and lies parallel to the aorta. The SMA and IMA are usually patent. A selective angiogram of the SMA and occasionally the IMA may visualize collaterals feeding the branches of the CA.[65]

Magnetic resonance angiography

Rapid developments in MRA-technology have enabled non-invasive visualization of the main visceral arteries. The small visceral branches can not be evaluated with MRA due to the limited spatial resolution compared with X-ray angiography. In a study of 10 patients with clinical symptoms of chronic splanchnic ischaemia we found significant disease in the proximal CA and the SMA in four patients by using systolically gated three-dimensional phase contrast MRA.[66] These patients underwent successful surgical reconstruction of their stenotic vessels. The disadvantage of this phase contrast technique, however, is the relatively long acquisition time (approximately 10 min). The technique is therefore prone to movement artefacts. Another disadvantage of this technique is the limited area of coverage that can be obtained during one acquisition (only the proximal 5–10 cm of the vessels can be visualized). Finally, the IMA is difficult to visualize using this technique.

With the introduction of contrast-enhanced MRA, it has become possible to obtain multiple thin slices in the coronal or fontal plane, allowing for visualization of the CA, the SMA and the IMA in a single breath-hold of 20–25 s. Due to the acquisition of a three-dimensional data set, the data can be reconstructed in any desired plane using maximum-intensity-projections (MIP) or surface-rendering techniques. The orifices of the mesenteric vessels can therefore always be visualized with MRA. In a study of 14 patients with correlative angiograms, stenosis was found in seven CAs, six SMAs and four IMAs. In two cases, IMA stenosis was overgraded. Overall sensitivity and specificity of MRA in this small study was 100% and 95%, respectively.[67]

Just as with X-ray angiography, MRA can only depict the morphological appearance of the mesenteric vessels but it does not provide physiological evidence for the symptoms of the patients. With magnetic resonance imaging (MRI), however, functional information on splanchnic blood-flow can also be obtained. Flow velocities and total flow volumes can be measured in the mesenteric vessels using two-dimensional cine phase contrast velocity mapping. Flow volumes in both the SMA and the superior mesenteric vein (SMV) have been measured with MRI. In one study, post-prandial flow augmentation in the SMA (exceeding 100% in normal volunteers) was found to be significantly reduced in a patient with high-grade stenosis.[68] In a study of 10 volunteers, the difference between fasting and post-prandial flows in the SMV was 245 ($\pm$74)%. In four patients with angiographically proven stenosis of the mesenteric arteries, post-prandial flow augmentation in the SMV was significantly reduced (64($\pm$28)%). In theory, measuring flow in the portal vein may provide a better representation of total splanchnic flow since portal venous flow encompasses blood returning from the stomach, small bowel and colon. A disadvantage of measuring portal venous flow is that splenic venous flow is also included in these measurements. Previously, we have shown that portal venous flow measurements are accurate and can be performed with low intra- and inter-subject variability.[70]

MRI has also been used to measure the oxygen saturation of haemoglobin in the blood. The principle behind MR oximetry is that deoxyhaemoglobin in erythrocytes is paramagnetic, but oxyhaemoglobin (HbO_2) is not. The signal intensity of blood can therefore be used to calculate the percentage of oxygenated haemoglobin. Mesenteric

oxygen extraction is determined by the rate of mesenteric blood flow. As blood flow decreases, oxygen extraction will increase to maintain the level of oxygen uptake. Li et al[71] measured the percentage of oxyhaemoglobin (%HbO_2) in the SMV before and after intake of a standard meal. Normally, the %HbO_2 in the SMV increases post-prandially by 4.6($\pm$0.6)%, but in six patients with chronic splanchnic ischaemia the %HbO_2 in the SMV decreased by 8.8($\pm$0.7)%.[72]

In summary, combining morphological evaluation of the splanchnic vasculature by MRA with a functional test (either by measurement of flow or %HbO_2) in a single session may become important in the detection of patients with chronic splanchnic ischaemia.

Tonometry

The mucosa of the intestine is at immediate risk when there is insufficient perfusion that results in anaerobic metabolism.[73,74] Therefore, an increase in the gastrointestinal laminal to blood P_{CO_2} gradient above the normal range may indicate the presence of anaerobic metabolism and mucosal ischaemia.[75] A tonometer can be used to measure the P_{CO_2} of the stomach, small intestine or sigmoid indirectly.[76] The principle of tonometry was first described in 1965.[77] A tonometry catheter is inserted into the stomach or the intestine. This catheter includes a gas-permeable silicone balloon. Carbon dioxide freely equilibrates between the gastric mucosa, the lumen and the content of the balloon. After equilibration the air is sampled from the balloon and analysed. Theoretically, hypoperfusion below a critical level causes mucosal carbon dioxide accumulation. Since carbon dioxide diffuses easily across membranes, the P_{CO_2} in the lumen of the gut also increases, leading to an increase in the gap between tonometrically measured luminal P_{CO_2} and the conventionally measured P_{CO_2} in the peripheral blood. In the early 1980s the application of tonometry as a test of intestinal perfusion was demonstrated in dogs[78] and humans.[79] Currently, tonometry has been advocated as a diagnostic test in patients with chronic splanchnic ischaemia.[40,75,80] The diagnostic value of post-prandial gastric P_{CO_2} levels is questionable[81], but gastric P_{CO_2} exercise tonometry seems more promising as a diagnostic test for gastrointestinal ischaemia.[82,83]

In a recent review Kolkman et al[76] concluded that gastrointestinal tonometry of the luminal to blood P_{CO_2} gradient could be used to assess the adequacy of mucosal perfusion provided that, if applied to the empty stomach, acid buffering and carbon dioxide generation were avoided. Appropriate use may broaden the clinical applicability of gastrointestinal luminal tonometry as a monitoring tool in a variety of conditions.[76]

INTERVENTION FOR SPLANCHNIC VASCULAR DISEASE AND ISCHAEMIA

Before considering intervention, information on the natural history of the disease is required. Theoretically, the options for intervention in symptomatic patients are conservative medical treatment, surgical reconstruction and angioplasty.

Natural course of splanchnic vascular disease

Unfortunately, information on the natural history of splanchnic occlusive disease and ischaemia is scarce. Most lesions of the CA and SMA are ostial stenoses and occlusions caused by atherosclerosis, and progression to occlusion can be anticipated. In that

respect the natural history will probably not be different from that of similar lesions in other visceral arteries such as the renal arteries, where progression was determined in the 1960s. This has recently been confirmed by serial duplex evaluation as having a progression rate of approximately 20% per year.[84] The same holds true for fibrodyplastic disease although numerically this is much less important.[85] Based on the natural history of chronic splanchnic disease, Connolly and Kwaan[2] advocated prophylactic reconstruction to prevent acute ischaemia and bowel infarction. This statement was supported by their later report[86] of 25 patients with acute intestinal ischaemia resulting from atherosclerotic occlusions that required surgical exploration. These patients had symptoms that were inconspicuous but diagnostically significant including progressive loss of body weight and symptoms mimicking peptic ulcer disease or cholecystitis. Delay and oversight in the clinical diagnosis resulted in 80% mortality.[86]

Recently, Thomas et al[11] evaluated 980 consecutive aortograms with anteroposterior and lateral projections to identify patients who had significant chronic splanchnic disease but no symptoms of chronic splanchnic ischaemia. A total of 82 patients were found to have 50% stenosis of at least one mesenteric artery and 15 patients had significant three-vessel disease. Follow-up was 1–6 years. Of these 15 patients with severe chronic splanchnic disease 86% had splanchnic ischaemia, other vague abdominal symptoms, or died. Thomas et al concluded that those with significant three-vessel chronic splanchnic disease should be considered for prophylactic arterial reconstruction and recommended that splanchnic arterial reconstruction should be routine when these patients undergo aortic reconstruction for aneurysmal or occlusive disease.[11] In a comment, it was argued that the incidence of acute and usually fatal bowel ischaemia was only 6%, which is approximately the operative mortality rate of elective reconstruction and that, therefore, the case for prophylactic repair was still not conclusive.[87] We agree with the view of others that splanchnic artery reconstructive surgery may prevent splanchnic infarction in selected patients without symptoms who have two or more severely stenotic or occluded splanchnic arteries including the SMA.[86,88] It is concluded that prophylactic reconstruction in chronic splanchnic disease will never be evidence-based, like e.g. carotid surgery and surgical treatment of abdominal aneurysms, and because of the small number of patients a prospective randomized trial is unrealistic. However, there is substantial evidence that prophylactic reconstruction in surgically fit selected patients with severe chronic splanchnic disease may be indicated either alone or in combination with other abdominal vascular reconstructions.

Conservative treatment

There is no evidence available supporting the conservative medical treatment of chronic splanchnic ischaemia. Suggested treatments are: eat small meals, use omeprazol to diminish the oxygen demand of the gastric mucosa, refrain from smoking and use vasodilative drugs to diminish vasospasm. The objective effect of all this advice is unknown.

Surgical reconstruction

Surgical correction of chronic splanchnic ischaemia is a challenge for the vascular surgeon. Careful selection of patients with regard to operative risk and selection of the surgical technique with regard to the cause and pattern of the disease is essential. In

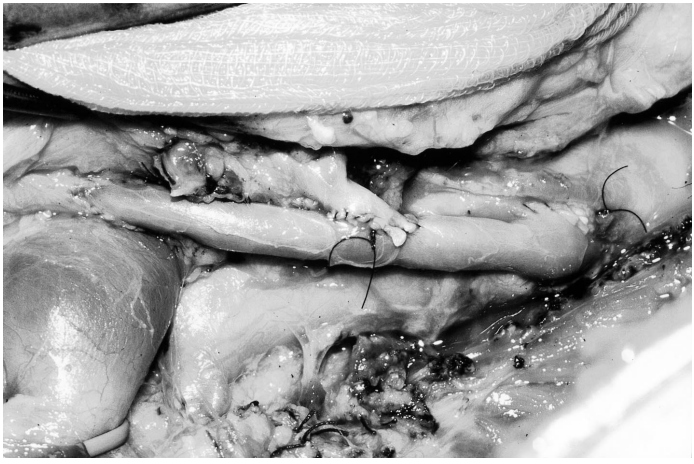

Figure 2. Intra-operative photograph of antegrade bypass to the coeliac and superior mesenteric artery (the patients' head is located at the right hand side, the left renal vein crossing the aorta is shown in the left of the picture).

1958 the first successful treatment of chronic splanchnic ischaemia by superior mesenteric thromboendarterectomy was reported.[89] A variety of surgical techniques have been advocated for repairing the mesenteric arteries including reimplantation, transarterial and transaortic endarterectomy, antegrade and retrograde aortovisceral bypass using vein or arterial autograft bypasses and prosthetic bypass with early success rates between 91 and 96% and late success rates between 80 and 90% (Figures 2 and 3).[1,32,34–36,90–95] Each of the various series is too small to draw any conclusions with respect to the superiority of one technique over the other. The choice of technique is usually based on the preference and experience of the surgeon. However, the majority of centres with larger experience believe that antegrade revascularization or transaortic endarterectomy of both the CA and the SMA offers the best long term results. Furthermore, the best long term results seem to have been reported from surgical repair of more than one artery.

Repair of only one of the occluded mesenteric arteries may relieve the symptoms of chronic splanchnic ischaemia and satisfactory results have been reported.[38,96] Occasionally, satisfactory results have been reported from an exclusive repair of the IMA usually in specific circumstances.[97]

Duplex ultrasonography is helpful for assessing intra-operatively the patency of splanchnic arterial repair. Duplex scanning is performed with a 7.5 or 10 MHz probe placed in a sterile glove and plastic sleeve. Both the velocities and the B-mode images are useful for evaluating the absence or presence of residual lesions with a sensitivity of 89% and a specificity of 77%.[98]

Surgical reconstruction of the splanchnic arteries is a relatively safe procedure associated with a low morbidity and mortality of between 2 and 5%, but mortality can be as high as 15% depending on the extent of the pathology and the patients' operative risk. The mortality is increased with 'redo' operations and when splanchnic repair is combined with aortic reconstruction.[3] Specific complications are related to clamping of the splanchnic circulation: (i) ischaemia and reperfusion which is not rare and (ii) bowel infarction which is a rare but often fatal complication.

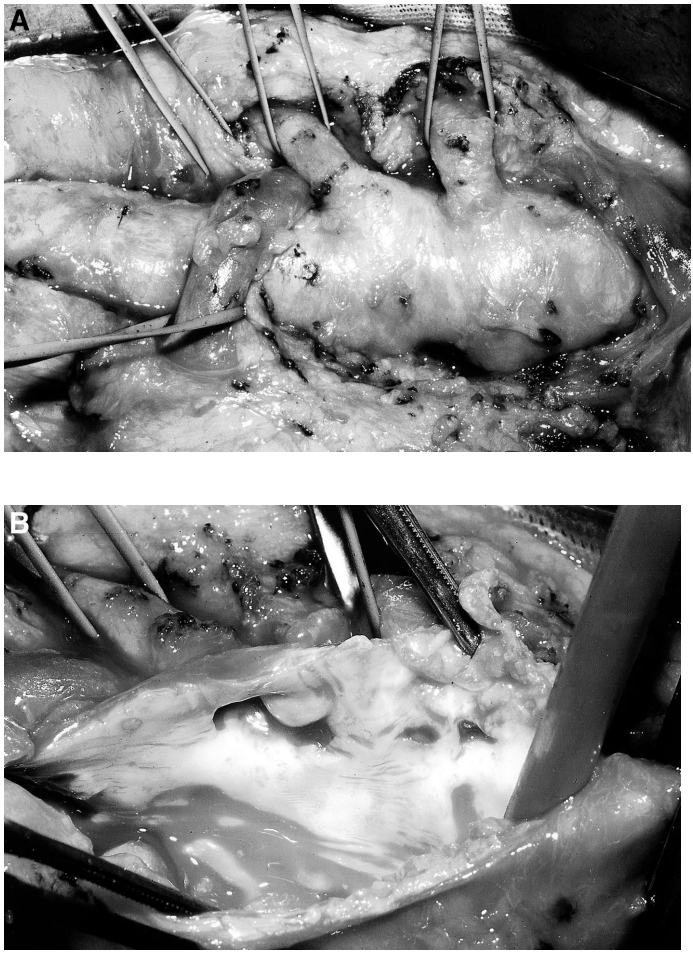

Figure 3A & B. Caption on facing page.

All authors report satisfactory patency. However patency objectively determined by angiography and/or duplex ultrasonography and calculated by the life table method is rarely reported. McMillan et al[99] presented their results as such and reported patency between 89 and 93% at 36 months and 89% at 72 months. Kihara et al[94] reported at 73% patency rate at 24 months and found superior results in females compared to males and superior patency rates in prosthetic bypass grafts compared to autologous material. Recurrent splanchnic ischaemia after a failed revascularization appears to be not rare. Schneider et al[100] reported from one of the centres with the largest experience a prevalence rate of up to one-third of patients. A total of 109 patients underwent primary visceral revascularization between 1959 and 1997 at their institution, and 17.4% had recurrent visceral ischaemia (12 with chronic splanchnic ischaemia). Thirty reoperations (22 first, five second and three third reoperations) were performed for current splanchnic ischaemia in 24 patients. Twelve patients (11%) had recurrent chronic splanchnic ischaemia. Patients with recurrent chronic splanchnic

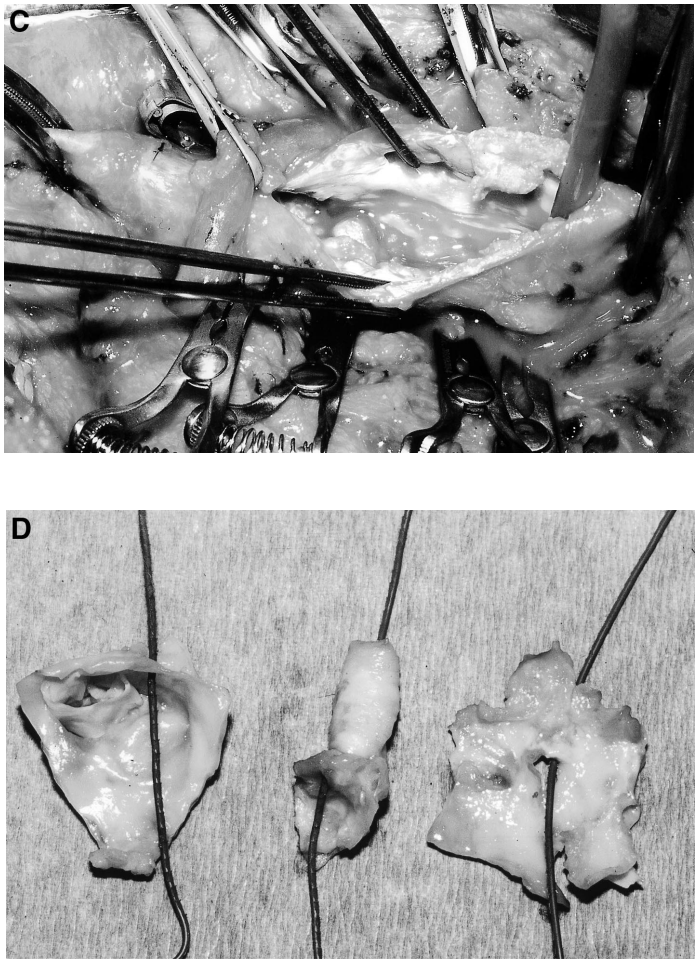

Figure 3C & D.

Figure 3. Open endarterectomy of the coeliac artery, the superior mesenteric artery and the right renal artery (the patients' head is located at the right hand side, the left renal vein crossing the aorta is shown at the left hand side of the photograph). (A) The vessels have been dissected free and the three arteries and the left renal vein have been secured with vessel loops. (B) The aorta has been longitudinally opened showing the stenotic and occluded orifices of the three arteries. (C) Endarterectomy is being performed with removal of the grossly thickened intima and media at the site of the orificial stenoses and occlusion. (D) The atherosclerotic specimen removed from the three arteries is shown.

ischaemia received their diagnoses earlier and lost less weight than at their initial presentation. Recurrent ischaemia was associated with younger age, greater weight loss, and modification of surgical technique at the time of initial operation. For most of the first reoperations, antegrade aortovisceral bypass or transaortic visceral endarterectomy was used. Multiple techniques were used in the second or third reoperations. Post-operative mortality and complication rates were 6.7% and 33%, respectively. Symptoms recurred in six out of 22 patients (27.3%) after the first reoperation, three

of the six were cured or improved after additional reoperations. The life table symptom-free survival was 63% at 5 years.[100]

The surgical treatment of CA compression syndrome consists of decompression of the CA at the diaphragm by a careful division of fibres and fibrous and nerve tissue. If a stenosis of the CA is still present after release, a reconstruction should be considered. Antegrade aortocoeliac bypass grafting or patch plasty can be performed. Some authors report satisfactory results for surgical treatment of this syndrome[51] but others have reported unsatisfactory results.[101] Decompression alone results in the relief of symptoms in between 41 and 75% of the patients, while decompression combined with surgical reconstruction of the CA results in relief of symptoms in 73–100%. However, it should be acknowledged that a number of patients respond well to conservative treatment e.g. by diet and psychotherapy.[65]

Angioplasty

An alternative to surgical reconstruction may be angioplasty with or without the use of a stent. Favourable results have been reported with early success rates of between 79 and 80%. It appears that surgical reconstruction is still superior to angioplasty.[102,103] However, the number of patients treated is still small and long-term results are not available. Percutaneous dilatation of CA compression seems to be associated with failure. Complications may occur in up to 16% and include dissection thrombosis, which occasionally may result in death.[104–106]

The combination of angioplasty with the placement of a stent has also been reported and seems to have a better result than angioplasty alone. Sheeran et al[107] reported on the treatment of 12 patients. Initial technical success was achieved in 11 out of the 12 patients (92%). There was one post-procedural death (<30 days) due to bowel ischaemia and infarction, despite a technically successful procedure. Primary patency up to 18 months was 74% but subsequent interventions were required to obtain a secondary patency of 83% at 3 years.[107] In conclusion, angioplasty seems to be a realistic alternative for the treatment of chronic splanchnic ischaemia if surgical reconstruction is not feasible or is associated with a high surgical risk. The procedure is not completely without risks and it seems that angioplasty in combination with a stent is superior to angioplasty alone.

CONCLUSION

Chronic splanchnic ischaemia is a rare disorder and it should be differentiated from splanchnic disease, which is more common. The diagnosis can be difficult but has been improved significantly over the past decades by new diagnostic techniques such as duplex ultrasound, magnetic resonance angiography and tonometry. Short and long term results of surgical reconstruction in selected patients are satisfactory. Prophylactic repair of significant but asymptomatic splanchnic disease to prevent acute bowel ischaemia is still controversial. It may be indicated in selected good risk patients with occlusions of at least two or all three main splanchnic arteries. Percutaneous intervention provides satisfactory initial and early results but is not completely without complications and long term results are not available yet. Angioplasty with or without a stent can be applied in symptomatic patients if the patient is at poor surgical risk, has a short life expectancy or if redo surgery has to be avoided.

Practice points

- chronic splanchnic ischaemia is a rare disease and no randomized, blind or controlled studies on diagnosis and treatment are available
- analysis for chronic splanchnic ischaemia is indicated when patients present with persistent abdominal pain and other more common causes of pain have been excluded
- duplex ultrasound is an excellent and well validated screening tool for occlusive disease of the CA and SMA
- chronic splanchnic ischaemia as a diagnosis is unlikely if the SMA is widely patent
- multiplane three vessel angiography is still the gold standard for the diagnosis of splanchnic occlusive disease and should be performed if intervention is being planned
- magnetic resonance angiography and tonometry have the potential for providing information on the functional deficiency of the splanchnic circulation
- chronic splanchnic ischaemia is likely to be a risk factor for acute mesenteric ischaemia
- surgical reconstruction is an effective therapy for chronic splanchnic ischaemia with a 2 year vascular patency of between 70 and 93%

Research agenda

- more insight is required into the role of vascular steal and the inter-relationship with feeding in the pathogenesis of chronic mesenteric ischaemia
- the role of magnetic resonance in functional testing for chronic splanchnic ischaemia requires further evaluation
- tonometry, alone or in combination with stress testing, should be further investigated to determine its potential for the functional evaluation of chronic splanchnic ischaemia
- more clinical information is required on the natural history of chronic splanchnic disease
- better techniques for the percutaneous treatment of chronic splanchnic ischaemia should be developed

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